United States Department of Commerce
National Institute of Standards and Technology

NIST Special Publication 432 (Revised 1990)

NIST

TIME AND FREQUENCY SERVICES

RADIO STATIONS WWV, WWVH, WWVB
GOES SATELLITE TIME CODE
AUTOMATED COMPUTER TIME SERVICE (ACTS)

NIST Special Publication 432 (Revised 1990)

NIST

TIME AND FREQUENCY SERVICES

Roger E. Beehler
Michael A. Lombardi

Time and Frequency Division
Physics Laboratory
National Institute of Standards and Technology
Boulder, CO 80303-3328

(Supersedes NBS Spec. Publ. 432 dated September 1979)

U.S. Department of Commerce
Robert A. Mosbacher, Secretary

National Institute of Standards and Technology
John W. Lyons, Director

June 1991

National Institute of Standards and Technology Special Publication 432 (Revised 1990)
(Supersedes NBS Special Publication 432 dated September 1979)
Natl. Inst. Stand. Technol., Spec. Publ. 432, 30 pages (June 1991)
CODEN: NSPUE2

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON, D.C. 1991

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

CONTENTS

Telephone Time-of-Day Services

WWV: (303) 499-7111 (Boulder, Colo.)
WWVH: (808) 335-4363 (Kauai, Hawaii)

(Regular long-distance charges apply when called from outside the local calling area.)

Questions? See top of page 27.

ABSTRACT

NIST Time and Frequency Services [Special Publication 432 (Revised 1990)] is a revision of SP 432, last published in 1979. It describes services available, as of December 1990, from NIST radio stations WWV, WWVH, and WWVB; from GOES satellites; from Loran-C; by telephone (voice and modem); and from the NIST Frequency Measurement Service.

Key words: broadcast of standard frequencies; computer time setting; frequency calibrations; GOES satellite; high frequency; low frequency; satellite time code; shortwave; standard frequencies; time calibrations; time signals.

Introduction

Precise time and frequency information is needed by electric power companies, radio and television stations, telephone companies, air traffic control systems, participants in space exploration, computer networks, scientists monitoring data of all kinds, and navigators of ships and planes. These users need to compare their own timing equipment to a reliable, internationally recognized standard. The National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, provides this standard for most users in the United States.

NIST began broadcasting time and frequency information from radio station WWV in 1923. Since then, NIST has expanded its time and frequency services to meet the needs of a growing number of users. NIST time and frequency services are convenient, accurate, and easy to use. They contribute greatly to the nation's space and defense programs, to manufacturers, and to transportation and communications. In addition, NIST services are widely used by the general public.

Broadcast services include radio signals from NIST radio stations WWV, WWVH, and WWVB; the GOES satellites, and Loran-C. Services are also available using telephone voice and data lines. This booklet is a guide to these services.

Summary of Radio Broadcast Services

Characteristics & Services:	WWV		WWVH		WWVB
Date Service Began	March 1923		November 1948		July 1956
Geographical Coordinates	40° 40′ 49.0″ N 105° 02′ 27.0″ W		21° 59′ 26.0″ N 159° 46′ 00.0″ W		40° 40′ 28.3″ N 105° 02′ 39.5″ W
Standard Carrier Frequencies	2.5 & 20 MHz	5, 10, & 15 MHz	2.5 MHz	5, 10, & 15 MHz	60 kHz
Power	2500 W	10,000 W	5000 W	10,000 W	13,000 W
Standard Audio Frequencies	440 (A above middle C), 500, & 600 Hz				——
Time Intervals	1 pulse/s; minute mark; hour mark				s; min.
Time Signals: Voice	Once per minute				——
Time Signals: Code	BCD code on 100-Hz subcarrier, 1 pulse/s				BCD code
UT1 Corrections	UT1 corrections are broadcast with an accuracy of ±0.1 s				
Special Announcements	Omega Reports, Geoalerts, Marine Storm Warnings, Global Positioning System Status Reports				——

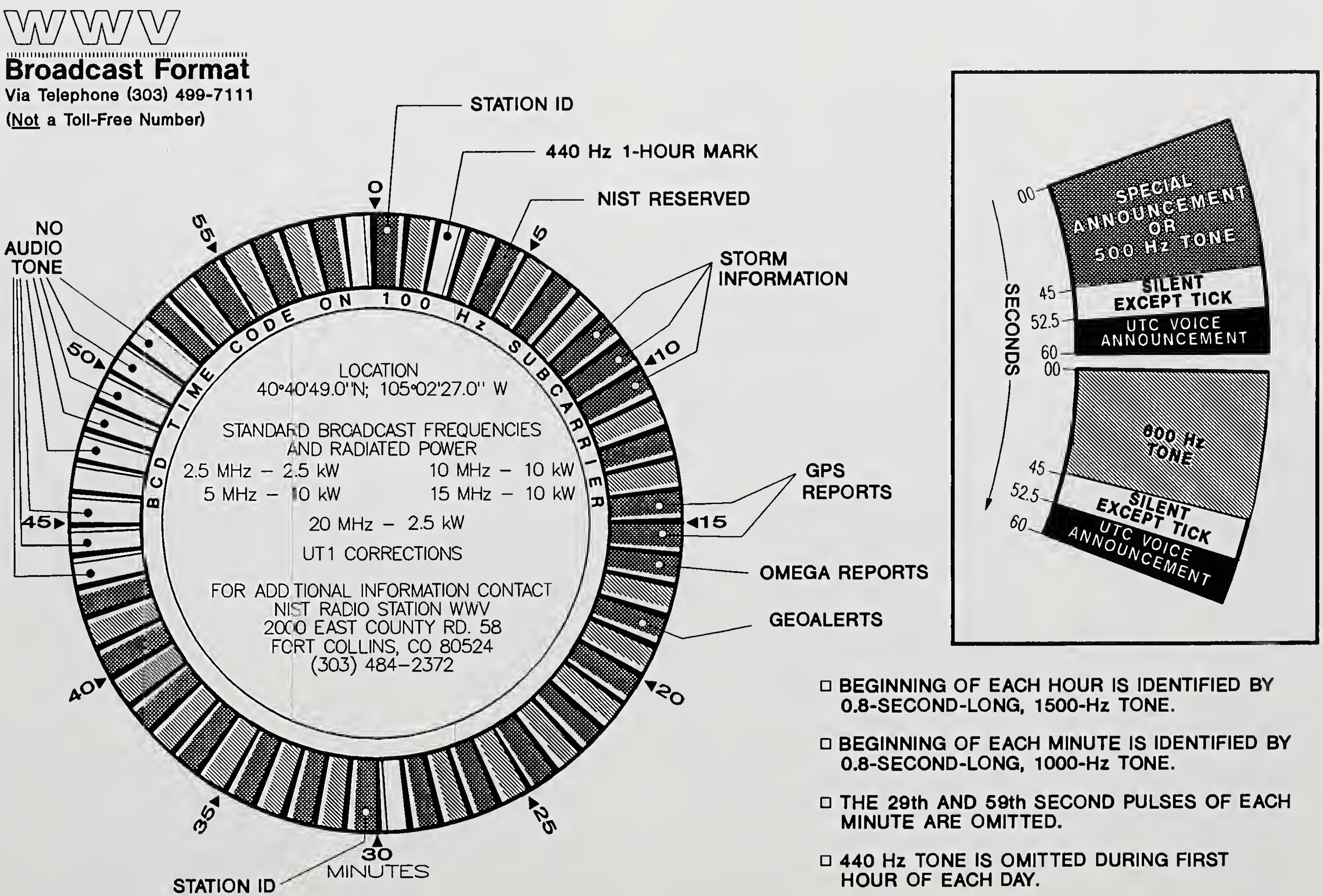


Figure 1. The hourly broadcast schedules of WWV.

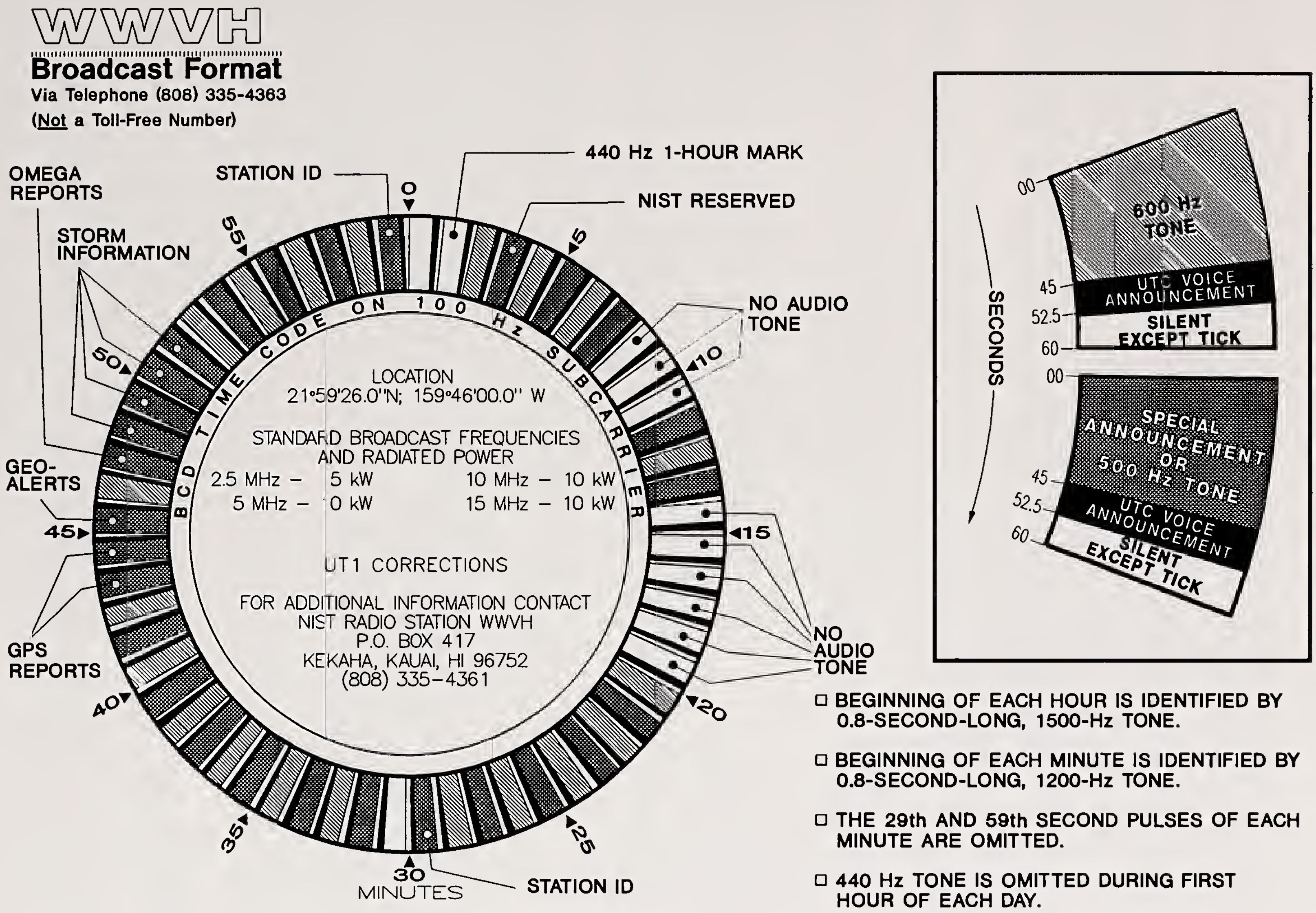


Figure 2. The hourly broadcast schedules of WWVH.

Shortwave Services—WWV and WWVH

NIST operates two high-frequency (shortwave) radio stations, WWV and WWVH. WWV is in Ft. Collins, Colorado, and WWVH is in Kauai, Hawaii. Both stations broadcast continuous time and frequency signals on 2.5, 5, 10, and 15 MHz. WWV also broadcasts on 20 MHz. All frequencies provide the same information. Although radio reception conditions in the high-frequency band vary greatly with factors such as location, time of year, time of day, the particular frequency being used, atmospheric and ionospheric propagation conditions, and the type of receiving equipment used, at least one frequency should be usable at all times. As a general rule, frequencies above 10 MHz work best in the daytime, and the lower frequencies work best at night.

Services provided by WWV and WWVH include:

Time announcements
Standard time intervals
Standard frequencies
UT1 time corrections
BCD time code
Geophysical alerts
Marine storm warnings
OMEGA Navigation System status reports
Global Positioning System (GPS) status reports

Figures 1 and 2 show the hourly broadcast schedules of these services along with station location, radiated power, and details of the modulation.

Accuracy and Stability

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 accurate to about 1 part in 100 billion (1×10^{-11}) for frequency and about 0.01 ms for timing. The day-to-day deviations are normally less than 1 part in 1,000 billion (1×10^{-12}). However, the *received* accuracy is far less due to various propagation effects. The usable received accuracy is about 1 part in 10 million for frequency (1×10^{-7}) and about 1 ms for timing.

Radiated Power, Antennas, and Modulation

WWV and WWVH radiate 10,000 W on 5, 10, and 15 MHz. The radiated power is lower on the other frequencies: WWV radiates 2500 W on 2.5 and 20 MHz while WWVH radiates 5000 W on 2.5 MHz and does not broadcast on 20 MHz.

The WWV antennas are half-wave dipoles that radiate omnidirectional patterns. The 2.5-MHz antenna at WWVH is also of this type. The other antennas at WWVH are phased vertical half-wave dipole arrays. They radiate a cardioid pattern with the maximum gain pointed toward the west.

Both stations use double sideband amplitude modulation. The modulation level is 50 percent for the steady tones, 25 percent for the BCD time code, 100 percent for the seconds pulses and the minute and hour markers, and 75 percent for the voice announcements.

Time Announcements

Voice announcements are made from WWV and WWVH once every minute. Since both stations can be heard in some locations, a man's voice is used on WWV, and a woman's voice is used on WWVH to reduce 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.

The announced time is "Coordinated Universal Time" (UTC). UTC was established by international agreement in 1972, and is governed by the International Bureau of Weights and Measures (BIPM) in Paris, France. Coordination with the international UTC time scale keeps NIST time signals in close agreement with signals from other time and frequency stations throughout the world.

UTC differs from your local time by a specific number of hours. The number of hours depends on the number of time zones between your location and the location of the zero meridian (which passes through Greenwich, England). When local time changes from Daylight Saving to Standard Time, or vice versa, UTC does not change. However, the difference between UTC and local time does change—by 1 hour. Use the chart of world time zones (figure 3) to find out how many hours to add to or subtract from UTC to obtain your local standard time. If DST is in effect at your location, subtract 1 hour less in the U.S. than shown on the chart. Thus, Eastern Daylight Time (EDT) is only 4 hours behind UTC, not 5 as shown on the chart for EST.

UTC is a 24-hour clock system. The hours are numbered beginning with 00 hours at midnight through 12 hours at noon to 23 hours and 59 minutes just before the next midnight.

The international agreement that established UTC in 1972 also specified that occasional adjustments of exactly

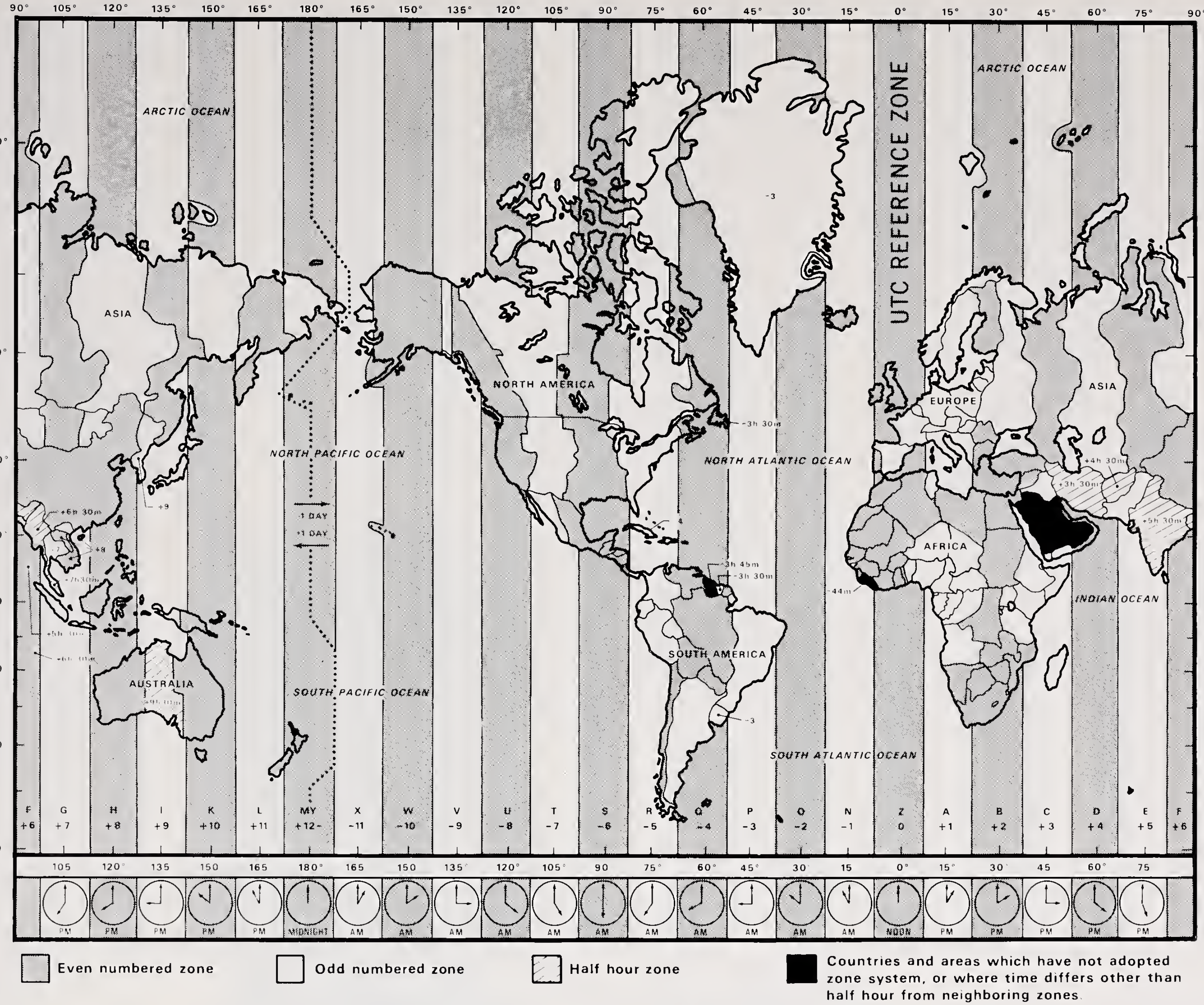


Figure 3. Standard time zones of the world and their relationship to UTC.

1 s will be made to UTC so that UTC should never differ from a particular astronomical time scale, UT1, by more than 0.9 s. This was done as a convenience for some time-broadcast users, such as boaters using celestial navigation, who need to know time that is based on the rotation of the Earth. These occasional 1-s adjustments are known as "leap seconds." When deemed necessary by the International Earth Rotation Service in Paris, France, the leap seconds are inserted into UTC, usually at the end of June or at the end of December, making that month 1 s longer than usual. Typically, a leap second has been inserted at intervals of 1 to 2 years. (See also: "UT1 Time Corrections," page 6, and appendix A).

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 29th and 59th 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 seconds 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.

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 4.

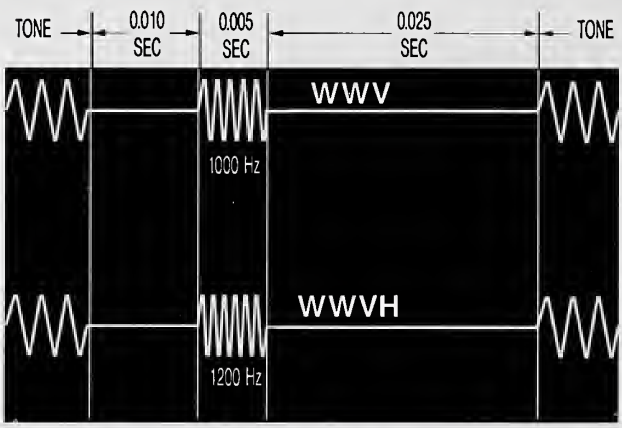


Figure 4. Format of WWV and WWVH seconds pulses.

Standard Audio Frequencies

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 1 and 2 for further details.

Silent Periods

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 46 and from 47 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.

BCD Time Code

WWV and WWVH continuously broadcast a binary coded decimal (BCD) time code on a 100-Hz subcarrier. The time code presents UTC information in serial fashion at a rate of 1 pulse 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. More information about the time code format is given in appendix B.

At the time of publication of this revision of Special Publication 432 (late 1990), further changes to the content of the WWV and WWVH time codes are in the planning stage. The proposed changes will not affect currently encoded information, but will add information in the form of the last two digits of the current year, improved indicators for when Daylight Saving Time is in effect, and a warning for the insertion of a leap second at the end of the current month. Details of the affected code bits are given in appendix B.

UT1 Time Corrections

The UTC time scale broadcast by WWV and WWVH meets the needs of most users. UTC runs at an almost perfectly constant rate, since its rate is based on cesium atomic frequency standards. Somewhat surprisingly, some users need time *less* stable than UTC but related to the rotation of the Earth. Applications such as celestial navigation, satellite observations of the Earth, and some types of surveying require time referenced to the rotational position of the Earth. These users rely on the UT1 time scale. UT1 is derived by astronomers who monitor the speed of the Earth's rotation.

You can obtain UT1 time by applying a correction to the UTC time signals broadcast from WWV and WWVH. UT1 time corrections are included in the WWV and WWVH broadcasts at two levels of accuracy. First, for those users only needing UT1 to within 1 s, occasional corrections of exactly 1 s are inserted into the UTC time scale. These corrections, called leap seconds, keep UTC within ± 0.9 s of UT1. Leap seconds are coordinated under international agreement by the International Earth Rotation Service in Paris, France. Leap seconds can be either positive or negative, but so far, only positive leap seconds have been needed. A positive leap second is normally added every 1 or 2 years, usually on June 30 or December 31. More information about leap seconds is given in appendix A.

The second level of correction is for the small number of users needing UT1 accurate to within 0.1 s. These corrections are encoded into the broadcasts by using doubled ticks during the first 16 s of each minute. The amount of correction (in tenths of 1 s) is determined by counting the number of successive doubled ticks heard each minute. The sign of the correction depends on whether the doubled ticks are in the first 8 s of the minute or in the second 8 s. If the doubled ticks are in the first 8 s (1-8) the sign is positive, and if they are in the second 8 s (9-16) the sign is negative. For example, if ticks 1, 2, and 3 are doubled, the correction is "plus" 0.3 s. This means that UT1 equals UTC + 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 "minus" 0.4 s. If UTC is 8:45:17, then UT1 is 8:45:16.6. An absence of doubled ticks indicates that the current correction is 0.

Official Announcements

Announcement segments 45 s long are available by subscription to other Federal agencies (see figures 1 & 2). These segments are used for public service messages. 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 (see inside back cover).

The segments currently in use (late 1990) are described below. Since these are subject to change from time to time, contact NIST for more current status information.

OMEGA Navigation System Status Reports—The OMEGA Navigation System status reports are voice announcements broadcast on WWV at 16 minutes after the hour, and on WWVH at 47 minutes after the hour. The OMEGA Navigation System consists of eight radio stations transmitting in the 10- to 14-kHz frequency band. These stations serve as international aids to navigation. The status reports are updated as necessary by the U.S. Coast Guard.

For more information about the OMEGA Navigation System or these announcements, contact: Commanding Officer, U.S. Coast Guard OMEGA Navigation System Center, 7323 Telegraph Road, Alexandria, VA 22310-3998; telephone (703) 866-3800.

Geophysical Alerts—Current geophysical alerts (Geoalerts) are broadcast in voice 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 3 hours (typically at 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC). Hourly updates are made when necessary.

Part A of the message gives the solar-terrestrial indices for the day: specifically the 1700 UTC solar flux from Ottawa, Canada, at 2800 MHz, the estimated A-index for Boulder, Colo., and the current Boulder K-index.

Part B gives the solar-terrestrial conditions for the previous 24 hours.

Part C gives optional information on current conditions that may exist (that is, major flares, proton or polar cap absorption [PCA] events, or stratwarm conditions).

Part D gives the expected conditions for the next 24 hours. For example:

A) "Solar-terrestrial indices for **26 October** follow: Solar flux **173** and estimated Boulder A-index **20**; repeat: Solar flux **one-seven-three** and estimated Boulder A-index **two-zero.**
The Boulder K-index at 1800 UTC on **26 October** was **four**; Repeat: **four.**"

B) "Solar-terrestrial conditions for the last 24 hours follow:
Solar activity was **high**.
Geomagnetic field was **unsettled to active.**"

C) **"A major flare occurred at 1648 UTC on 26 October. A satellite proton event and PCA are in progress."**

D) "The forecast for the next 24 hours follows:
Solar activity will be **moderate to high**. The geomagnetic field will be **active.**"

DEFINITIONS

1. **SOLAR ACTIVITY** is defined as transient perturbations of the solar atmosphere as measured by enhanced x-ray emission, typically associated with flares. Five standard terms are used to describe solar activity:

Very low:	X-ray events less than C-class.
Low:	C-class x-ray events.
Moderate:	isolated (1 to 4) M-class x-ray events.
High:	several (5 or more) M-class x-ray events, or isolated (1 to 4) M5 or greater x-ray events.
Very High:	several M5 or greater x-ray events.

2. The **GEOMAGNETIC FIELD** experiences natural variations classified quantitatively into six standard categories depending upon the amplitude of the disturbance. The Boulder K- and estimated A-indices determine the category according to the following table:

Condition	Range of A-index	Typical K-indices
Quiet	$0 \le A < 8$	usually no K-indices > 2
Unsettled	$8 \le A < 16$	usually no K-indices > 3
Active	$16 \le A < 30$	a few K-indices of 4
Minor storm	$30 \le A < 50$	K-indices mostly 4 and 5
Major storm	$50 \le A < 100$	some K-indices 6 or greater
Severe storm	$100 \le A$	some K-indices 7 or greater.

3. **SOLAR FLARES** are classified by their x-ray emission as:

Peak Flux Range (1-8 Angstroms)

Class	SI system ($W\ m^{-2}$)	cgs system ($erg\ cm^{-2}\ s^{-1}$)
A	$\phi < 10^{-7}$	$\phi < 10^{-4}$
B	$10^{-7} \le \phi < 10^{-6}$	$10^{-4} \le \phi < 10^{-3}$
C	$10^{-6} \le \phi < 10^{-5}$	$10^{-3} \le \phi < 10^{-1}$
M	$10^{-5} \le \phi < 10^{-4}$	$10^{-2} \le \phi < 10^{-1}$
X	$10^{-4} \le \phi$	$10^{-1} \le \phi$

The letter designates the order of magnitude of the peak value. Following the letter the measured peak value is given. For descriptive purposes, a number from 1.0 to 9.9 is appended to the letter designation. The number acts as a multiplier. For example, a C3.2 event indicates an x-ray burst with peak flux of $3.2 \times 10^{-6}\ Wm^{-2}$.

Forecasts are usually issued only in terms of the broad C, M, and X categories. Since x-ray bursts are observed as a full-Sun value, bursts below the x-ray background level are not discernible. The background drops to class A level during solar minimum; only bursts that exceed B1.0 are classified as x-ray events. During solar maximum the background is often at the class M level, and therefore class A, B, and C x-ray bursts cannot be seen. Data are from the NOAA GOES satellites, monitored in real time at the NOAA Space Environment Services Center. Bursts greater than $1.2 \times 10^{-3}\ Wm^{-2}$ may saturate the GOES detectors. If saturation occurs estimated peak flux values are reported.

4. The remainder of the report is as follows:

Major Solar Flare	= flare which produces some geophysical effect, usually flares that have x-rays ≥ M5 class.
Proton Flare	= protons by satellite detectors (or polar cap absorption by riometer) have been observed in time association with H-alpha flare.
Satellite Level Proton Event	= proton enhancement detected by Earth-orbiting satellites with measured particle flux of at least 10 protons $cm^{-2}s^{-1}sr^{-1}$ at ≥ 10 MeV.
Polar Cap Absorption	= proton-induced absorptien ≥ 2 dB daytime, 0.5 dB night, as measured by a 20-MHz riometer located within the polar cap.
Stratwarm	= reports of stratospheric warmings in the high latitude regions of the winter hemisphere of the Earth associated with gross distortions of the normal circulation associated with the winter season.

To hear these Geophysical Alert messages by telephone (at any minute of the hour, but without time information), dial (303) 497-3235.

Inquiries regarding these messages should be addressed to:

Space Environment Services Center
NOAA R/E/SE2
325 Broadway — or call (303) 497-5127
Boulder, CO 80303-3328 — FTS: 320-5127

MARINE STORM WARNINGS—Marine storm warnings are broadcast for the marine areas that the United States has warning responsibility for under international agreement. The storm warning information is provided by the National Weather Service. Storm warnings for the Atlantic and eastern North Pacific are broadcast by voice on WWV at 8, 9, and 10 minutes after the hour. Storm warnings for the western, eastern, southern, and north Pacific are broadcast by WWVH at 48, 49, 50, and 51 minutes after the hour. An additional segment (at 11 minutes after the hour on WWV and at 52 minutes after the hour on WWVH) is used occasionally if there are unusually widespread storm conditions. The brief voice messages warn mariners of storm threats present in their areas.

The storm warnings are based on the most recent forecasts. Updated forecasts are issued by the National Weather Service at 0500, 1100, 1700, and 2300 UTC for WWV; and at 0000, 0600, 1200, and 1800 UTC for WWVH.

A typical storm warning announcement text is 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."

For more information about marine storm warnings, write to: The Director, National Weather Service, Silver Spring, MD 20910.

Global Positioning System (GPS) Status Announcements—Since March 1990 the U.S. Coast Guard has sponsored two voice announcements per hour on WWV and WWVH, giving current status information about the GPS satellites and related operations. The 45-s 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 Commanding Officer, U.S. Coast Guard Center, 7323 Telegraph Road, Alexandria, VA 22310-3998.

WWV and WWVH Audio Signals by Telephone

The audio portions of the WWV and WWVH broadcasts can also be heard by telephone. The accuracy of the telephone time signals is normally 30 ms or better in the continental United States. In rare instances when the telephone connection is made by satellite, there is an additional delay of 0.25 to 0.5 s.

To hear these broadcasts, dial (303) 499-7111 for WWV, and (808) 335-4363 for WWVH. Callers are disconnected after 3 minutes. These are not toll-free numbers; callers outside the local calling area are charged for the call at regular long-distance rates.

Low-Frequency Services—WWVB

Radio station WWVB is located on the WWV site near Ft. Collins, Colorado. WWVB continuously broadcasts time and frequency signals at 60 kHz, primarily for the continental United States. WWVB does not broadcast voice announcements, but provides standard time information, including the year; time intervals; Daylight Saving Time, leap second, and leap-year indicators; and UT1 corrections by means of a BCD time code. In addition, the 60-kHz carrier frequency provides an accurate frequency standard which is referenced to the NIST Frequency Standard.

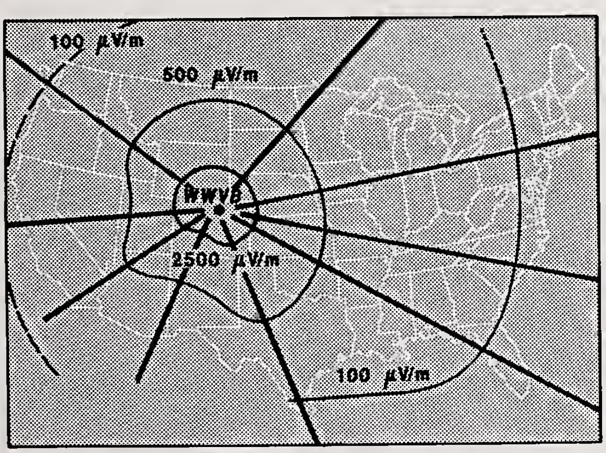


Figure 5. Measured field intensity contours of WWVB at 13-kW effective radiated power.

Accuracy and Stability

The transmitted accuracy of WWVB is normally better than 1 part in 100 billion (1×10^{-11}). Day-to-day deviations are less than 5 parts in 1000 billion (5×10^{-12}). The BCD time code can be received and used with an accuracy of approximately 0.1 ms. Propagation effects are minor compared to those of WWV and WWVH. When proper receiving and averaging techniques are used, the received accuracy of WWVB should be nearly as good as the transmitted accuracy.

Station Identification

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. WWVB is also identified by its unique time code.

Radiated Power, Antenna, and Coverage

The effective radiated power from WWVB is 13,000 watts. The antenna is a 122-m, top-loaded vertical, installed over a radial ground screen. Some measured field intensity contours are shown in the coverage map in figure 5.

WWVB Time Code

The WWVB time code is synchronized with the 60-kHz carrier and is broadcast continuously at a rate of 1 pulse per second using pulse-width modulation. Each pulse is generated by reducing the carrier power 10 dB at the start of the second, so that the leading edge of every negative-going pulse is on time. Full power is restored either 0.2, 0.5, or 0.8 s later to convey either a binary "0", "1", or a position marker, respectively. Details of the time code are in appendix C.

The WWVB code contains information on the current year (since early 1990), day of year, hour, minute, second, status of Daylight Saving Time, leap year, and a leap-second warning (planned for mid-1991 implementation). Since the WWVB code is undergoing some revision as of the publication date of this booklet, users are encouraged to contact the NIST Time and Frequency Division for the most current information.

How NIST Controls the Transmitted Frequencies

Figure 6 shows the relationship between the NIST broadcasts, the primary NIST Frequency Standard, and the NIST atomic time scale. The NIST Frequency Standard and atomic time scale systems are located in Boulder, Colorado. They include:

- The primary NIST Frequency Standard. This standard is a laboratory cesium beam device, built and maintained by NIST. It provides a frequency and time interval reference, based on the international definition of the second.
- A group of commercial cesium standards, hydrogen maser frequency standards, and possibly other devices. These are kept in controlled environments, and serve as the continuously operating "working" standards.
- Sophisticated time comparison equipment, computer systems, and computer software. This equipment generates a composite time scale that is better than any of the individual standards. The composite time scale, TA(NIST), is based on (approximately) annual calibrations of the working standards using the primary NIST Frequency Standard.
- Provisions for inserting small adjustments and leap seconds into the time scale. These adjustments let NIST generate UTC(NIST), an internationally coordinated UTC time scale. UTC(NIST) is distributed to users of the services described in this booklet, including WWV, WWVH, WWVB, the GOES satellites, the Frequency Measurement Service, and the telephone services.

The NIST radio station sites (Fort Collins, Colorado, and Kauai, Hawaii) each have three commercial atomic standards that emulate UTC(NIST). Each standard can provide the frequency input to the station's time-code generators and transmitters.

The local standards at each station are compared to the UTC(NIST) time scale in Boulder, Colorado. These comparisons are made using GPS (Global Positioning System) satellites. GPS consists of orbiting navigation satellites that broadcast precise timing signals. These signals are received simultaneously at Boulder and at both radio station sites. The results obtained at the radio stations are then compared to the results obtained in Boulder. The timing differences (accurate to less than 100 ns), are then used to calibrate the local standards.

Other time and frequency resources are also used to check the local standards. These include portable clocks (physically carried to the radio station sites), Loran-C, and GOES satellite broadcasts.

GOES Satellite Time Services

In 1974, NIST began broadcasting a time code from the GOES (Geostationary Operational Environmental Satellite) satellites of the National Oceanic and Atmospheric Administration (NOAA). This cooperative arrangement between NIST and NOAA was formalized by a renewable agreement, the latest version of which extends until 1997. The primary purpose of the GOES satellites is to collect environmental data from thousands of sensing platforms located throughout the Western Hemisphere and to relay this information to a central processing facility from where it is made available to interested organizations, such as the World Meteorological Organization, radio and TV stations, and various government agencies. The time code is referenced to UTC(NIST) and is broadcast continuously to the entire Western Hemisphere from two satellites (GOES/East and GOES/West).

GOES time-code receivers are commercially available. Some of them provide timing signals accurate to within 100 μs over periods of hours, months, or years. Other versions are accurate to within 1-2 ms over the same time periods.

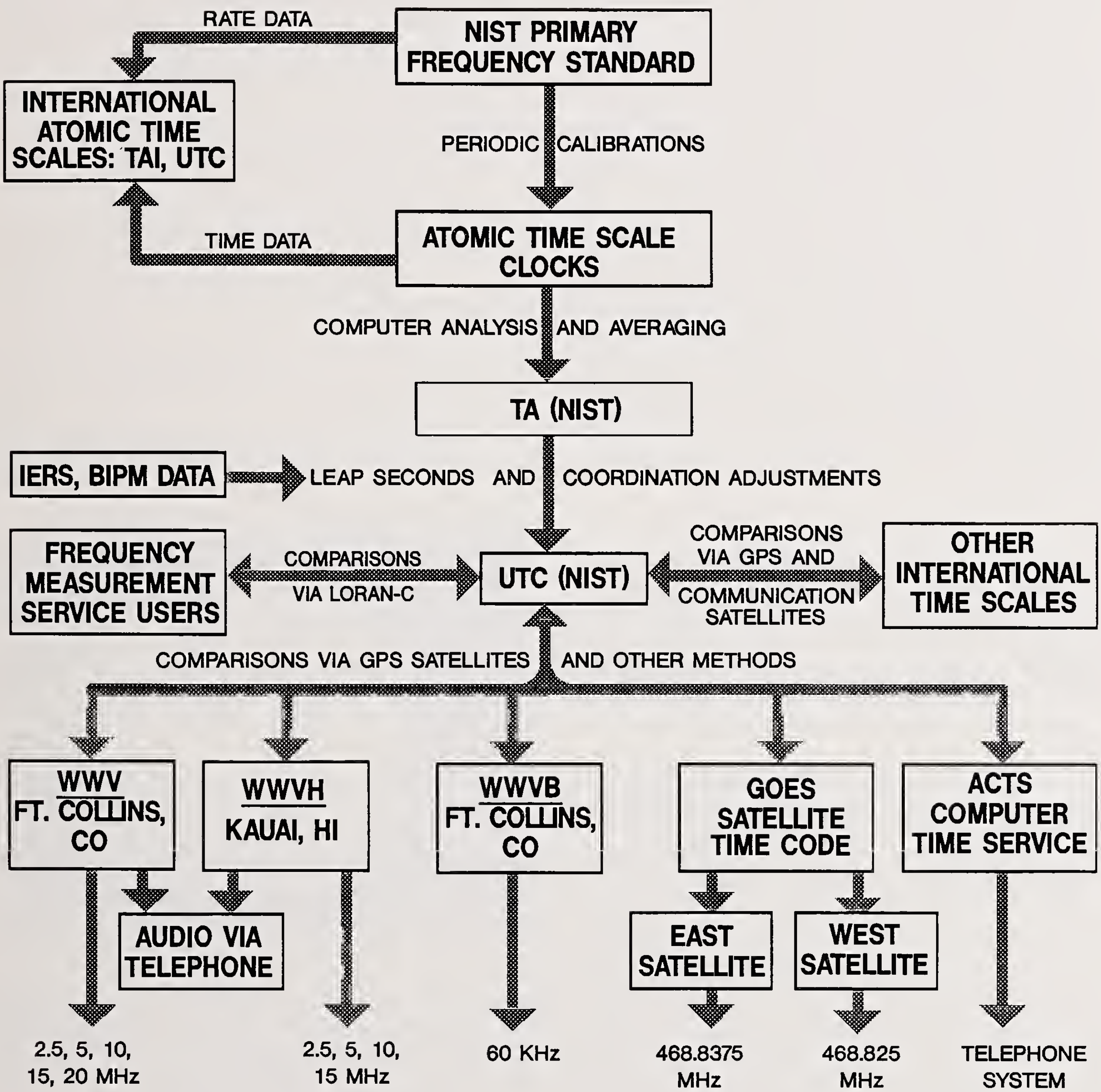


Figure 6. How NIST controls the various time and frequency services.

GOES Satellites

The GOES satellites are in geostationary orbit about 36,000 km (22,300 miles) above the equator; that is, they stay above the same spot on the Earth's surface. Because they are geostationary, the path delay for the time code will remain relatively constant at all times.

In the normal GOES satellite configuration there are always at least three GOES satellites in orbit. Two are operational, and one is a spare. GOES/West is normally located at 135° West longitude and transmits at 468.825 MHz. GOES/East is normally located at 75° West longitude and transmits at 468.8375 MHz. The spare is located at approximately 105° West longitude. The satellites do not have clocks on board but rather serve to relay the time-code signals which originate on the ground from NOAA's satellite control facility at Wallops Island, Va.

During periods when satellite malfunctions occur or when a smaller-than-normal number of fully functional satellites are available, NOAA may alter the normal satellite configuration. As an example, NOAA plans to transmit the GOES/East time code from a satellite located at 60° West longitude temporarily from mid-1990 until new replacement GOES satellites are launched sometime during 1992.

GOES Time Code

The GOES time code includes the current year, complete time-of-year information (day-of-year number, hour, and minute), the UT1 correction (the approximate difference between the astronomical UT1 time scale and UTC), satellite position information, accuracy indicators, Daylight Saving Time and leap second indicators, and system status information.

The satellite position data are included in the time code to provide users with an option for correcting the received time signal for motion of the satellites in their orbits. These relatively small motions cause variations in the signal path delay, which, in turn, produce variations (usually less than 5 ms) in the received time signal. The position data in the time code are predictions, updated each minute, of each satellite position. They are computed from satellite tracking measurements, using a large computer at NIST/Boulder, and then transferred electronically to the time-code equipment at Wallops Island. GOES time-code receivers can be equipped to decode the satellite position information, compute a path delay correction each minute, and automatically correct the output reference signal to remain within 100 μs of UTC(NIST). (Also see "Performance Levels," page 13.)

The time code is interlaced with interrogation messages that do not contain time and frequency information. The interrogation messages are used by NOAA to communicate with systems gathering weather data. Once every half-second, a 4-bit time-code word is transmitted at a data rate of 100 bits/s. A complete time-code message is transmitted every 30 s, beginning on each minute and half-minute. The GOES time code is described in more detail in appendix D.

The time code is generated from a set of three atomic clocks maintained by NIST at NOAA's facility at Wallops Island, Va. The NIST time-code system also includes triply redundant time-code generators, monitoring equipment to receive Loran-C and GPS satellite signals for comparisons with external time scales, automatic fault detection and alarm systems, and a dial-up telephone link with NIST/Boulder for monitoring and controlling the Wallops Island system remotely.

The atomic frequency standards at Wallops Island provide a stable and accurate reference for the time code. They are compared to UTC(NIST) using Loran-C and GPS. The transmitted accuracy from Wallops Island is kept within ±10 μs of UTC(NIST).

Coverage Area of the GOES Time Code

Figure 7 shows the coverage area of the GOES time signals. Much of the Western Hemisphere is covered by at least one satellite. The continental United States is covered by both satellites. The heavy and light oval boundary lines in figure 7 show where the elevation angles to the GOES satellites are 7° and 3°, respectively.

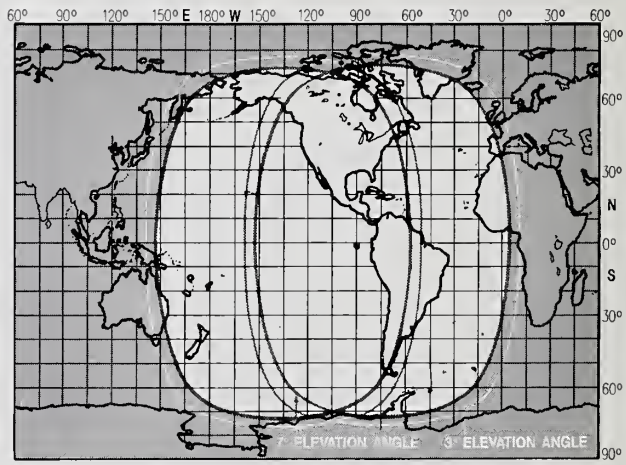


Figure 7. GOES/East and GOES/West coverage areas.

Signal Characteristics

The satellites' signal characteristics are summarized in table 1.

Antenna Pointing

It is relatively simple to point an antenna to either satellite. If the path to the satellite is clear, pointing in the general direction of the satellite is usually sufficient, particularly for relatively low-gain antennas (<10 dB).

If more detailed information about antenna pointing is needed, figures 8 and 9 provide the elevation and azimuth angles. For example, figure 8 shows that the pointing angles to GOES/East from San Francisco are about 119° azimuth and 24° elevation.

Performance Levels

The GOES time code can be used at three performance levels: uncorrected for path delay, corrected for mean path delay only, and fully corrected.

Uncorrected: The total path delay from Wallops Island, Va. (where the time code originates) to the satellite and then back to Earth is about 260 ms. To compensate for this path delay, the signals are advanced by 260 ms before transmission from Wallops Island. The uncorrected signal arrives back on Earth nearly on time (within 16 ms), depending upon the receiver's location. The received time signal will also vary by 1-2 ms during a 24-hour period due to path delay variations produced by satellite motion.

Corrected for Mean Path Delay: If the appropriate mean path delay correction is made, the signal arrival time is usually accurate within ±1 ms. (During some periods, however, NOAA uses satellites with larger-than-normal orbit inclinations that may produce delay variations of several ms during a 24-hour period.) For example, the mean path delay from San Francisco through GOES/East is 255 ms. The mean path delay consists of 130.5 ms from satellite to Earth (see Figure 10), and 124.5 ms from Earth to satellite. Since the time is advanced by 260 ms before leaving Wallops Island, it arrives at San Francisco 5 ms early. A correction for mean path delay in San Francisco can be made by subtracting 5 ms from the received time signal. Use Figure 11 to calculate mean delays for GOES/West.

Fully Corrected: The satellite's orbit is not perfectly circular and is not precisely in the plane of the equator. Therefore, the path delay at a fixed location on the Earth typically varies by anywhere from a few hundred μs to several ms (depending mainly on the satellite's orbit inclination) throughout the day. Also, the satellites are sometimes moved to keep their orbital position within assigned limits. This movement causes irregular changes in the path delay. Obtaining a fully corrected time signal requires correcting for these position changes. Since satellite position data are included in the time code, users (and automatic receivers) can make these corrections.

A fully corrected time signal is usually accurate to within ±100 μs. The ultimate accuracy depends on equipment delays and noise levels in addition to the path delay.

Special Considerations

Interference from land-mobile radio services—The land-mobile radio services can interfere with the GOES time code, since they use the same, or nearly the same, frequencies (468.8250 and 468.8375 MHz). This interference occurs mainly in urban areas with high land-mobile activity. Since the land-mobile frequency allocations have

Table 1. Characteristics of GOES satellite signals.

Satellite Signal Characteristics:	GOES/West	GOES/East
Frequency	468.8250 MHz	468.8375 MHz
Polarization	RHCP*	RHCP*
Modulation	CPSK ($\pm60°$)†	CPSK ($\pm60°$)†
Data Rate	100 bits/s	100 bits/s
Satellite Location	135° West	75° West
Signal Strength (output from isotropic antenna)	-131 dBm	-131 dBm
Coding	Manchester	Manchester
Bandwidth	400 Hz	400 Hz

* right-hand circularly polarized

† coherent phase shift keying

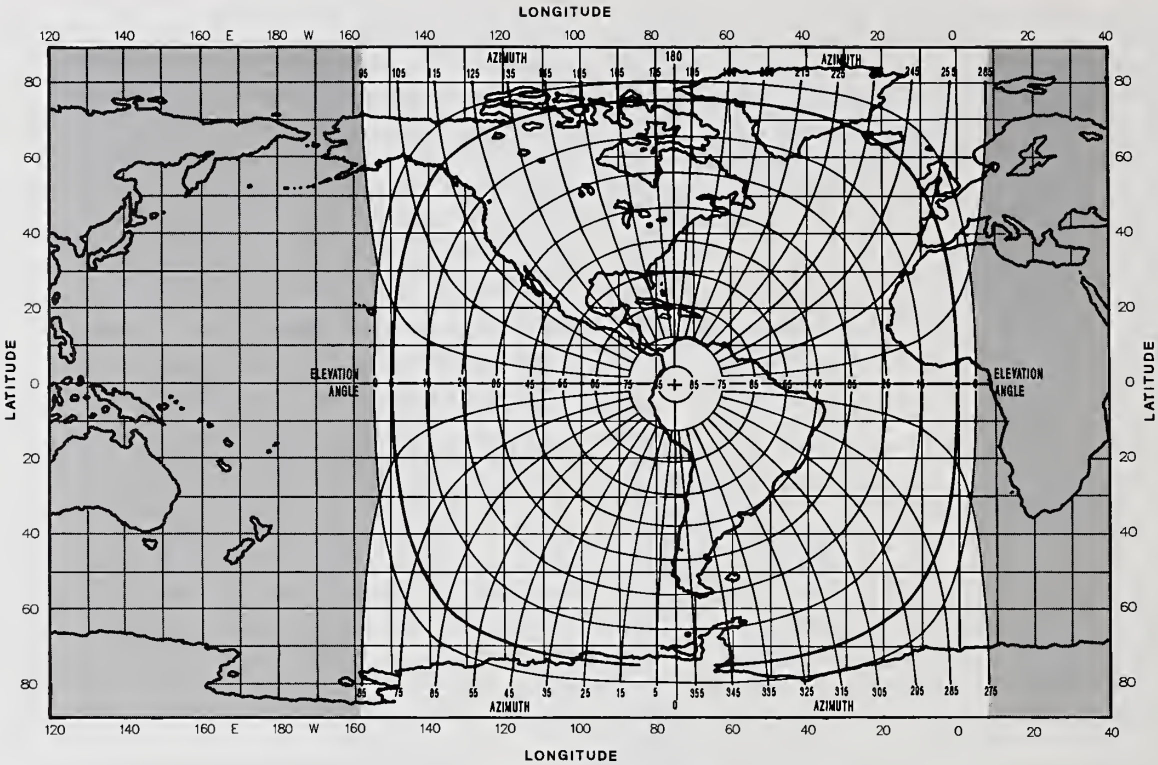


Figure 8. Pointing angles for GOES/East.

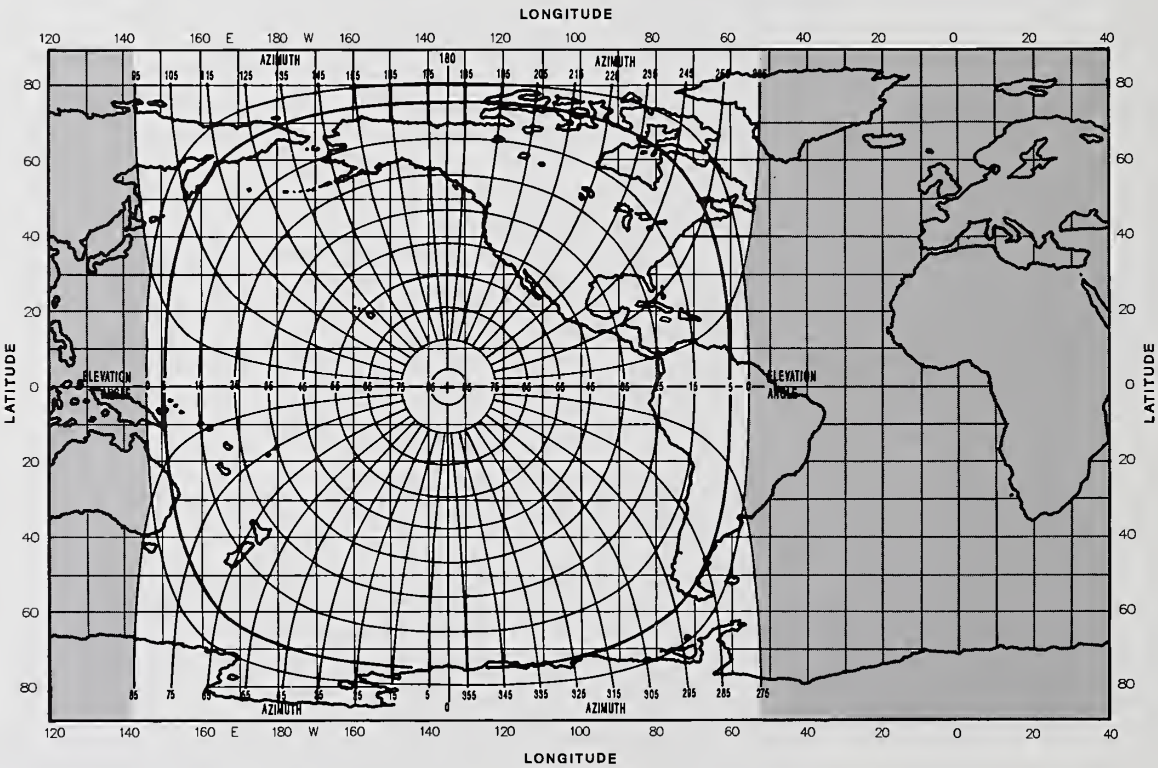


Figure 9. Pointing angles for GOES/West.

priority over the GOES allocations, complaining to the FCC will not help.

Because of the specific frequencies involved, the land-mobile services affect GOES/West more than GOES/East. Therefore, users in urban areas should use GOES/East if land-mobile interference is a problem.

Larger-than-Normal Time Code Deviations—The GOES time code is as accurate as stated more than 99 percent of the time. However, some situations can cause larger-than-normal time code deviations.

One such situation occurs when NOAA uses a GOES/East and/or GOES/West satellite with larger-than-normal orbit inclinations. In this instance, users in "uncorrected" mode may receive time with variations of several ms.

A more common problem (though of much shorter duration) occurs when stationkeeping maneuvers are performed on the satellites. These maneuvers are performed every 1 or 2 months to keep the satellites in their assigned orbit locations. Receivers that use the position data can compensate for these maneuvers; however, the position data are not updated until 0000 UTC on the day after the maneuver. This means that for up to 24 hours following a maneuver the time code may be off by more than the normal 100 μs. NIST changes the accuracy-indicator bit in the time code to indicate when this condition occurs.

Continuity—Since the GOES satellites are owned and operated by NOAA rather than by NIST, NIST cannot guarantee continuation of the service in the same sense as it can for its own radio stations WWV, WWVB, and WWVH. However, both NOAA and NIST have stated their intentions of maintaining the time-code service via a formal Memorandum-of-Agreement, the current version of which covers the period up until at least 1997. Availability of the service at any time, and the achievable time-code performance, is dependent on the status of NOAA's current satellite configuration and related support operations.

User Support

Information about the current status of the GOES time code can be obtained from the U.S. Naval Observatory's Automated Data Service database in Washington, D.C., and from the monthly *NIST Time and Frequency Bulletin*. These sources inform users about outages, any recent departures from normal performance, announcements of upcoming maneuvers, and other events. To find out more about these information sources, contact the NIST Time and Frequency Division.

NIST Frequency Measurement Service

The NIST Frequency Measurement Service (FMS) has been offered since 1984. The FMS lets users make accurate frequency calibrations at their site, rather than sending their oscillators to NIST or elsewhere for calibration. The FMS calibrates oscillators with accuracy levels from 1×10^{-5} to 1×10^{-12}. This includes nearly all quartz, rubidium, and cesium oscillators.

Users subscribe to the FMS by paying a one-time subscription fee. They then pay a monthly fee for as long as they use the service. Each subscriber receives and installs a frequency measurement system. This system remains the property of NIST, and NIST immediately replaces any system parts that fail.

Up to four oscillators can be connected to the measurement system. Each oscillator is measured continuously for 24 hours, its performance is plotted and printed out, and then the measurements begin again. The system is controlled by computer software, and almost no operator attention is required.

Each measurement system is linked by telephone to NIST, and the measurements are compared to measurements made at NIST and at other sites. By virtue of these comparisons, NIST can certify that the calibrations made by FMS users are traceable to NIST. Traceability to NIST is often required of organizations in both the public and private sectors.

The FMS measures oscillator performance using Loran-C radio signals as a reference frequency. Loran-C is a radio navigation system (Loran stands for LOng RAnge Navigation), consisting of stations located in many regions throughout the Northern Hemisphere. The stations are maintained by the U.S. Coast Guard. All Loran-C stations broadcast on 100 kHz, but each station has a unique emission delay so that receivers can distinguish among signals from different stations.

Loran-C is ideal for calibrating oscillators. It is easy to receive, more accurate (1×10^{-12} per day) than the other services described in this booklet, and widely available. However, unlike WWV/ WWVH, WWVB, and GOES, Loran-C does not have a time code and is not normally used to obtain time.

For more information about the FMS, write to the NIST Frequency Measurement Service, Time and Frequency Division (see page 27).

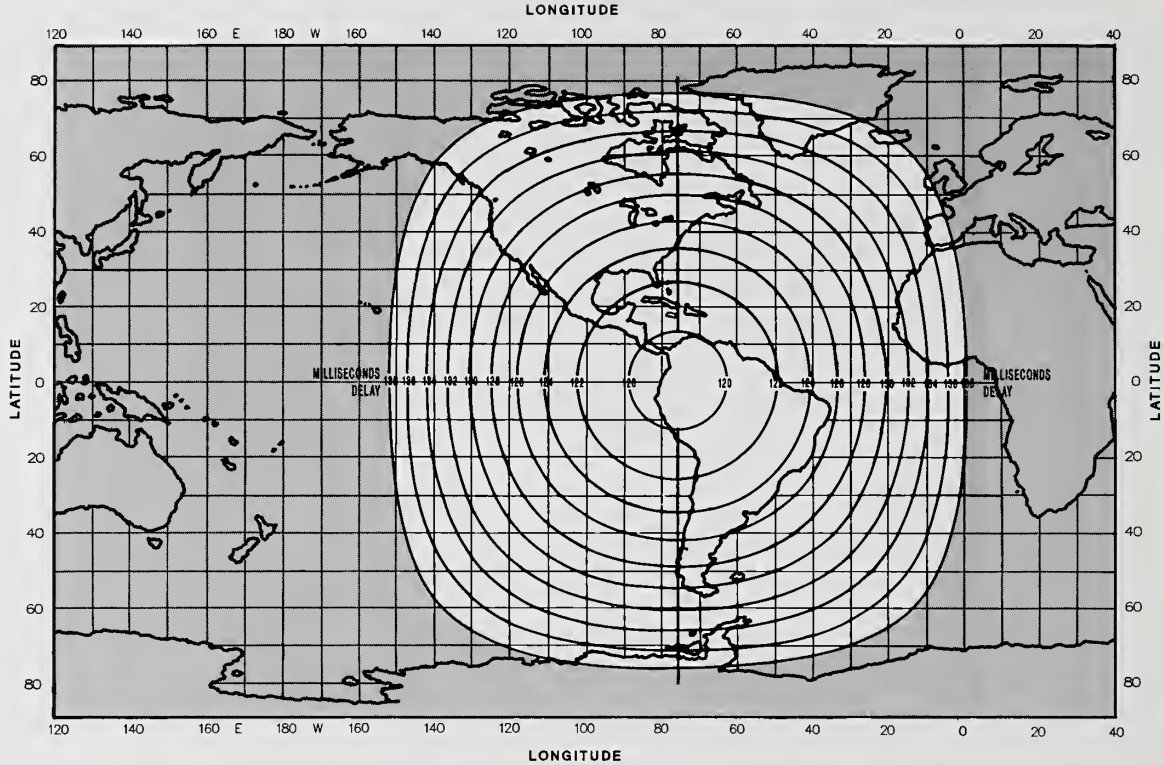


Figure 10. Mean delays for GOES/East; for total delay, add 124.5 ms to downlink delays shown.

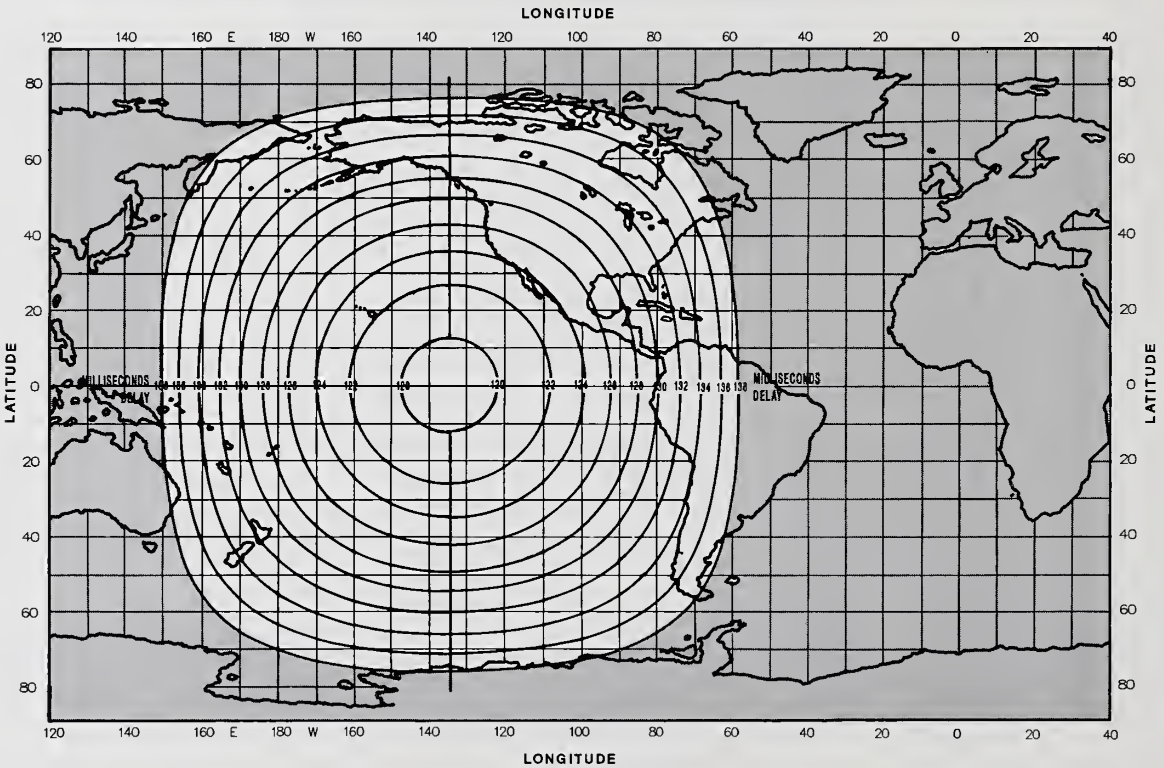


Figure 11. Mean delays for GOES/West; for total delay, add 133.5 ms to downlink delays shown.

Automated Computer Time Service (ACTS)

In 1988, NIST began the Automated Computer Time Service (ACTS). This service provides computers with telephone access to NIST time at accuracies approaching 1 ms. Since the time code uses the standard ASCII character set, it works with nearly all computer systems and modems. Simple hardware can also be built to set noncomputer clock systems.

The phone number for ACTS is (303) 494-4774. Six telephone lines are available on a rotary system and 6 redundant time-code generator systems are used to insure reliability. ACTS operates at 300 or 1200 Baud, with 8 data bits, 1 stop bit, and no parity. Users of the 1200-Baud service receive the full time code once each second. In addition to the UTC hours, minutes, and seconds, the time code includes the date, the Modified Julian Date (MJD), Daylight Saving Time and leap second indicators, a leap second flag, a UT1 correction, and other information. Users at 300 Baud receive somewhat less information over a 2-s interval due to the lower information transfer rate. For more details about the time code, see appendix E.

With appropriate software, ACTS can set or check computer time-of-day clocks in one of two different modes:

- **Fixed Delay Mode**—In this mode, the user receives the time code and an on-time marker character. The marker character has been advanced in time by a fixed amount to compensate for typical modem and telephone line delays. Unless the connection is routed through a satellite, the accuracy in this mode should be better than 0.1 s.
- **Measured Delay Mode**—In this mode, the user's computer echoes all characters back to NIST where the round trip line delay is measured. The on-time marker character is then advanced to compensate for the line delay. The accuracy in this mode should be less than 10 ms using a 1200-Baud modem, or about 1 ms using a 300-Baud modem. Accuracy at 1200 Baud is limited by the internal delays in 1200-Baud modems. Repeatability at both 300 and 1200 Baud is about 1 ms.

These accuracies assume that the telephone connection is reciprocal. Reciprocal connections follow the same path, that is, the path delay is the same in both directions. Most phone connections are of this type.

NIST offers software (Research Material 8101) which lets users use ACTS on several popular personal computers. The documentation for this software includes more information about the features of the service, and a simple circuit diagram that can be used to obtain an on-time pulse. These materials cost $35 (late 1990). To order RM 8101, contact: NIST Office of Standard Reference Materials, B311 Chemistry Building, NIST, Gaithersburg, MD 20899-0001; telephone (301) 975-6776.

For further information about ACTS, write to NIST-ACTS, Time and Frequency Division (see page 27).

NIST Time and Frequency Bulletin

The NIST Time & Frequency Bulletin is published monthly and distributed free to users of the NIST services. The bulletin includes data related to WWV, WWVH, WWVB, GOES, Loran-C, GPS, and the NIST time scales.

To receive the bulletin, write to: Editor, Time and Frequency Bulletin, Division 847, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303-3328.

Appendices

Appendix A: Dating of Events in the Vicinity of Leap Seconds

Leap seconds are sometimes needed to keep UTC within ± 0.9 s of UT1. The addition or deletion of a leap second always occurs at the end of a month. By international agreement, first preference is given to December 31 or June 30. Second preference is given to March 31 or September 30, and third preference is given to any other month.

When UT1 is slow relative to UTC, a positive leap second is needed. The second is inserted beginning at 23h 59m 60s of the last day of the month and ending at 0h 0m 0s of the first day of the following month. The minute containing the leap second is 61 s long. Figure A shows how to assign dates to events occurring near the leap second.

Since UTC has historically run faster than UT1, only positive leap seconds have been needed thus far. However, if the speed of the Earth's rotation were to increase to the point where UT1 runs faster than UTC, a negative leap second would be needed. In that case, exactly 1 s would be deleted at the end of some UTC month. The minute containing the negative leap second would be only 59 s long.

Positive leap seconds were inserted in all NIST broadcasts on June 30, 1972, on December 31, 1972-1979, on June 30, 1981-1983 and 1985, and on December 31 of 1987 and 1989. The dates for future leap seconds will be determined by the International Earth Rotation Service in France.

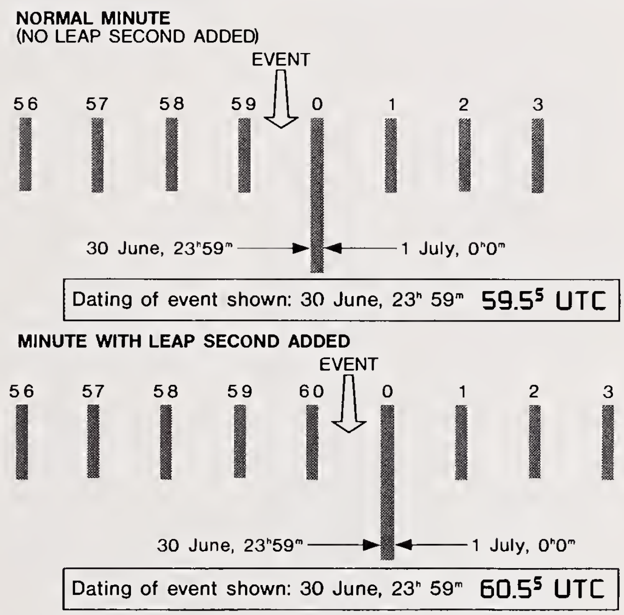


Figure A. Dating of events near a leap second.

Appendix B: WWV/ WWVH Time Code

The WWV/ WWVH time code is a modified version of the IRIG-H code. The code is transmitted on a 100-Hz subcarrier at a rate of 1 pulse per second. The code is in binary coded decimal (BCD) format. Groups of binary digits (bits) are used to represent decimal numbers. The binary-to-decimal weighting scheme is 1-2-4-8. The least significant bit is always sent first. Table 2 shows the BCD groups and the equivalent decimal number.

The decimal number is obtained by multiplying each bit in the binary group by the weight of its respective column and then adding the four products together. For example, the table shows that the binary group 1010 is equal to 5. This is derived by:

$$(1\times1) + (0\times2) + (1\times4) + (0\times8) = 1 + 0 + 4 + 0 = 5$$

In the standard IRIG-H code, a "0" bit consists of exactly 20 cycles of 100-Hz amplitude modulation (200-ms duration), and a "1" bit consists of 50 cycles of 100-Hz (500-ms duration). The WWV/ WWVH code differs from IRIG-H because all tones are suppressed briefly while the seconds pulses are transmitted (see Standard Time Intervals, page 6).

Table 2. 1-2-4-8 BCD-Decimal Equivalents

BINARY GROUP (Weight: 1 2 4 8)	DECIMAL 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

Tone suppression also deletes the first 30 ms of each binary pulse in the time code. This makes the WWV/-WWVH bits 30 ms shorter than the IRIG-H bits. Therefore, 170-ms pulses are recognized as "0" bits, and 470-ms pulses are recognized as "1" bits. The leading edge of each pulse coincides with the positive-going crossing of the 100-Hz subcarrier, but due to the tone suppression, it occurs 30 ms after the start of the second.

Within 1 minute, enough bits are sent to express the minute, hour, and day of year; two digits of the current year (to be implemented during the first half of 1991); a leap-second warning indicator (to be implemented during the first half of 1991); the UT1 correction, and a Daylight Saving Time (DST) indicator. The coded time information refers to the time at the start of the one-minute frame. Seconds are determined by counting pulses within the frame. Two BCD groups are needed to express the hour (00 to 23), minute (00 to 59), and year (00-99); and three groups are needed to express the day of year (001 to 366). Some bits in the BCD groups are unused, but may provide additional information in the future. To represent units, tens, or hundreds, the basic 1-2-4-8 weights are multiplied by 1, 10, or 100 as appropriate.

Each 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. This creates a 1-s (1000-ms) hole. 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, a position identifier pulse is transmitted every 10 s. The position identifier pulse lasts for 770 ms (77 cycles of 100 Hz).

UT1 corrections are sent during the final 10 s of each frame. These corrections are to the nearest 0.1 s. The UT1 correction is expressed with bits called control functions. Control function #1 occurs at 50 s, and tells whether the UT1 correction is negative or positive. If a "0" bit is sent the correction is negative, and if a "1" bit is sent the correction is positive. Control functions #7, #8, and #9, tell the amount of the UT1 correction. They occur at 56, 57, and 58 s, respectively. Since the UT1 corrections are in tenths of seconds, the binary-to-decimal weights are multiplied by 0.1.

Currently (late 1990), DST information is sent only by control function #6, at 55 s. If DST is in effect, a "1" bit is sent. If Standard Time is in effect, a "0" is sent. The setting of this bit is changed a few hours prior to 0000 UTC on the date of change. This schedule notifies users in the continental United States of the time change several hours before it occurs locally (usually at 2:00 a.m.). Receivers that display local time can read control function #6 and make the one-hour adjustment automatically when time changes occur.

During the first half of 1991, an improved procedure for alerting users of impending DST changes will be implemented. Two bits, #2 and the currently used bit #55, will be used to indicate whether "Standard" or "Daylight Saving Time" is in effect at any particular time. Bit #55 will be used essentially as it is now—that is, it will be changed from "0" to "1" at 0000 UTC of the day the time is to be changed from "Standard" time to DST and from "1" to "0" for the change back to "Standard" time in the Fall. The second DST bit, #2, will be changed in the same way as bit #55 but 24 hours later, at 0000 UTC on the day *following* the time change. The use of two separate bits in this manner will allow timing receivers that are powered on during the day of a time change to be able to determine whether it is a day of change and, if so, how to adjust their current time correctly.

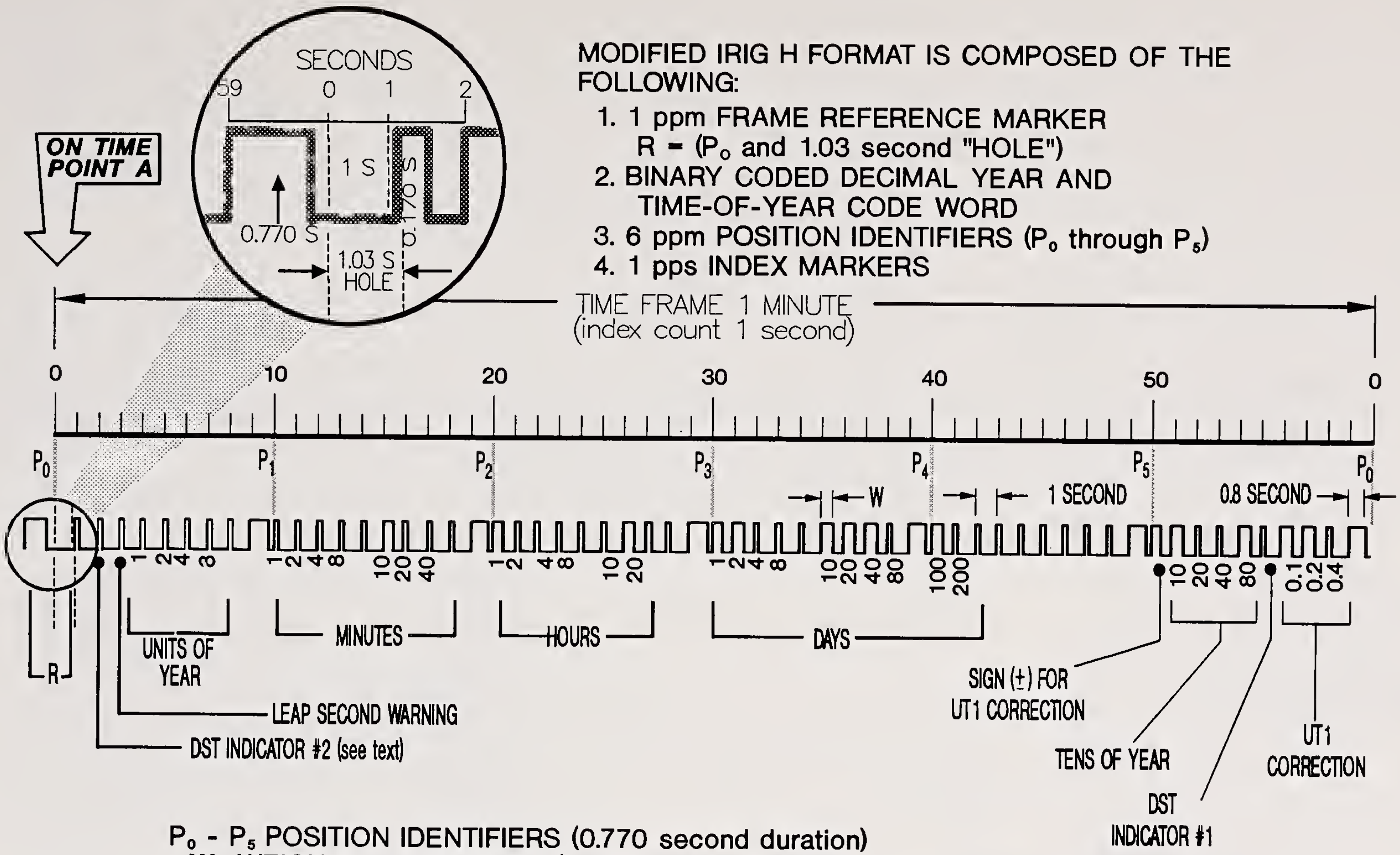
Also beginning during 1991, the last two digits of the current year (for example, "90" for 1990) will be encoded using bits #4-7 (for units of year) in a 1-2-4-8 weighting sequence and bits #51-54 (for tens of year) in a 10-20-40-80 weighting sequence.

Bit #3 will be used, beginning in 1991, to indicate that a leap second is to be inserted at the end of the current month. A "1" will be transmitted beginning early in the month at the end of which a leap second is to be inserted. Bit #3 will be returned to "0" at 0000 UTC of the first day of the following month.

Figure B shows one frame of the time code. The six position identifiers are labeled P1, P2, P3, P4, P5, and P0. 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. This diagram includes all changes planned for implementation in 1991.

In figure B, the decoded UTC at the start of the frame is 1990, 173 days, 21 hours, and 10 minutes. Since the UT1 correction is + 0.3 s, the decoded UT1 is 1990, 173 days, 21 hours, 10 minutes, and 0.3 s.

Manufacturers, users, and others who may need to know more definitely when these changes in the code formats are to be implemented should contact the NIST Time and Frequency Division for the most current status.



P_0 - P_5 POSITION IDENTIFIERS (0.770 second duration)
W WEIGHTED CODE DIGIT (0.470 second duration)
DURATION OF INDEX MARKERS, UNWEIGHTED CODE, AND UNWEIGHTED CONTROL ELEMENTS = 0.170 SECONDS

NOTE: BEGINNING OF PULSE IS REPRESENTED BY POSITIVE-GOING EDGE.

UTC AT POINT A = 1990, 173 DAYS, 21 HOURS, 10 MINUTES

UT1 AT POINT A = 1990, 173 DAYS, 21 HOURS, 10 MINUTES, 0.3 SECONDS

Figure B. WWV and WWVH time code format.

Appendix C: WWVB Time Code

The WWVB time code is also sent in BCD format, but the weighting is different from the WWV/WWVH weighting. Bits are sent by shifting the power of the 60-kHz carrier. The carrier power is reduced 10 dB at the start of each second. If full power is restored 200 ms later, it represents a "0" bit. If full power is restored 500 ms later, it represents a "1" bit. Reference markers and position identifiers are sent by restoring full power 800 ms later.

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. The BCD groups and the equivalent decimal numbers are shown in table 3.

Table 3. 8-4-2-1 BCD-Decimal Equivalents

	BINARY GROUP	DECIMAL EQUIVALENT
Weight:	8 4 2 1	
	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 number is obtained by multiplying each bit in the binary group by the weight of its respective column and then adding the four products together. For example, the table shows that the binary group 0101 is equal to 5. This is derived by:

$$(0\times8) + (1\times4) + (0\times2) + (1\times1) = 0 + 4 + 0 + 1 = 5$$

Every minute, the WWVB time code sends the current minute, hour, day of year, 2 digits of the current year, a UT1 correction, a leap-second warning bit, and Daylight Saving Time (DST) and leap year indicators. Two BCD groups are needed to express the hour (00 to 23), minute (00 to 59), and year (00-99); and three groups are needed to express the day of year (001 to 366). Some bits in the BCD groups are unused, but may provide additional information in the future. To represent units, tens, or hundreds, the basic 8-4-2-1 weights are simply multiplied by 1, 10, or 100 as appropriate. The coded information refers to the time at the start of the one-minute frame. Seconds are determined by counting pulses within the frame.

Each minute begins with a frame reference pulse lasting for 0.8 s. A position identifier pulse lasting for 0.8 s is transmitted every ten s.

UT1 corrections are broadcast at seconds 36 through 43 of each frame. These corrections are to the nearest 0.1 s. 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. The amount of the UT1 correction is sent in a four-bit BCD group at seconds 40, 41, 42, and 43. The binary-to-decimal weights are multiplied by 0.1, because the UT1 corrections are expressed in tenths of seconds.

The WWVB time code also contains information about leap years, DST, and leap seconds. The leap year bit 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 sometime after January 1 but before February 29. It is set back to "0" shortly after January 1 of the year following the leap year. Receivers that read this bit can automatically adjust themselves during leap years.

The two DST bits are sent at 57 and 58 s after each minute. If "Standard" time is in effect, both bits (#57 and #58) are set to 0. If DST is in effect, both bits are set to 1. On the day of change from "Standard" to DST bit #57 is changed from "0" to "1" at 0000 UTC. Exactly 24 hours later, bit #58 also changes from "0" to "1" at 0000 UTC. On the day of change from DST back to "Standard" time bit #57 goes from "1" to "0" at 0000 UTC, followed 24 hours later by bit #58. Receivers displaying local time can read the DST bits and make the one-hour adjustment automatically when time changes occur locally.

Bit #56 is used to warn users that a leap second will be inserted into the UTC(NIST) time scale at the end of the current month. The bit is set to "1" near the beginning of the month in which a leap second is added. It is reset to "0" immediately following the leap second insertion.

Figure C shows one frame of the time code. The six position identifiers are labeled as P1, P2, P3, P4, P5, and P0. 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".

In Figure C, the decoded UTC at the start of the frame is 1990, 258 days, 18 hours, and 42 minutes. Since the UT1 correction is 0.7 s, the decoded UT1 is 1990, 258 days, 18 hours, 41 minutes, 59.3 s.

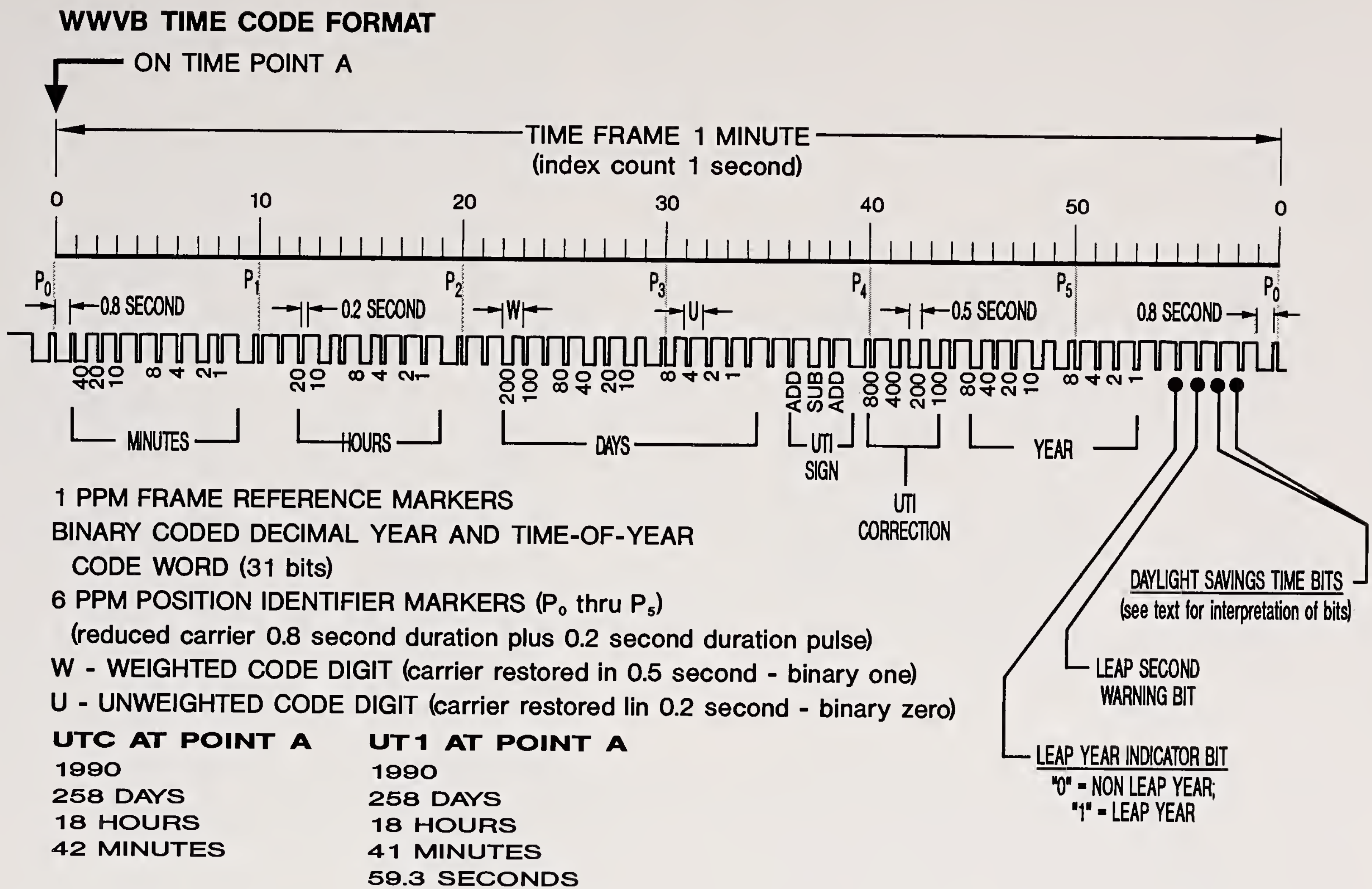


Figure C. WWVB time code format.

Appendix D: GOES Satellite Time Code

The interrogation channel format and the time-code format are shown in figure D.

The GOES time code is interlaced with interrogation messages used for other purposes. The interrogation messages are broadcast at a rate of 100 bits per second. They are one-half second, or 50 bits in length. The first 4 bits of the message form a BCD time-code word. The remaining 46 bits do not contain timing information.

A time-code frame consists of 60 BCD time-code words. It takes 60 interrogation messages, or 30 s, to complete a time-code frame. The completed time-code frame contains a synchronization word, the last two digits of the current year, the time-of-year (day of year, hour, and minute), time-code accuracy indicators, Daylight Saving Time (DST) and leap second indicators, system status information, the UT1 correction, and the satellite's position. The position information is updated every minute. It includes the satellite's latitude, longitude, and height above the Earth's surface.

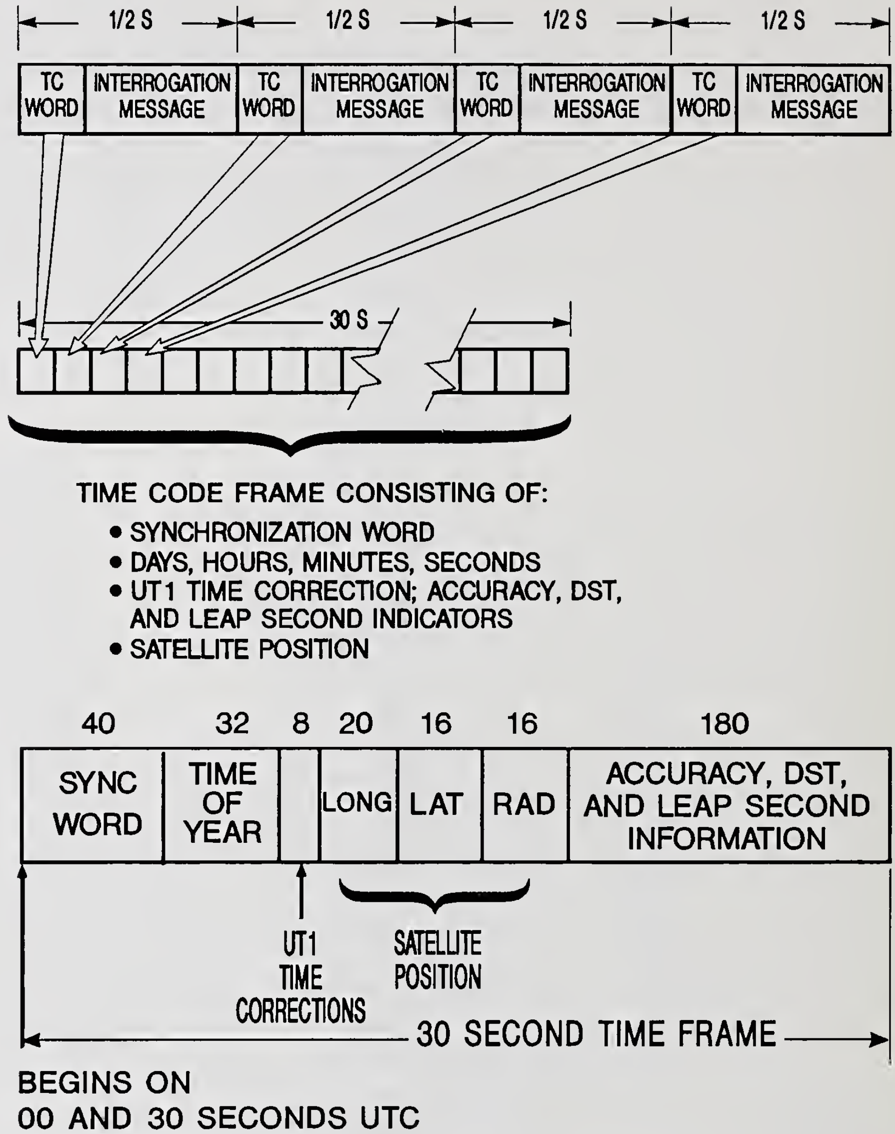


Figure D. (Top) GOES satellite interrogation channel format.
(Bottom) GOES time code format.

Appendix E: Time-code Format for Automated Computer Time Service (ACTS)

The time code for ACTS is sent in ASCII at either 300 or 1200 Baud. Both Baud rates require 8 data bits, 1 stop bit, and no parity. The 1200-Baud format is shown in figure E.

The first part of the time code contains the Modified Julian Date (MJD), the date (year, month, day), and the time (UTC hours, minutes, and seconds). This information is followed by the Daylight Saving Time (DST) information. The DST code is always a two-digit number (00 to 99). This code is normally a 00 when Standard Time (ST) is in effect, or a 50 when DST is in effect. About 48 days prior to a time change, however, this code starts counting the days until the change. When ST is in effect, the DST code counts down from 99 to 51 in the 48 days prior to the time change. When DST is in effect, the DST code counts down from 49 to 01 in the 48 days prior to the time change. In both cases, the code is updated at 0000 UTC.

The leap second (LS) flag is always a "0", a "1", or a "2". If no leap second is scheduled at the end of the current month, it is a "0". It is a "1" if a (positive) leap second is scheduled to be **added** on the last day of the current month. The LS flag remains on for the entire month before the leap second is added. Once the leap second is added, the LS flag is reset to "0". The leap second flag is a "2" only if a (negative) leap second is to be **deleted** on the last day of the current month. So far, a negative leap second has never been needed.

The UT1 correction is shown as either a positive or negative number in steps of 0.1 s.

The remainder of the time code shows the ms advance (msADV) and the on-time marker (OTM). The displayed time is valid at the OTM. The OTM is either a "*" or a "#" character. When the connection is established, the "*" OTM is displayed. This marker is transmitted 45 ms early with respect to UTC(NIST). The 45 ms accounts for the 8 ms required to send 1 character at 1200 Baud, an additional 7 ms to compensate for delay from NIST to the user, plus a 30-ms "scrambler" delay. The "scrambler" delay approximately compensates for the internal delay found in 1200-Baud modems.

If the user's equipment is set to echo all characters, or at least the OTM, NIST measures the round-trip delay and advances the OTM so that the midpoint of the stop bit arrives at the user's computer on time. When this happens, the msADV shows the actual required advance in ms and the OTM becomes a "#". Four consecutive stable measurements are needed before the OTM switches from "*" to "#". If the user's 1200-Baud modem has the same internal delay used by NIST (30 ms), then the "#" OTM should arrive at the user's location within ± 2 ms of the correct time. Different brands of 1200 Baud modems have different internal delays, and the actual offset of the "#" OTM may be as large as ± 10 ms. This should still be more than adequate, however, since many computer clocks can only be set within 20-50 ms.

The 300-Baud time code includes less information than the 1200-Baud code, but is more accurate. At 300 Baud, the MJD and DUT1 values are deleted and the time is sent every 2 s with the OTM referring to the even-numbered second. Due to a simpler modulation scheme, the OTM should arrive at the user's computer within 1 ms of the correct time.

Users are allowed 56 s on ACTS unless all lines are busy. In that case, the first call that reaches 28 s is terminated.

```
? = HELP
 National Institute of Standards and Technology
 Telephone Time Service
          (1 second pause here)
                           D  L D
MJD  YR MO DA H  M  S  ST S UT1 msADV          <OTM>
47222 88-03-02 21:39:15 83 0 +.3 045.0 UTC(NIST) *
47222 88-03-02 21:39:16 83 0 +.3 045.0 UTC(NIST) *
47222 88-03-02 21:39:17 83 0 +.3 045.0 UTC(NIST) *
47222 88-03-02 21:39:18 83 0 +.3 045.0 UTC(NIST) *
47222 88-03-02 21:39:19 83 0 +.3 037.6 UTC(NIST) #
47222 88-03-02 21:39:20 83 0 +.3 037.6 UTC(NIST) #
 etc. etc. etc....
```

Figure E. Automated Computer Time Service (ACTS) screen display.

Inquiries about NIST Time and Frequency Services

If you have specific questions about the **operations of NIST radio stations**, contact:

Engineer-in-Charge NIST Radio Stations WWV and WWVB 2000 East County Road 58 Fort Collins, CO 80524 (303) 484-2372	*OR:*	Engineer-in-Charge NIST Radio Station WWVH P.O. Box 417 Kekaha, Kauai, HI 96752 (808) 335-4361

If you have specific questions about the **other time and frequency services**, contact:

NIST Time and Frequency Services, 847.40
National Institute of Standards and Technology
325 Broadway
Boulder, CO 80303-3328
(303) 497-3294

Tours of NIST Facilities:

Public guided tours of the NIST Laboratories in Boulder are held twice a week from Memorial Day to Labor Day, and once a week the rest of the year. They offer a chance to see the NIST Atomic Clock that provides the basis for the time and frequency services, as well as visiting other laboratories of NIST and the National Oceanic and Atmospheric Administration.

Contact the Tour Program Office, Division 360.06, NIST, 325 Broadway, Boulder, CO 80303-3328; telephone (303) 497-5507; for information about when tours are scheduled or to arrange special tours for groups of 15 to 30 people.

There are no public tours available at the radio stations.

A Brief History of NIST Time and Frequency Services

March	1923	First scheduled broadcasts of WWV, Washington, D.C.
April	1933	WWV gets first 20-kW transmitter, Beltsville, Maryland.
January	1943	WWV relocated to Greenbelt, Maryland.
November	1948	WWVH commenced broadcasts, Maui, Hawaii.
January	1950	WWV added voice announcements.
July	1956	WWVB began 60-kHz broadcasts (as KK2XEI), Sunset, Colorado.
April	1960	WWVL began 20-kHz experimental broadcasts, Sunset, Colorado.
July	1963	WWVB began high power broadcasts, Ft. Collins, Colorado.
August	1963	WWVL began high power broadcasts, Ft. Collins, Colorado.
July	1964	WWVH added voice announcements.
December	1966	WWV relocated to Ft. Collins, Colorado.
July	1971	WWVH relocated to Kauai, Hawaii.
June	1972	First leap second in history was added to UTC time scale.
July	1972	WWVL went off the air.
January	1974	Voice announcements changed from GMT to UTC (WWV/ WWVH).
July	1974	GOES satellite time code initiated.
March	1975	Frequency calibration using network color TV became a nationwide service.
August	1975	Line-10 time comparisons using TV synchronization pulses became a nationwide service.
February	1977	20- and 25-MHz broadcasts from WWV and 20-MHz broadcasts from WWVH were discontinued.
December	1978	20-MHz broadcasts from WWV were reinstated.
February	1984	Frequency Measurement Service began.
March	1988	Automated Computer Time Service (ACTS) began on experimental basis.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991-281-616/42755

BL-114A (5-90)	U.S. DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY **BIBLIOGRAPHIC DATA SHEET**	1. PUBLICATION OR REPORT NUMBER NIST/SP-432 (Revised 1990) 2. PERFORMING ORGANIZATION REPORT NUMBER 3. PUBLICATION DATE June 1991

4. TITLE AND SUBTITLE

NIST Time and Frequency Services

5. AUTHOR(S)

Roger E. Beehler and Michael A. Lombardi

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)	7. CONTRACT/GRANT NUMBER
U.S. DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY BOULDER, COLORADO 80303-3328	8. TYPE OF REPORT AND PERIOD COVERED Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

Same as item 6 above.

10. SUPPLEMENTARY NOTES

Supersedes NBS Special Publication 432 dated September 1979

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

NIST Time and Frequency Services [Special Publication 432 (Revised 1990)] is a revision of SP 432, last published in 1979. It describes services available, as of December 1990, from NIST radio stations WWV, WWVH, and WWVB; from GOES satellites; from Loran-C; by telephone (voice and modem); and from the NIST Frequency Measurement Service.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

broadcast of standard frequencies; computer time setting; frequency calibrations; GOES satellite; high frequency; low frequency; satellite time code; shortwave; standard frequencies; time calibrations; time signals

13. AVAILABILITY		14. NUMBER OF PRINTED PAGES
X	UNLIMITED	30
	FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).	15. PRICE
X	ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402.	
X	ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.	

ELECTRONIC FORM

NIST Technical Publications

Periodical

Journal of Research of the National Institute of Standards and Technology—Reports NIST research and development in those disciplines of the physical and engineering sciences in which the Institute is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Institute's technical and scientific programs. Issued six times a year.

Nonperiodicals

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

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

Special Publications—Include proceedings of conferences sponsored by NIST, NIST annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

Applied Mathematics Series—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NIST under the authority of the National Standard Data Act (Public Law 90-396). NOTE: The Journal of Physical and Chemical Reference Data (JPCRD) is published bi-monthly for NIST by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements are available from ACS, 1155 Sixteenth St., NW., Washington, DC 20056.

Building Science Series—Disseminates technical information developed at the Institute on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

Technical Notes—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NIST under the sponsorship of other government agencies.

Voluntary Product Standards—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The standards establish nationally recognized requirements for products, and provide all concerned interests with a basis for common understanding of the characteristics of the products. NIST administers this program as a supplement to the activities of the private sector standardizing organizations.

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

Order the **above** *NIST publications from: Superintendent of Documents, Government Printing Office, Washington, DC 20402.*

Order the **following** *NIST publications—FIPS and NISTIRs—from the National Technical Information Service, Springfield, VA 22161.*

Federal Information Processing Standards Publications (FIPS PUB)—Publications in this series collectively constitute the Federal Information Processing Standards Register. The Register serves as the official source of information in the Federal Government regarding standards issued by NIST pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations).

NIST Interagency Reports (NISTIR)—A special series of interim or final reports on work performed by NIST for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Service, Springfield, VA 22161, in paper copy or microfiche form.

U.S. Department of Commerce
National Institute of Standards and Technology
(formerly National Bureau of Standards)
Gaithersburg, MD 20899