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NBS Frequency and Time Broadcast Services

RADIO STATIONS
WWV WWVH WWVB WWVL

U.S.
DEPARTMENT
OF
COMMERCE
National
Bureau
of
Standards

UNITED STATES DEPARTMENT OF COMMERCE
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NBS FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV, WWVH, WWVB, AND WWVL

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Frequency-Time Standards
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National Bureau of Standards
Boulder, Colorado 80302

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Contents

Services Provided by NBS Standard Frequency and Time Stations

Detailed descriptions are given of the technical services provided by the National Bureau of Standards radio stations WWV, WWVH, WWVB, and WWVL. These services are: 1. Standard radio frequencies; 2. Standard audio frequencies; 3. Standard musical pitch; 4. Standard time intervals; 5. Time signals; 6. UT2 corrections; 7. Radio propagation forecasts; and 8. Geophysical alerts. In order to provide users with the best possible services, occasional changes in broadcasting schedules are required. This publication shows the schedules in effect on February 1, 1970. Annual revisions will be made. Current data relating to standard frequencies and time signals are available monthly in the Time and Frequency Services Bulletin. Advance notices of changes occurring between revisions will be sent to users of NBS broadcast services who request such notice on the basis of need.[1]

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

Introduction

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

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

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

To supplement the coverage of WWV, broadcasts from station WWVH were instituted in 1948. These play an increasingly important role in various types of operations in the Pacific and Far East, both military and civilian.

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

Thus in the 47 years since the beginning of its radio broadcasts, NBS has expanded such services so that it is making major contributions today to the nation's space and defense programs, to world-wide transportation and communications, and to a multitude of industrial operations, as well as providing convenient time service to thousands of listeners.

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

1. Technical Services and Related Information

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

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

The NBS radio stations are located as follows:

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

Correspondence pertaining directly to station operations may be addressed to:

John Stanley, Engineer-in-charge

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

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

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

1.1. Standard Radio Frequencies

(a) Program

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

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

Station WWVB broadcasts on the standard frequency of 60 kHz and station WWVL on the nominal frequency of 20 kHz. These two stations have scheduled maintenance periods on alternate Tuesdays between 1300 UT and 2400 UT. Otherwise the service is continuous.

(b) Accuracy and Stability

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

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

On January 1, 1960, the NBS standard was brought into agreement with f_{Cs} as quoted above by arbitrarily increasing its assigned value by 74.5 parts in 10^{10}. Frequencies measured in terms of the NBS standard between December 1, 1957 and January 1, 1960, may be referred to the above value of f_{Cs} and to the Ephemeris second by means of this relative correction.[4]

The frequencies transmitted by WWV and WWVH are held stable to better than ± 2 parts in 10^{11} at all times. Deviations at WWV are normally much less than 1 part in 10^{11} from day to day. Incremental frequency adjustments not exceeding 1 part in 10^{11} are made at WWV as necessary. Frequency adjustments made at WWVH do not exceed 4 parts in 10^{11}.

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

WWVB and WWVL frequencies are normally stable to better than 2 parts in 10^{11}. Devi-

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

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

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

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

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

(c) Corrections

All carrier and modulation frequencies at WWV are derived from cesium controlled oscillators and at WWVH are derived from precision quartz oscillators. Coordinated by the Bureau International de l'Heure (BIH) in Paris, these frequencies are intentionally offset from standard frequency by a small but precisely known amount to reduce departure between the time signals as broadcast and astronomical time, UT2. The offset for 1960 and 1961 was −150 parts in 10^{10}; in 1962 and 1963, −130 parts in 10^{10}; in 1964 and 1965, −150 parts in 10^{10}; and in 1966 through 1970, −300 parts in 10^{10}. Although UT2 is subject to unpredictable changes readily noted at this level of precision, a particular offset from standard frequency will remain in effect for the entire calendar year.

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

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

(d) Offset Frequencies

WWV, WWVH, and WWVL transmit reminders of the fact that all transmitted frequencies are offset from nominal by a fixed amount (for 1966, 1967, 1968, 1969, and 1970 by -300×10^{-10}). International Morse Code symbols for M300, representing minus 300, are transmitted from WWV and WWVH immediately following the "on-the-hour" voice announcement. WWVL transmits experimental programs with multiple frequencies. Transmissions presently alternate between 20.0 kHz and 19.9 or 20.9 kHz, the change being made every 10 seconds. The transmission format and the frequencies used by WWVL are subject to change to meet the requirements of the particular experiment(s) being conducted. All three of the above stations are coordinated under the UTC (Universal Time Coordinated) system by the BIH.

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

1.2. Standard Audio Frequencies

(a) Program

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

(b) Accuracy

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

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

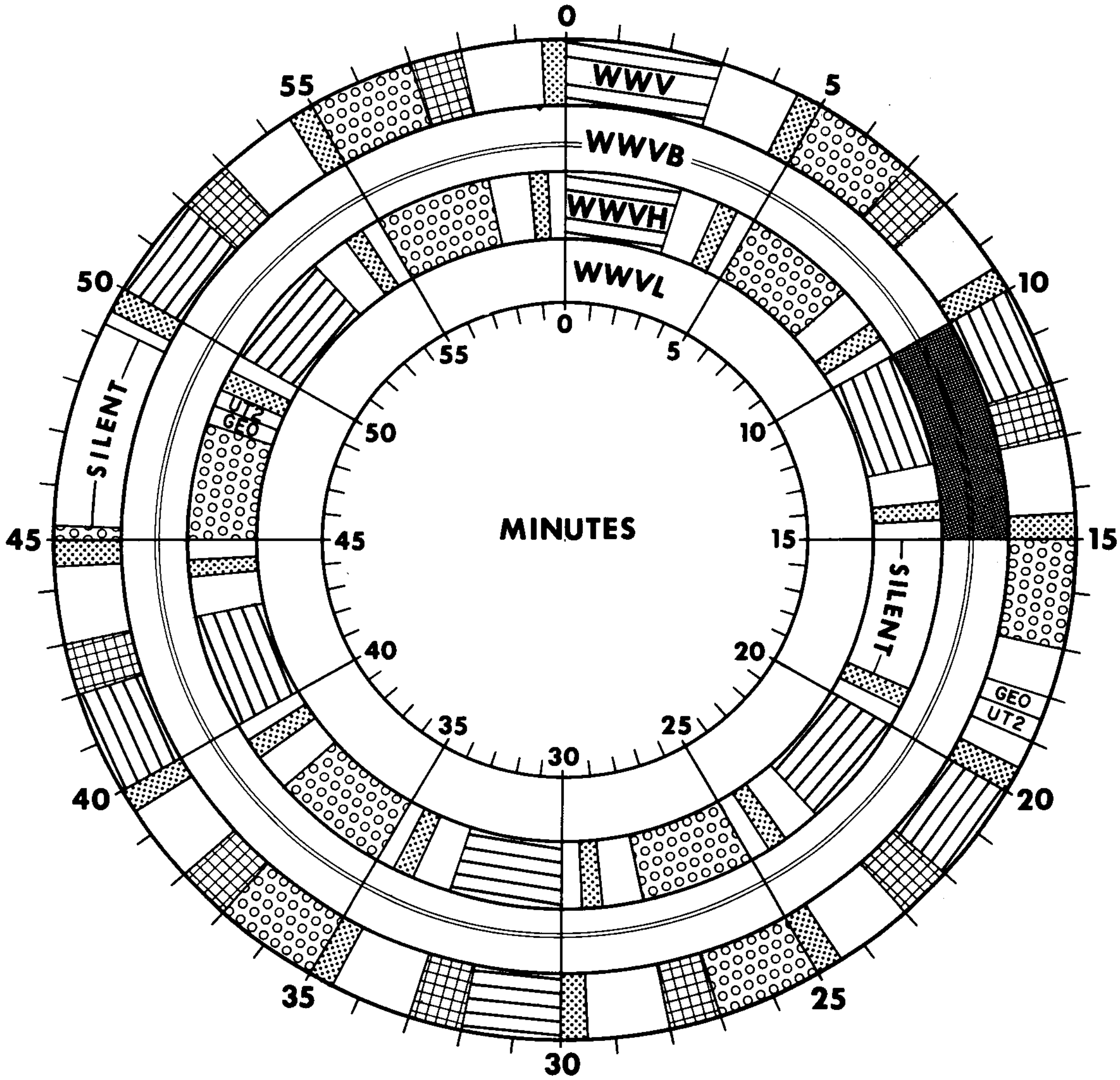
1.3. Standard Musical Pitch

The frequency 440 Hz, for the note A above middle C, is the standard in the music industry in many countries and has been in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. The periods of transmission of 440 Hz from WWV and WWVH are shown in figure 1. With this broadcast the standard pitch is maintained, and musical instruments are manufactured and adjusted in terms of this practical standard. The majority of musical instruments manufactured can be tuned to this frequency.

1.4. Standard Time Intervals

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

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



STATION ANNOUNCEMENT
WWV: Morse Code - Call letters; universal time; propagation forecast; frequency offset (on the hour only)
Voice - Greenwich mean time
WWVH: Morse Code - Call letters; universal time; frequency offset (on the hour only)
Voice - Greenwich mean time
WWVL, WWVB: - No station identification

100 pps 1000 Hz MODULATION WWV TIMING CODE

GEOALERTS

UT2 TIME CORRECTION

TONE MODULATION 600 Hz

TONE MODULATION 440 Hz

IDENTIFICATION PHASE SHIFT

SPECIAL TIME CODE

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

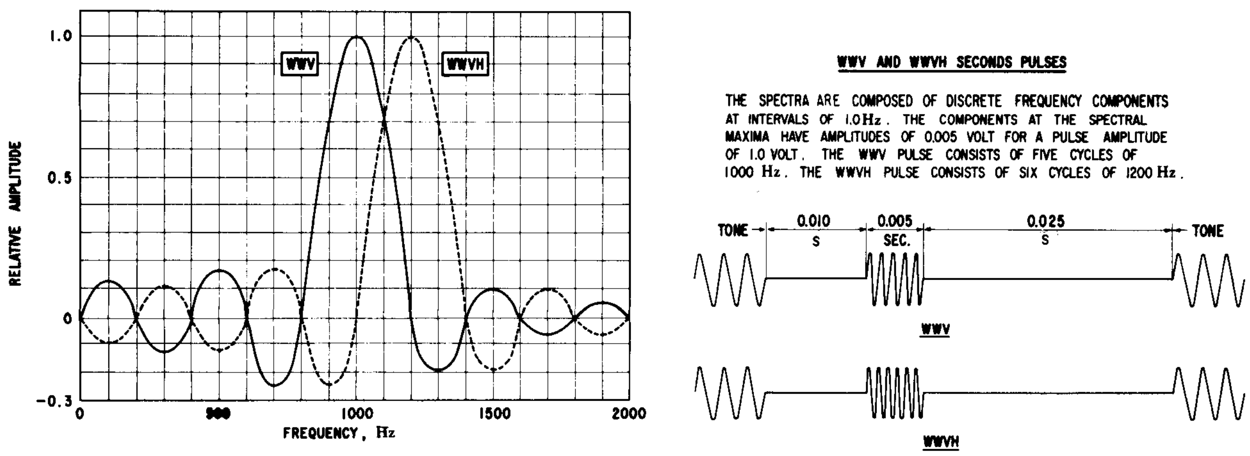


FIGURE 2. *Sample characteristics of time pulses broadcast from NBS radio stations WWV and WWVH.*

at intervals of 5 000 000 cycles of the 5 MHz carrier. They are given by means of double-sideband amplitude-modulation on each radio carrier frequency. Intervals of 1 min are marked by the omission of the pulse at the beginning of the last second of every minute and by commencing each minute with two pulses spaced by 0.1 second.

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

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

1.5. Time Signals

(a) Program

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

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

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

The 0 to 24 hour system is used starting with 0000 at midnight at longitude zero. The first two figures give the hour, and the last two figures give the number of minutes past the hour when the tone returns. For example, at 1655 GMT, the four figures 1-6-5-5 are broadcast in code. The time announcement refers to the end of an announcement interval, i.e., to the time when the audio frequencies are resumed.

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

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

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

(b) Corrections

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

Seconds pulses broadcast from WWVB will depart from UT2 at a different rate due to the fact that WWVB broadcasts 60 kHz with no offset (see 1.1(c)). Step time adjustments of 200 milliseconds will be made at 0000 UT on the first day of a month with appropriate advance notice. The BIH advises when such adjustments are to be made in order to maintain the seconds pulses within about 100 milliseconds of UT2.

(c) UT2 Corrections

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

The symbols which are broadcast are as follows:

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

followed by a three-digit number. This number is the correction in milliseconds. To obtain UT2, add the correction to the time indicated by the Time Signal pulse if "AD" is broadcast. Subtract if "SU" is broadcast. Thus a clock, keeping step with the time signals being broadcast, will be early with respect to UT2 if "SU" is the symbol used. These corrections will be revised daily, the new value appearing for the first time during the hour after 0000 UT, and will remain unchanged for the succeeding 24 hour period.

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

1.6. Propagation Forecasts

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

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

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

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

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

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

Intelligibility Scale

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

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

1.7. Geophysical Alerts

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

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

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

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

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

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

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

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

GEO TTT EEE DDD

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

1.8. WWV Time Code

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

This time code provides a standardized timing base for use when scientific observations are made simultaneously at widely separated locations. It may be used, for instance, where signals telemetered from a satellite are recorded along with the time code; subsequent analysis of the data is then aided by having unambiguous time markers accurate to a thousandth of a second. Astronomical observations may also benefit by the increased timing potential provided by the pulse-coded signals.

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

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

The binary coded decimal (BCD) system is used. Each second contains 9 BCD groups in this order: 2 groups for seconds, 2 groups for minutes, 2 groups for hours, and 3 groups for day of year. The code digit weighting is 1-2-4-8 for each BCD group multiplied by 1, 10, or 100 as the case may be.

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

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

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

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

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

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

1.9. WWVB Time Code

(a) Code and Carrier

On July 1, 1965, Radio Station WWVB, Fort Collins, Colorado began broadcasting time information using a level-shift carrier time code. The code, which is binary coded decimal (BCD), is broadcast continuously and is synchronized with the 60 kHz carrier signal. The new system replaces the method whereby seconds pulses of uniform width obtained by level-shift carrier keying were broadcast. The carrier is no longer interrupted for keyed station identification.

(b) Marker Generation

As shown in figure 4, the signal consists of 60 markers each minute, with one marker occurring during each second. (Time progresses from left to right.) Each marker is generated by reducing the power of the carrier by 10 dB at the beginning of the corresponding second

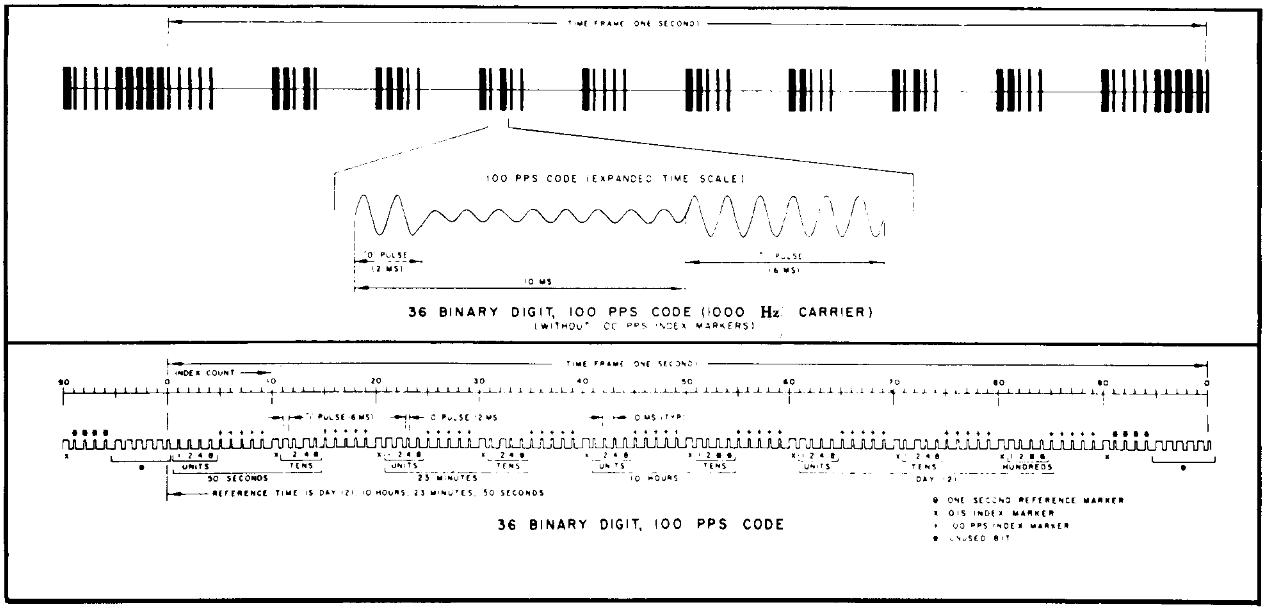


FIGURE 3. *Chart of time code transmissions from NBS radio station WWV.*

and restoring it 0.2 second later for an uncoded marker or binary "zero," 0.5 second later for a binary "one," and 0.8 second later for a 10-second position marker or for a minute reference marker. Several examples of binary "ones" are indicated by I in figure 4.

(c) Marker and Groups

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

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

(d) Information Sets

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

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

The twelfth group is not used to convey information.

(e) Digital Information

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

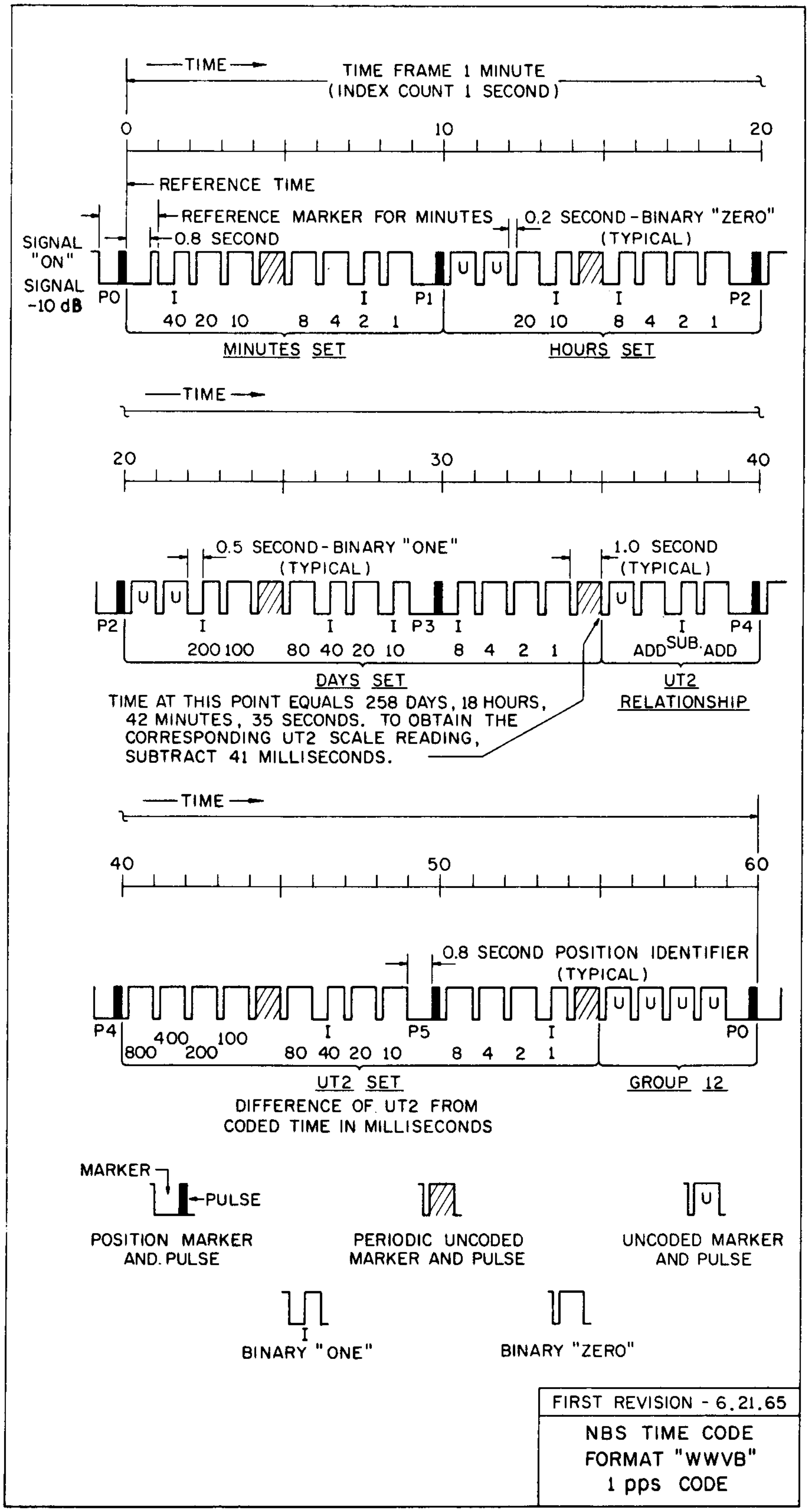


FIGURE 4. *Chart of time code transmissions from NBS radio station WWVB.*

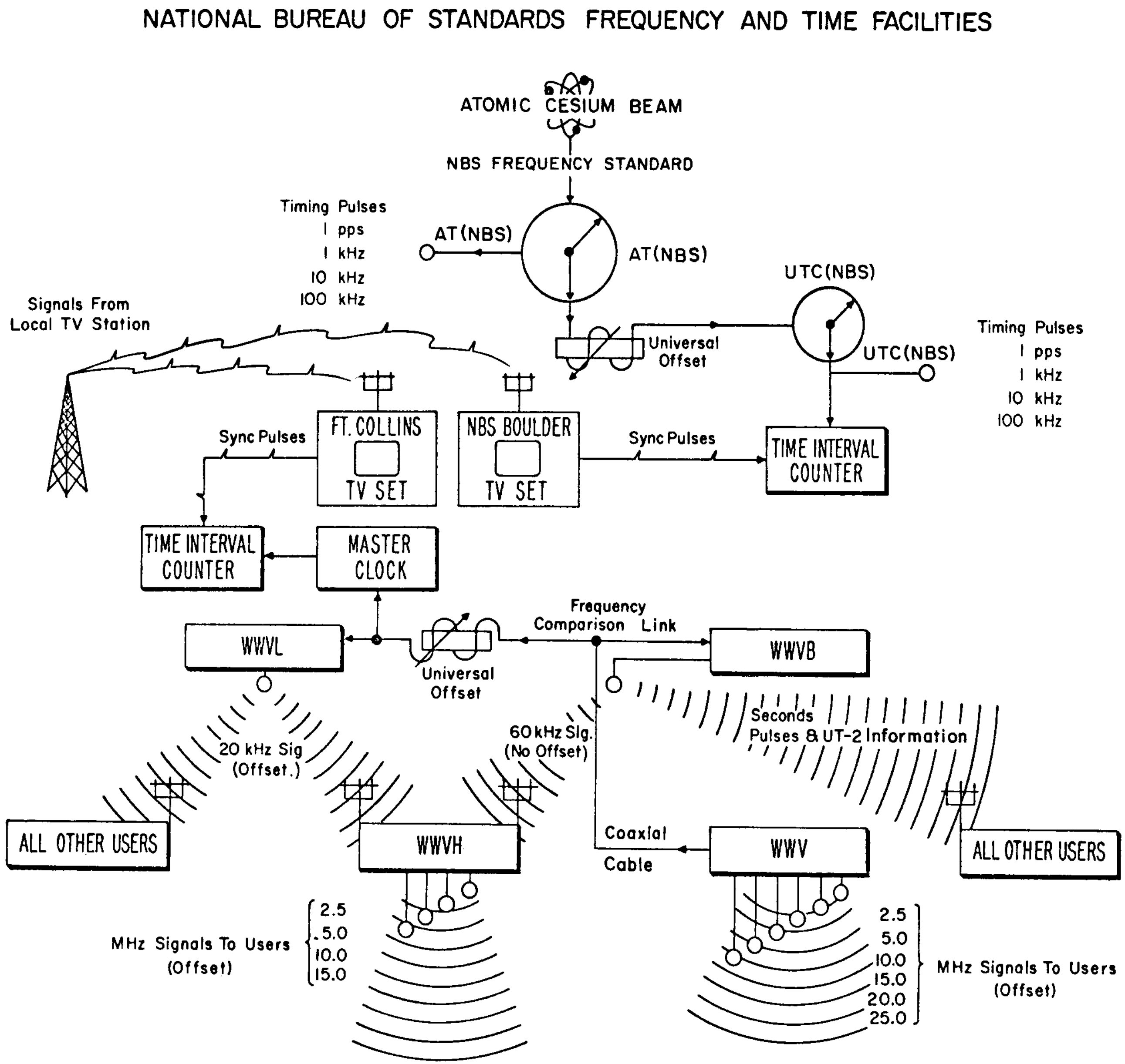


FIGURE 5. *NBS frequency control system.*

Example

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

1.10. Station Identification

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

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

1.11. Radiated Power, Antennas and Modulation

(a) Radiated Power

Frequency, MHz	Radiated Power, kw WWV	WWVH	WWVB	WWVL
0.020	—	—	—	2
0.060	—	—	16	—
2.5	2.5	1	—	—
5	10	2	—	—
10	10	2	—	—
15	10	2	—	—
20	2.5	—	—	—
25	2.5	—	—	—

(b) Transmitting Antennas

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

(c) Modulation

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

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

WWVL uses no modulation. Various experimental techniques are being studied in an attempt to develop a good timing system at Very Low Frequencies.

2. How NBS Controls the Transmitted Frequencies

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

Utilizing the line-10 horizontal synchronizing pulses from a local television station, the Fort Collins Master Clock is compared on a daily basis with the NBS Master Clock #8.[6] All other clocks and time-code generators at the site are then compared with this master clock. Frequency corrections of the WWVB and WWVL quartz crystal oscillators are based on their time or phase relative to the master clock.

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

Control of the signals transmitted from WWVH is based upon signals from WWVB and WWVL as received by phase-lock receivers. The oscillator controlling the transmitted frequencies and time signals is continuously compared with the received signals. Manual adjustments are then made to the controlling oscilla-

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

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

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

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

NATIONAL BUREAU OF STANDARDS

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

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Measurement Services and the following technical divisions:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics [2]—Radio Engineering [2]—Time and Frequency [2]—Astrophysics [2]—Cryogenics.[2]

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

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THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations in the development of technological standards, and test methodologies; and provides advisory and research services for Federal, state, and local government agencies. The Institute consists of the following technical divisions and offices:

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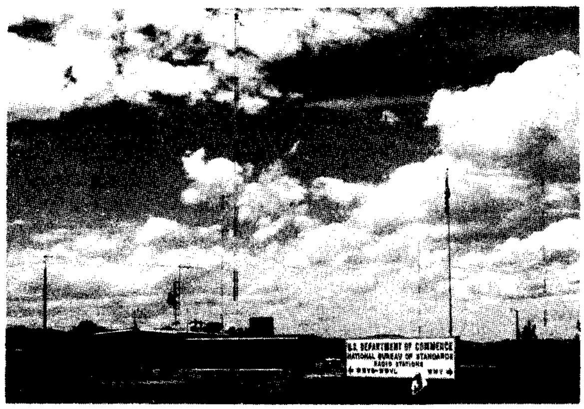
THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System, and provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

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

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

NBS Fort Collins facility showing WWV transmitter building.

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



WWVB/WWVL transmitter building and antennas.

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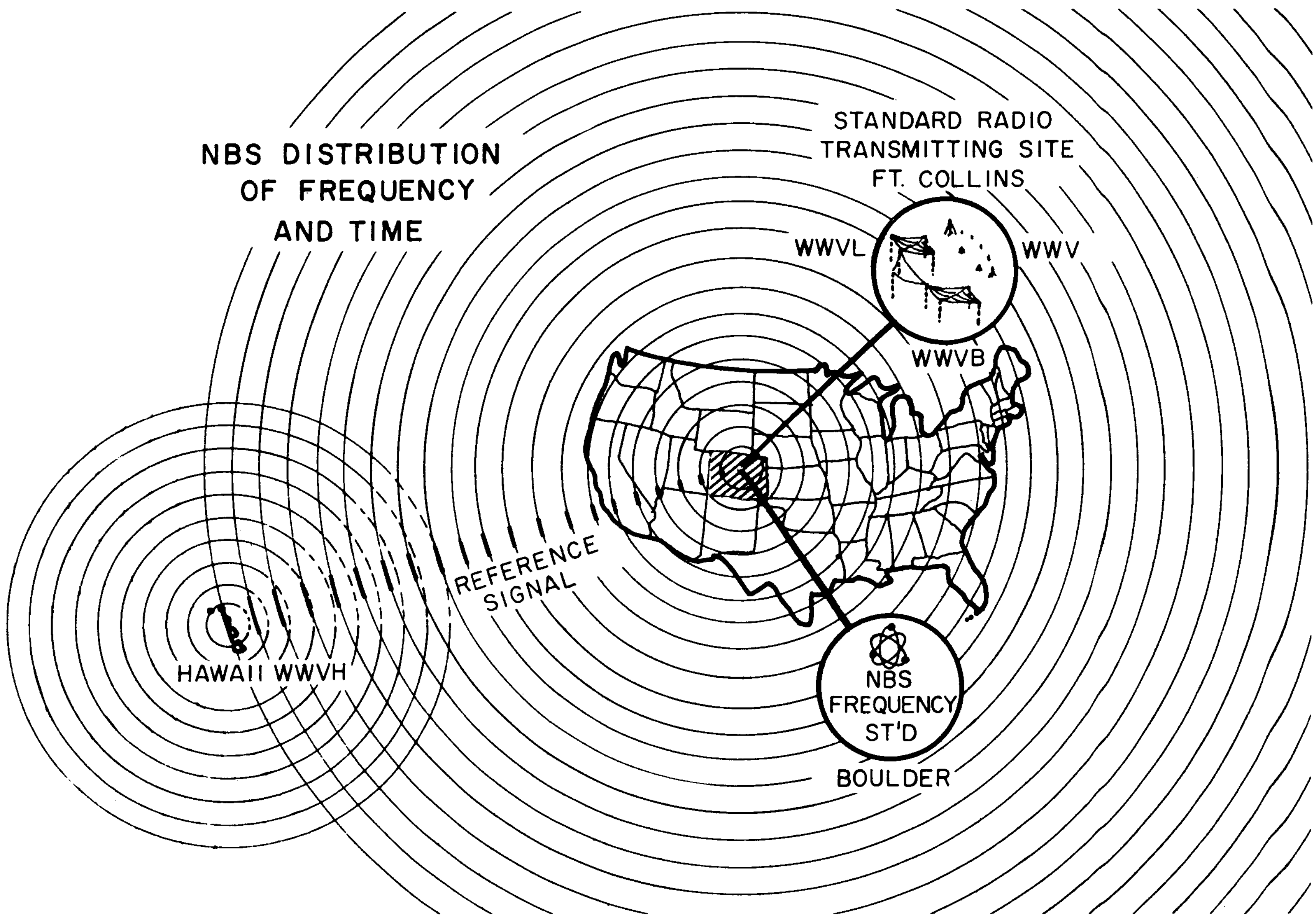
NBS DISTRIBUTION
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