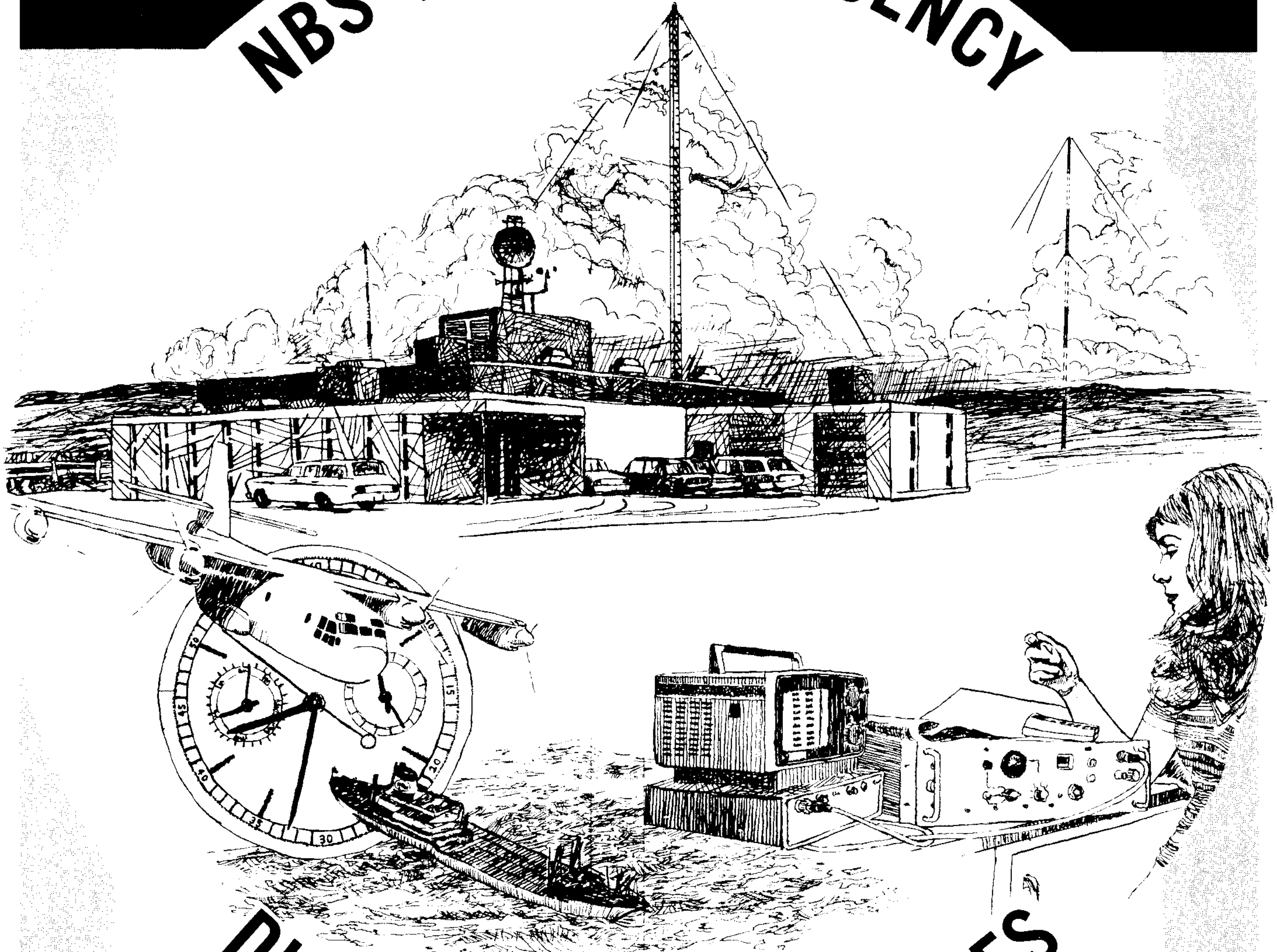
NBS SPECIAL PUBLICATION 432

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

Feb. 1977 20 and 25 MHz broadcasts from WWV and 20 MHz broadcasts from WWVH discontinued

May 1977 GOES satellite time code officially initiated

Dec. 1978 20 MHz broadcasts from WWV reinstated

NBS
TIME AND FREQUENCY DISSEMINATION SERVICES

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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 9, *OTHER PUBLICATIONS*.

This SPECIAL PUBLICATION 432 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, and WWVB, and time and frequency calibration services using television and satellites. This publication shows services available on April 1, 1979.

Key words: Broadcast of standard frequencies; frequency calibrations; GOES satellite; high frequency; low frequency; satellite time code; standard frequencies; television color subcarrier; time calibrations; 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 55 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 addiiton, services using network television and satellite signals 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 and 15 MHz. WWV also broadcasts on an additional frequency of 20 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
Geophysical alerts
Marine storm warnings
Omega Navigation System status reports
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 (1×10^{-11}) at all times. Deviations are normally less than one part in 1,000 billion (1×10^{-12}) 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.

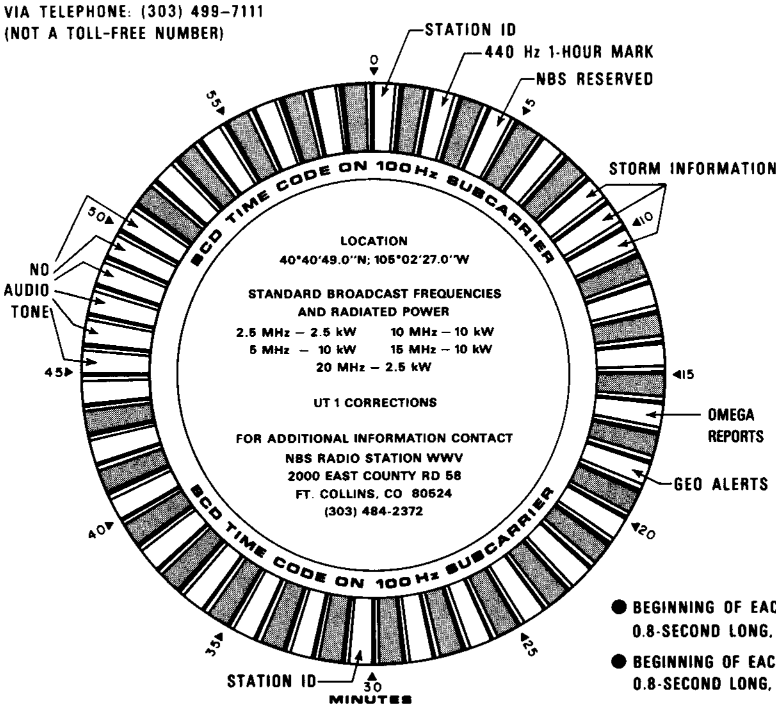
1b. Radiated Power, Antennas and Modulation

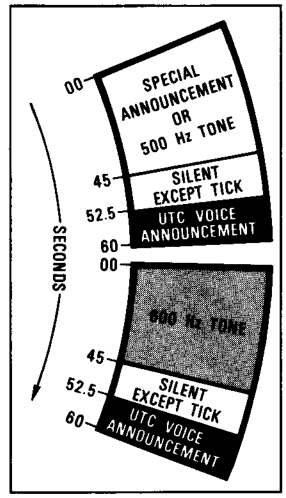
Frequency, MHz	Radiated Power, kW	
	WWV	WWVH
2.5	2.5	5.0
5.0	10.0	10.0
10.0	10.0	10.0
15.0	10.0	10.0
20.0	2.5	—

The broadcasts on 5, 10, and 15 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.

WWV BROADCAST FORMAT

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

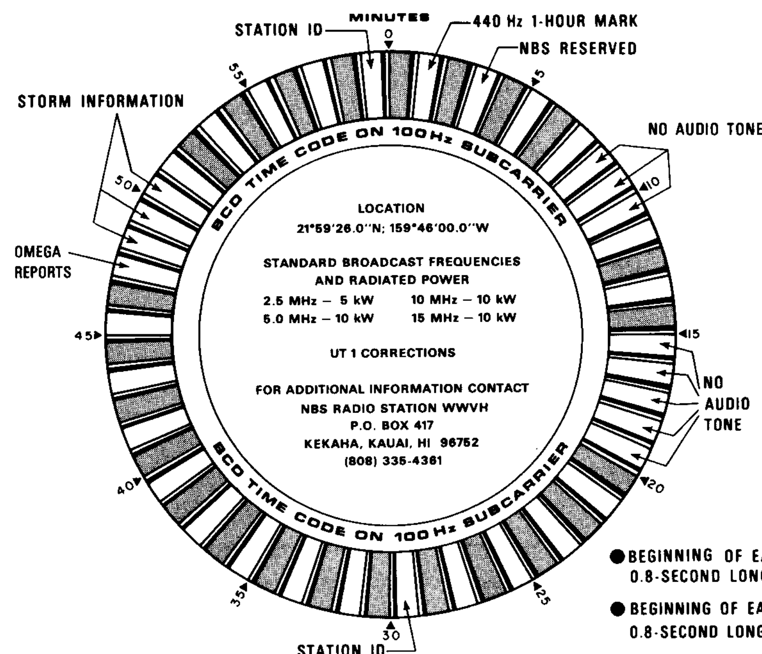


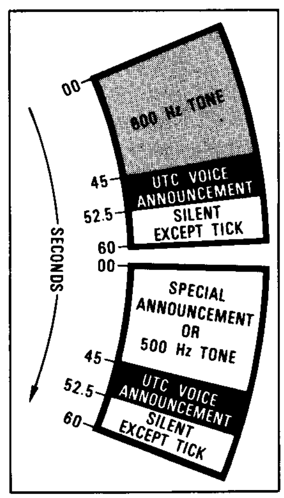


- BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8-SECOND LONG, 1500-Hz TONE.
- BEGINNING OF EACH MINUTE IS IDENTIFIED BY 0.8-SECOND LONG, 1000-Hz TONE.
- THE 29th & 59th SECOND PULSE OF EACH MINUTE IS OMITTED.

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.

5/79

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

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.

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.

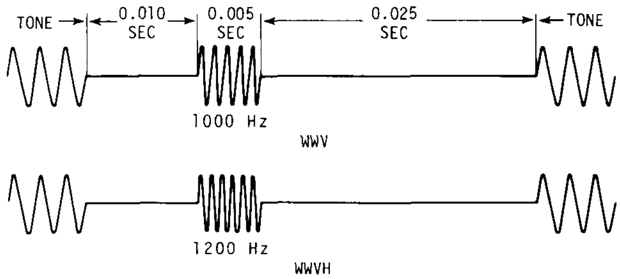


Figure 2. Format of WWV and WWVH seconds pulses.

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.

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 Group, 524.06, National Bureau of Standards, Boulder, CO 80303.*

Omega Navigation System Status Reports

Omega Navigation System status reports are broadcast in voice from WWV at 16 minutes after the hour and from WWVH at 47 minutes after the hour. The international Omega Navigation System is a very low frequency (VLF) radio navigation aid operating in the 10 to 14 kHz frequency band. Eight stations are in operation around the world. Omega, like other radio navigation systems, is subject to signal degradation caused by ionospheric disturbances at high latitudes. The Omega announcements on WWV and WWVH are given to provide users with immediate notification of such events and other information on the status of the Omega system.

For more information about the Omega Navigation System, contact *Mr. David Scull, U.S. Coast Guard HQ, (G-ONSOD/43), Washington, DC 20590.*

Geophysical Alerts

Current geophysical alerts (Geoalerts) are broadcast in voice from WWV at 18 minutes after each hour. The messages are changed approximately every six hours at 1800, 0000, 0600, and 1300 UTC. Part A of the message gives the solar-terrestrial indices for the day; namely, the 1700Z solar flux from Ottawa, Canada at 2800 MHz, the estimated A value for Fredericksburg, Virginia, and the current, Boulder, Colorado, K-index. Part B gives the solar-terrestrial conditions for the previous 24 hours, and Part C gives the forecast for the next 24 hours. If strat-

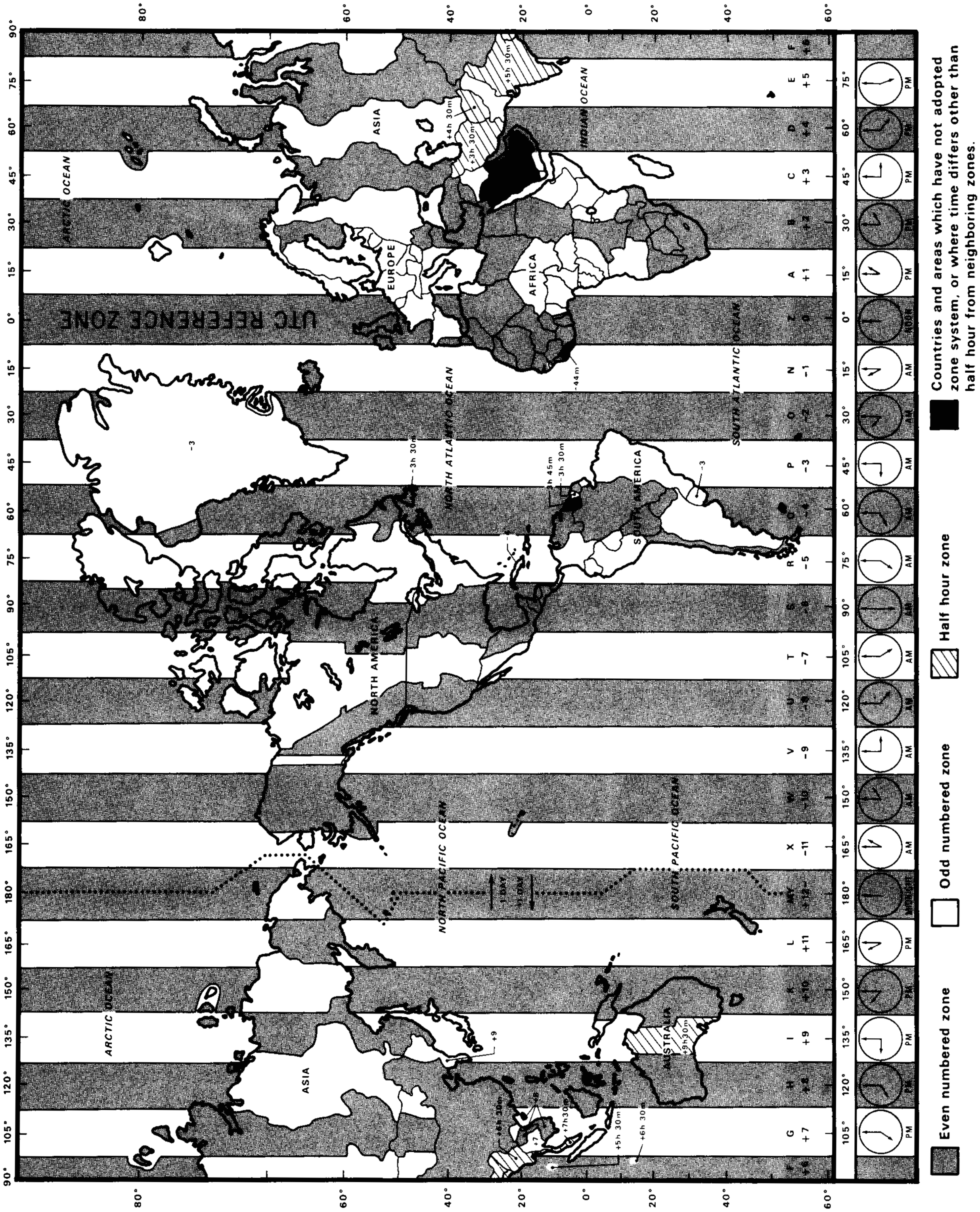


Figure 3. Standard time zones of the world and their relationship to UTC.

warm conditions exist, a brief advice is given at the end of the message.

1. Solar activity is classified as:

VERY LOW	= usually only quiet regions on the solar disk and no more than five of these; fewer than ten class-C subflares without centimetric radio burst or SID (sudden ionospheric disturbance) observed or expected.
LOW	= usually more than five but less than ten quiet regions on the solar disk; only class-C subflares without centimetric radio bursts or SID observed or expected.
MODERATE	= eruptive regions on the solar disk; fewer than five class-M X-ray events with centimetric radio bursts and SID observed or expected.
HIGH	= active regions on solar disk; several class-M X-ray events with centimetric radio bursts and strong SID; and/or one to two importance-2 chromospheric flares or class-X X-ray events observed or expected.
VERY HIGH	= region capable of producing protons on the sun; one or more chromospheric flares of importance-2 or greater; with outstanding centimetric radio bursts (500 flux units or greater), class-X X-ray bursts, and major SID observed or expected.

2. The geomagnetic field is classified as:

QUIET	= $A \leq 7$, usually no K-indices>2.
UNSETTLED	= $7<A<15$, usually no K-indices >3.
ACTIVE	= $15 \leq A<30$, a few K-indices of 4.

3. The geomagnetic storms are classified as:

MINOR	= $30 \leq A<50$, K-indices mostly 4 and 5.
MAJOR	= $A \geq 50$, some K-indices 6 or greater. Sudden commencements indicated by beginning time given to nearest minute. Gradual commencements indicated by beginning time to nearest hour.

4. The rest of the report is as follows:

SOLAR FLARES

CLASS C	= any solar X-ray burst with a peak flux at 1-8Å of less than 10^{-6} watts m^{-2}.
CLASS M	= a solar X-ray burst with a peak flux at 1-8Å greater than or equal to 10^{-5} but less than 10^{-4} watts m^{-2}.
CLASS X	= a solar X-ray burst with peak flux at 1-8Å greater than or equal to 10^{-4} watts m^{-2}.
MAJOR SOLAR FLARE	= a flare of optical importance ≥2B (Bright) with a centimetric radio outburst of 500 flux units or more; or an X-ray event of Class-X intensity of duration≥180 minutes regardless of optical flare importance.
PROTON FLARE	= protons by satellite detectors (or polar cap absorption by riometer) have been observed in time association with the Hα flare.
SATELLITE-LEVEL PROTON EVENT	= a proton enhancement detected by Earth orbiting satellites with measured particle flux of at least 10 protons cm^{-2} sec^{-1} $ster^{-1}$ at ≥10 MeV.
POLAR CAP ABSORPTION	= proton-induced absorption ≥2dB as measured by a 30 MHz riometer located within the polar cap.
STRATWARM	= reports of stratospheric warmings in the high latitude regions of winter hemisphere of the earth associated with gross distortions of the normal circulation associated with the winter season.

Inquiries regarding these messages should be addressed to *NOAA, Space Environment Services Center R43, Boulder, Colorado 80303.* These messages are also available by dialing (303) 499-8129.

Propagation Forecasts

The radio propagation forecasts broadcast on WWV were discontinued on September 30, 1976. Some of the information previously contained in these forecasts is now included in the Geophysical Alert announcements at 18 minutes after each hour. However, neither NBS nor the Space Environment Services Center which sponsors the Geophysical Alerts make radio propagation predictions, nor do they maintain a literature file on the subject. Users interested in further reading material on the effect of solar and geophysical activity on radio propagation should consult the latest edition of the *Amateur Radio Handbook*, published by the American Radio Relay League.

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 (1×10^{-11}). Deviations from day to day are less than 5 parts in 1,000 billion (5×10^{-12}). Effects of the propagation medium on received signals are relatively minor at low frequencies; therefore, frequency comparisons to better than 1 part in 10^{11} 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

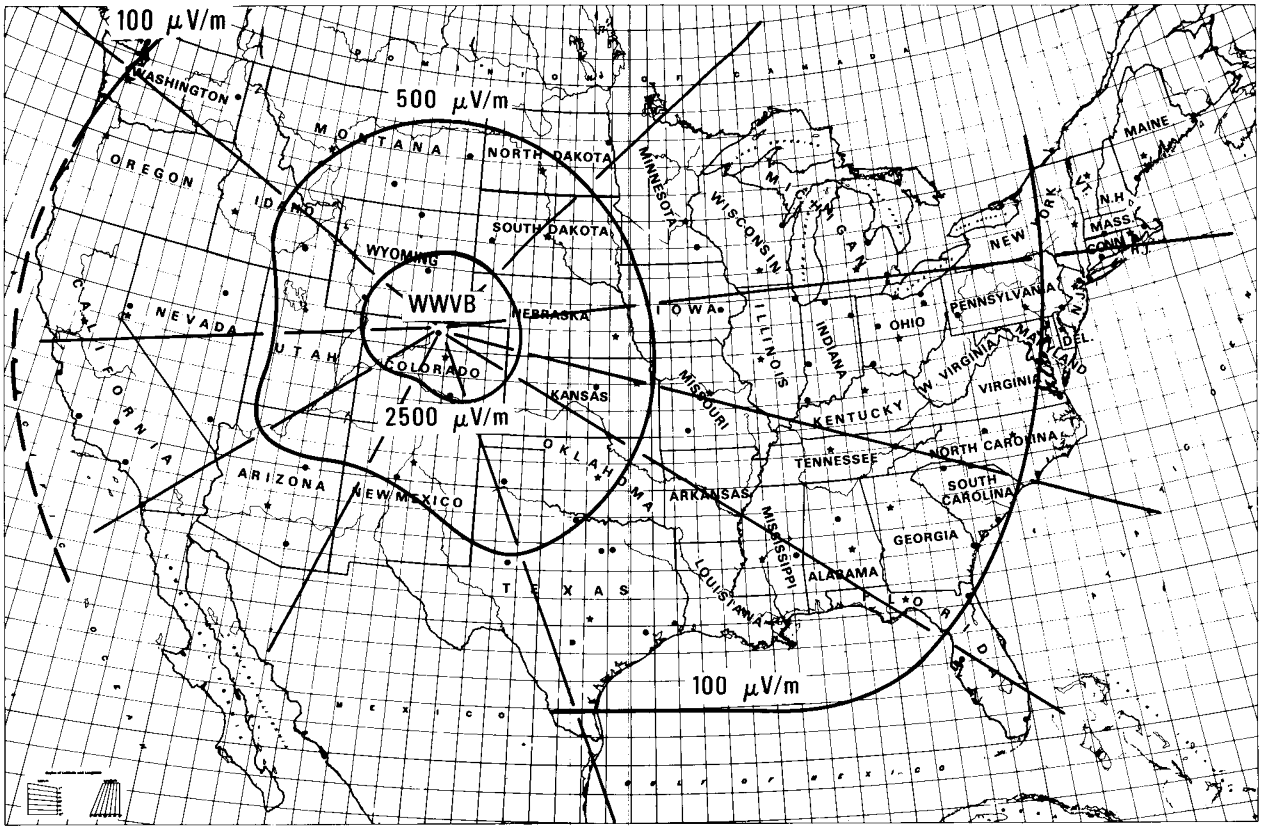


Figure 4. Measured field intensity countours of WWVB at 13 kW ERP.

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 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. 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.

4. 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, TA

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	

COORDINATES:

WWV	40°40'49.0''N	105°02'27.0''W
WWVB	40°40'28.3''N	105°02'39.5''W
WWVH	21°59'26.0''N	159°46'00.0''W

(NBS). Another scale, UTC (NBS), is also generated by adding leap seconds and small corrections to TA (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 controlling 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.

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FREQUENCY AND TIME FACILITIES

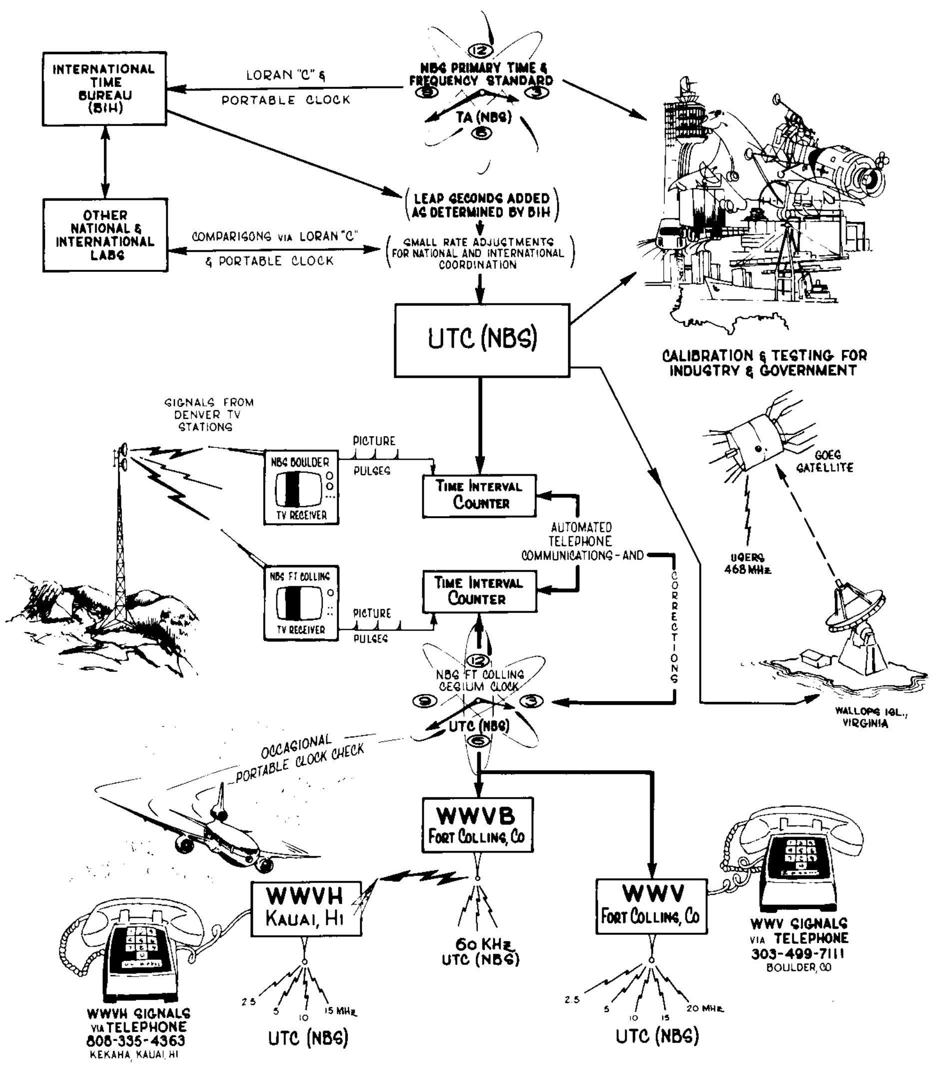

Figure 5. The NBS frequency control system.

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.

5. Frequency Calibration Service Using Network Television

For those users who require only frequency calibrations, an alternative to the radio broadcasts is available. This 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. (See Section 7 for limitations on use of this method.)

The service is very reliable because the networks use extremely stable rubidium or cesium 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.

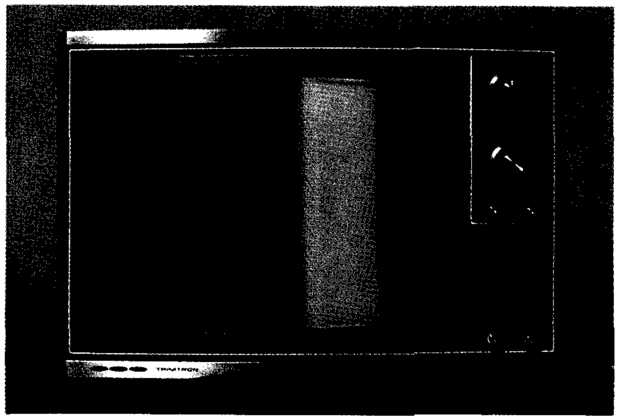

Figure 7: Prototype of a color bar comparator.

5a. Color Bar Comparator Method

The color bar comparator is a simple circuit that connects to a standard color television set (figure 7). It pro-

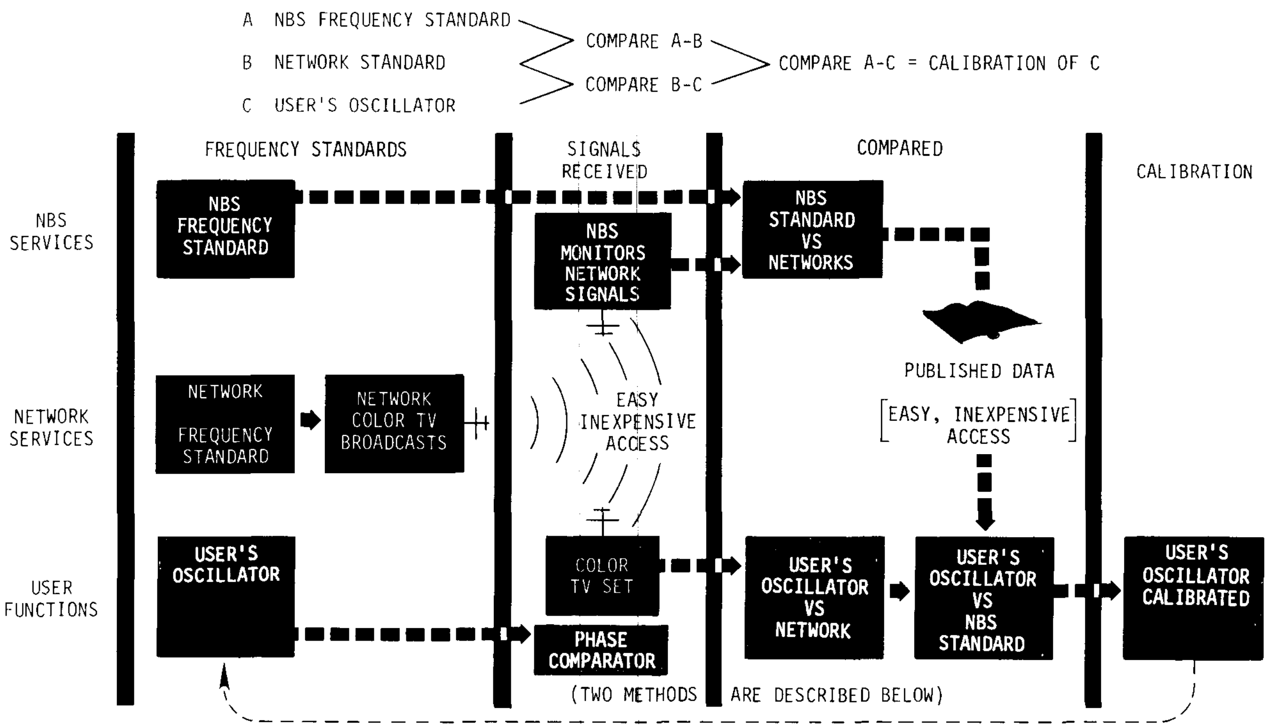

Figure 6. How the frequency calibration service using color television works.

duces 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 (1×10^{-9}).

5b. 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 (figure 8) as parts in 100 billion (parts in 10^{11}). If 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 Group, NBS, Boulder, CO 80303.*

6. 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 (See Section 7 for limitations on use of this method.)

Figure 8: Prototype of a digital offset computer.

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 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 supplied by the Hewlett-Packard Co. in Santa Clara, California and are referenced to UTC(NBS) with an accuracy of about 0.5 micro-second. 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 Bulletin* or contact the *Time and Frequency Services Group, 524.06, NBS, Boulder, CO 80303.*

7. Digital Frame Synchronizers and TelevisionTechniques

Although both the color subcarrier and Line-10 methods are effective for time and/or frequency calibrations, a word of caution is necessary. Some local stations are now using digital frame synchronizers on their incoming network lines. This is presently true of the ABC stations in the San Francisco and Chicago areas, which provide network feeds to other local stations in their areas, as well as a number of other local stations throughout the country.

The frame synchronizer stores one complete TV frame (1/30 second) in digital memory and "reads" the TV picture under control of the local station sync generator. Since most sync generators are driven by a crystal oscillator, the color subcarrier is no longer referenced to the network atomic standard, and the signals *cannot* be used for frequency calibration. The frame synchronizer eliminates the use of Line-10 for time transfer when it is in the differential path.

For instance, the ABC stations in Los Angeles and New York also use frame synchronizers on the incoming network lines so Line-10 reference is lost, *but* these stations are co-located with the network studios and use the network cesium standards for their 3.58 MHz reference. Therefore, WABC and KABC still provide stable frequency references and can be used for *frequency* transfer measurements.

At present, only a few of the largest TV stations have two or more frame synchronizers. The smaller stations that have a single frame synchronizer will use it for their "electronic news," not on the incoming network line. Of course, this situation may change in five years if the price of synchronizers drops.

If you are using the TV networks for time and/or frequency transfer, the best precaution is simply to use more than one network so that data can be verified.

8. NBS Time via Satellite

As a complement to its other time and frequency services, NBS is now sponsoring a satellite-disseminated time code using the GOES (Geostationary Operational Environmental Satellite) satellites of the National Oceanic and Atmospheric Administration (NOAA). The time code is referenced to the NBS time scale and gives Coordinated Universal Time (UTC). Although the time code was designed to provide a means of dating environmental data collected by the GOES satellites, it can also be used as a general-purpose time reference for many other applications. The time code is available to the entire Western Hemisphere from two satellites on a near full-time basis.

There are three GOES satellites in orbit, two in operational status with a third serving as an in-orbit spare. The western satellite operates at 468.825 MHz and is located at 135° West Longitude. The eastern satellite is received on 468.8375 MHz and is positioned at 75° West Longitude. The spare is at 105° West Longitude. Coverages of the two operational satellites are shown in figure 9.

The GOES satellites collect environmental data from remote sensors. The time code is part of the interrogation channel which is used to communicate with these sensors. The interrogation messages and time code are prepared and sent to the GOES satellites from Wallops Island, Virginia. NBS maintains atomic clocks, referenced to UTC(NBS), at this site to generate the time code. The time code includes a sync word, a time-of-year message (including day of year, hour, minute, and second), UT1 correction, and satellite position. A description of the time code is given in the Appendix.

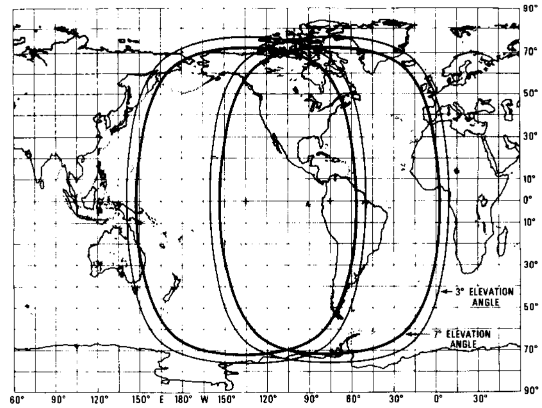

Figure 9: Coverage of the GOES satellites

8a. Performance

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

Uncorrected: The path delay from point of origin (Wallops Island, Virginia) to the earth via the satellite is approximately 260,000 microseconds. Since the signals are advanced in time by this amount before transmission from Wallops Island, they arrive at the earth's surface on time to within 16 milliseconds.

Corrected for Mean Path Delay: Accounting for the mean path delay to any point on the earth's surface, but ignoring the cyclic (24-hour) delay variation, generally guarantees the signal arrival time to ±0.5 millisecond.

Fully Corrected: The cyclic delay variation is a result of the satellite orbit or path around the earth not being perfectly circular and not in the plane of the equator. The orbit is actually an ellipse and has a small inclination — usually less than 1°. To compensate for these and other effects, the satellite position is included with the time message for correction of path delay by the user. This correction provides path delays accurate to ±10 microseconds. The ultimate accuracy of the recovered time depends upon knowledge of user equipment delays and noise levels as well as path delay.

8b. Equipment

Figure 10 shows one antenna used by NBS with satisfactory results. The antenna can be of small size and pointed in the general direction of the satellite. The receiver shown in figure 11 is completely automatic, requiring no tuning or auxilliary equipment to operate.

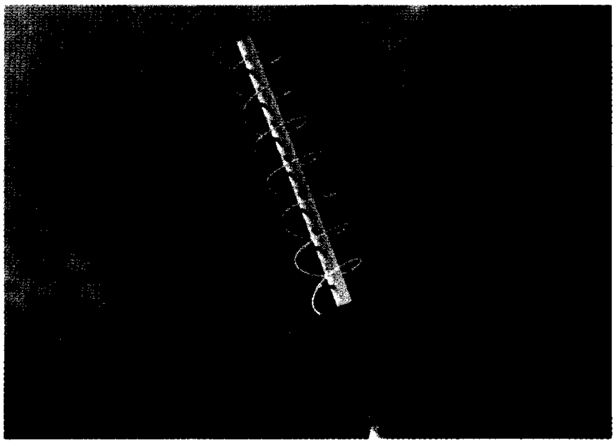

Figure 10: Antenna used by NBS to receive GOES time code.

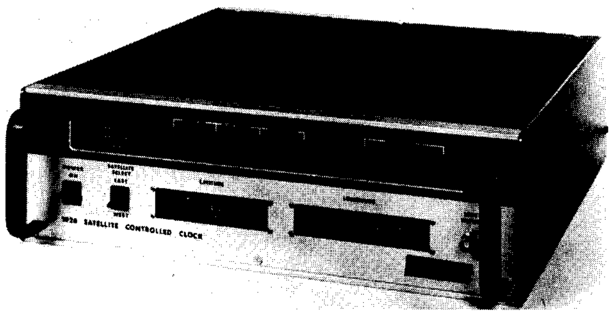

Figure 11: GOES time code receiver.

8c. Precautions

Since the GOES time code is transmitted outside the spectrum reserved exclusively for time and frequency broadcasts, it *cannot* be considered an NBS service in the same sense that the radio broadcasts and television methods are services. The "land-mobile" services and the GOES interrogation channels use the same frequency allocations (468.825 and 468.8375 MHz), which means the time code may suffer interference from land-mobile transmissions. This is particularly true in urban areas where there is a high density of land-mobile activity. The satellite frequency allocations are secondary to the land-mobile services. Therefore, any interference must be accepted by the time signal users. Complaints to the FCC will not result in any adjustments in favor of time code users.

Because of the spacing of frequency assignments to the land-mobile users, there is far less interference to the eastern satellite than to the western satellite. Therefore, the eastern satellite should be used by those users situated in large urban areas.

Outages

Although the GOES satellites transmit continuously, there may be interruptions during the periods of solar eclipses. The GOES satellites undergo spring and autumn eclipses during a 46-day interval at the vernal and autumnal equinoxes. The eclipses vary from approximately 10 minutes at the beginning and end of eclipse periods to a maximum of approximately 72 minutes at the equinox. The eclipses begin 23 days prior to equinox and end 23 days after equinox; i.e., March 1 to April 15 and September 1 to October 15. The outages occur during local midnight for the satellite's mean meridian.

There will also be shutdowns for periodic maintenance at the Wallops Island ground station.

8d. Continuity

NBS cannot give an absolute guarantee to the long-term continuance of the GOES time code since the satellites belong to NOAA. However, NBS and NOAA have agreed to include the time code in the transmissions to the maximum extent possible. The GOES system presently has a sufficient number of satellites to operate into the late 1980's, and it is expected that the time code will be included throughout this period.

For further information on the GOES time code or commercial equipment availability, write the *Time and Frequency Services Group, 524.06, NBS, Boulder, CO 80303*.

9. 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 Group, NBS, Boulder, CO 80303* or call (303) 499-1000, x 3276. The following is available:

"Frequency Standards and Clocks: A Tutorial Introduction," Helmut Hellwig, NBS Tech. Note 616R, March 1974.

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 Group, NBS, Boulder, CO 80303* (Phone (303) 499-1000, x 3212):

"The Use of NBS High Frequency Broadcasts for Time & Frequency Calibrations," N. Hironaka and C. Trembath, NBS Tech. Note 688, May 1975.

"NBS Time Via Satellites," NBS Time & Frequency Division Publication TFS-602, January 1978.

"Time and Frequency Users' Manual," G. Kamas, Ed., NBS Technical Note 695, May 1977.

"From Sundials to Atomic Clocks: Understanding Time and Frequency," J. Jespersen and J. Fitz-Randolph, NBS Monograph 155, December 1977. Order from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Stock No.: 003-003-01650-1. Price: $4 ($5 for other than U.S. mailing.)

Appendix

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 Oh Om Os 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.

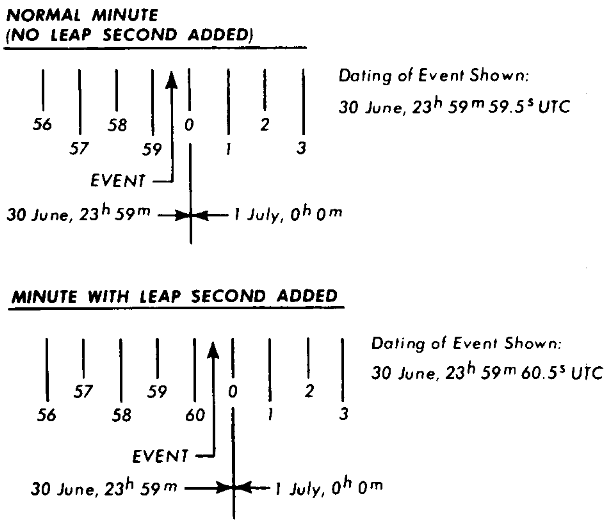

Figure 1A. Dating of events in the vicinity of a leap second.

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 30, 1972, and December 31, 1972 through 1978.

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 EQUIVALENT
Weight:	1 2 4 8	
	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. 1d).

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

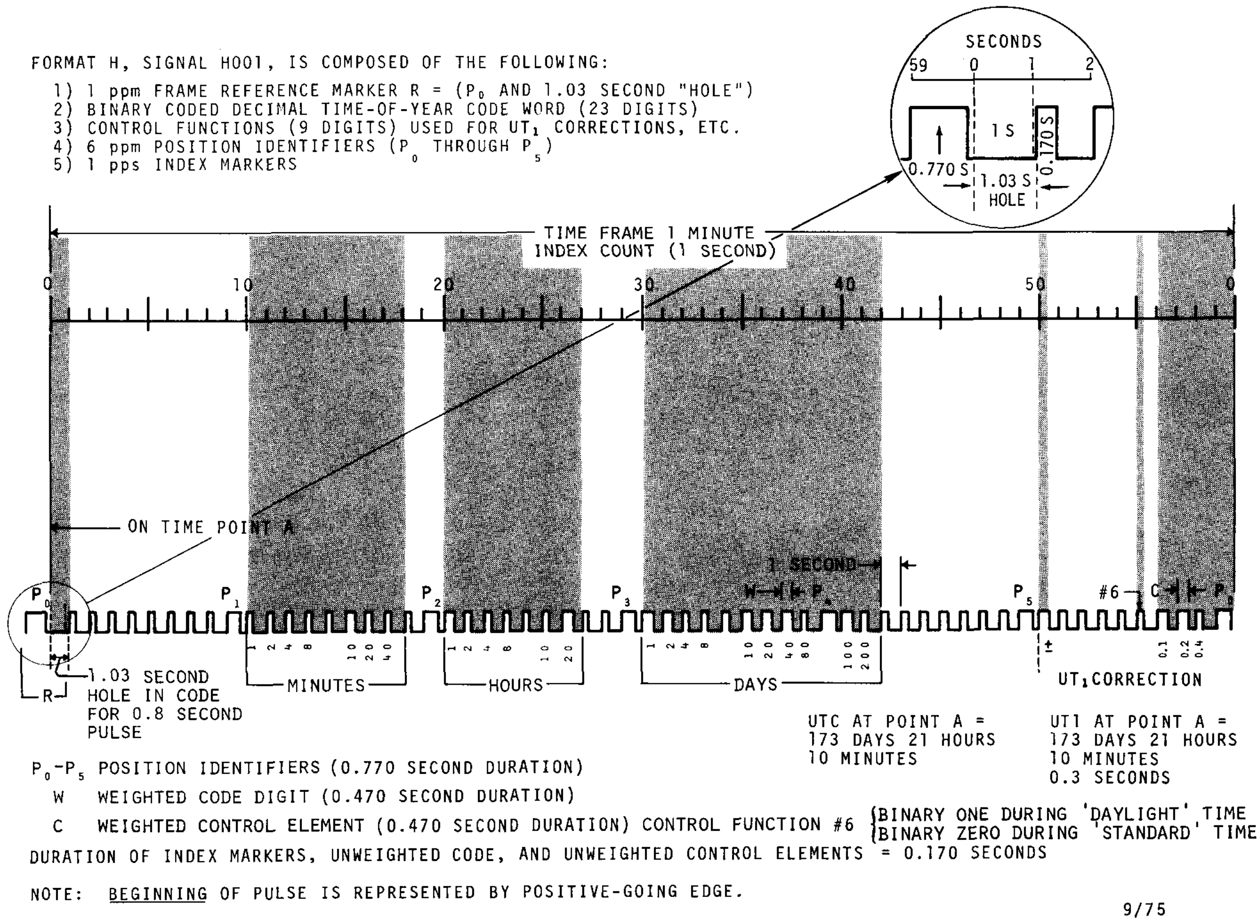

Figure 2A. WWV and WWVH time code format.

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 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 the correction to be added to the UTC signals to obtain UT1 is a positive. 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 is negative. 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 × 40) + (0 × 20) + (0 × 10) = 40; the least significant digit of that set is (0 × 8) + (0 × 4) + (1 × 2) + (0 × 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.

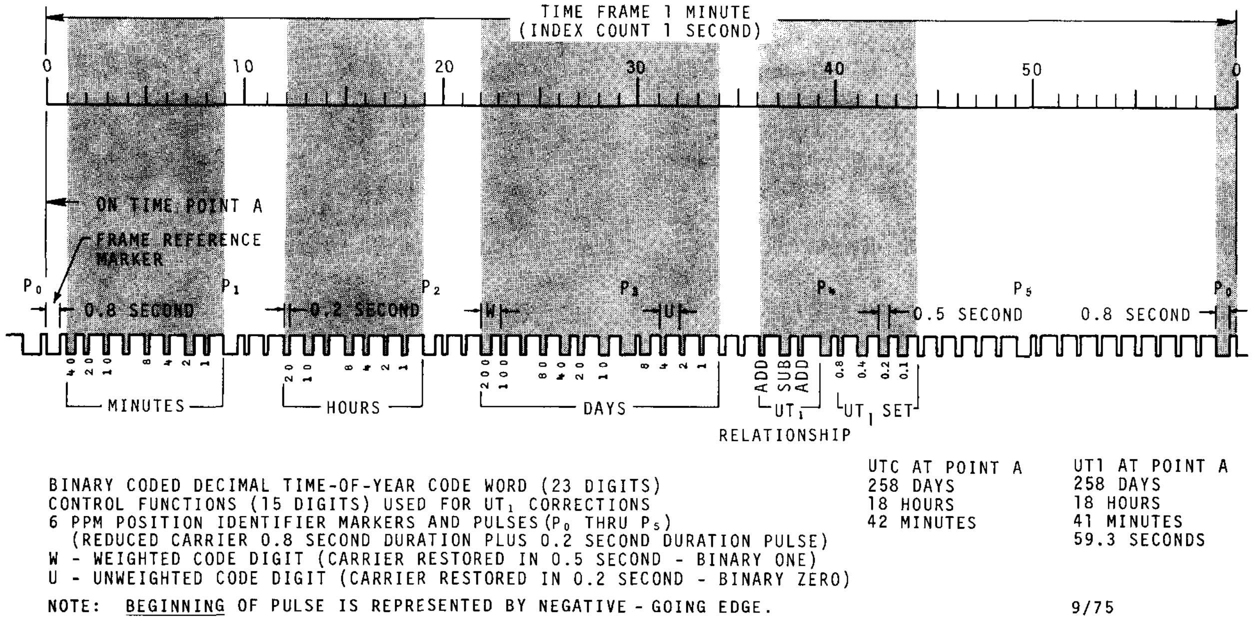

Figure 3A. WWVB time code format.

4A. GOES Satellite Time Code

The GOES time code is part of the interrogation channel which is used to communicate with remote data sensors that send information to GOES. Interrogation messages are continuously relayed through the GOES satellites. The format of the messages is shown in figure 4A.

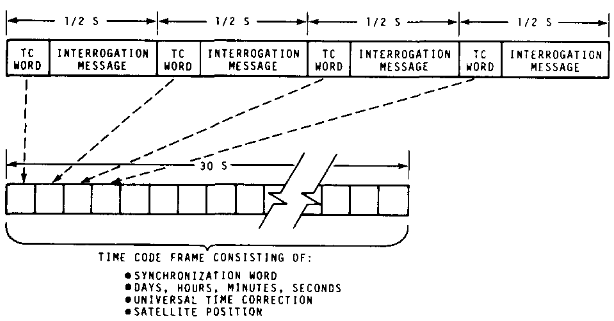

Figure 4A. GOES interrogation channel format.

As shown, an interrogation message contains more than timing information. A complete message consists of four bits representing a BCD time code word followed by a maximum length sequence (MLS) 15 bits in length for message synchronization, and ends with 31 bits as an address for a particular remote weather data sensor.

Each interrogation message is one-half second in length or 50 bits. The data rate is 100 bits per second. The time-code frame begins on the one-half minute and takes 30 seconds to complete (see figure 5A). Sixty interrogation messages are required to send the 60 BCD time-code words constituting a time-code frame.

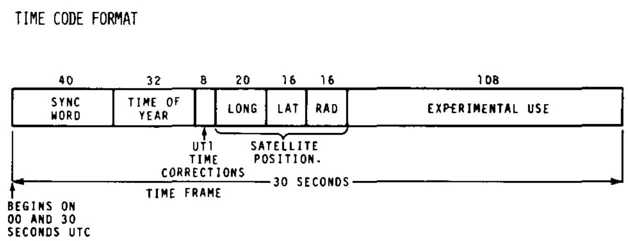

Figure 5A. GOES time code format.

The time-code frame contains a synchronization word, a time-of-year word (UTC) (including day of year, hour, minute, and second), the UT1 correction, and the satellites position in terms of its latitude, longitude, and height above the earth's surface minus a bias of 119,300 microseconds. The position information is presently updated on the half-hour.

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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. However, arrangements for visiting the sites should be made in advance with the Engineer-in-Charge (see below). There are *no* regularly scheduled visiting hours.

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 80303.*

Inquiries About the Stations

Correspondence pertaining directly to station operations may be addressed to:

Engineer-in-Charge
NBS Radio Stations WWV and WWVB
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