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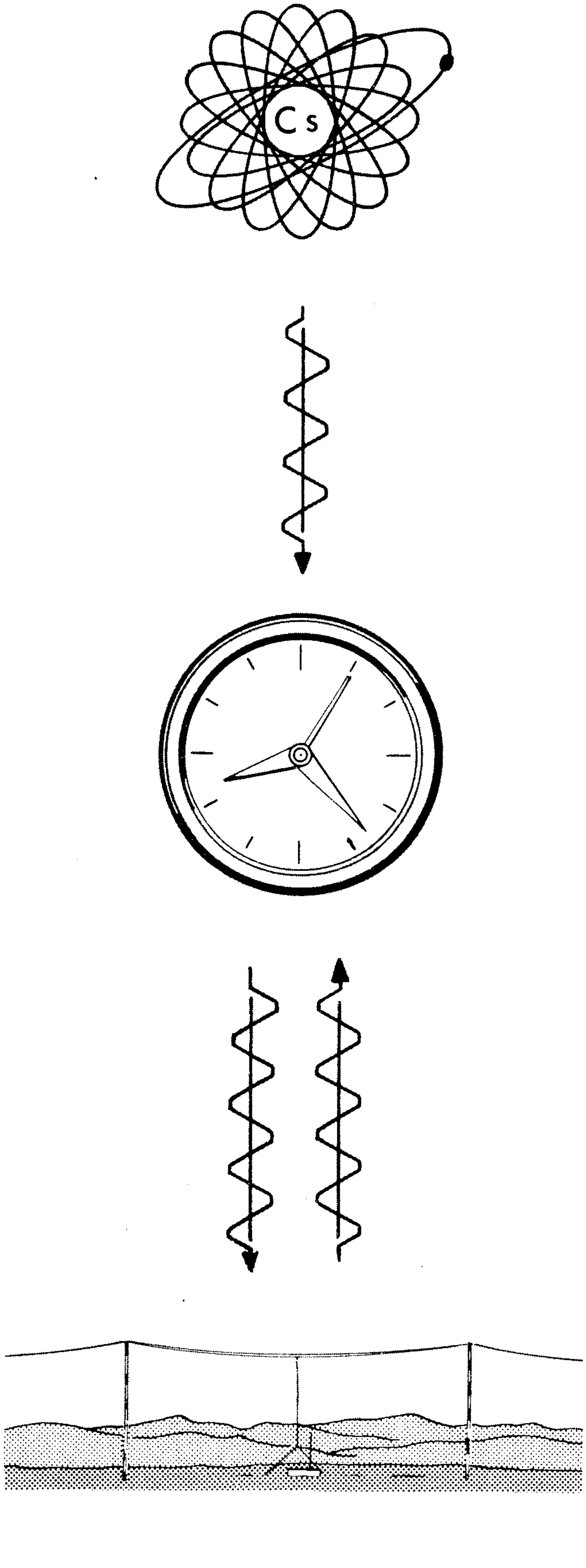

NBS FREQUENCY AND TIME BROADCAST SERVICES

Radio Stations

WWV WWVH WWVB WWVL

U.S DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NBS
FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV WWVH WWVB WWVL

U. S. DEPARTMENT OF COMMERCE
C. R. SMITH, Secretary

NATIONAL BUREAU OF STANDARDS
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Services Provided by NBS Standard Frequency Stations

WWV, WWVH, WWVB, and WWVL

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 the broadcasting schedules are required. This publication shows the schedules in effect on January 1, 1968. Annual revisions will be made. Current data relating to standard frequencies and time signals are available monthly in the Time and Frequency Services Bulletin.[1] 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.[2]

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 at the pioneer site. From 1931 to 1966 the station was moved successively from Washington, D. C. to College Park, Beltsville, and Greenbelt (all Maryland suburbs) and finally to Fort Collins, Colorado, where it went on the air at 0000 GMT December 1, 1966.

The move to Fort Collins was prompted by several considerations. Among these were: 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 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. The received accuracy, beyond the ground wave range, is one or two parts in 10^7.

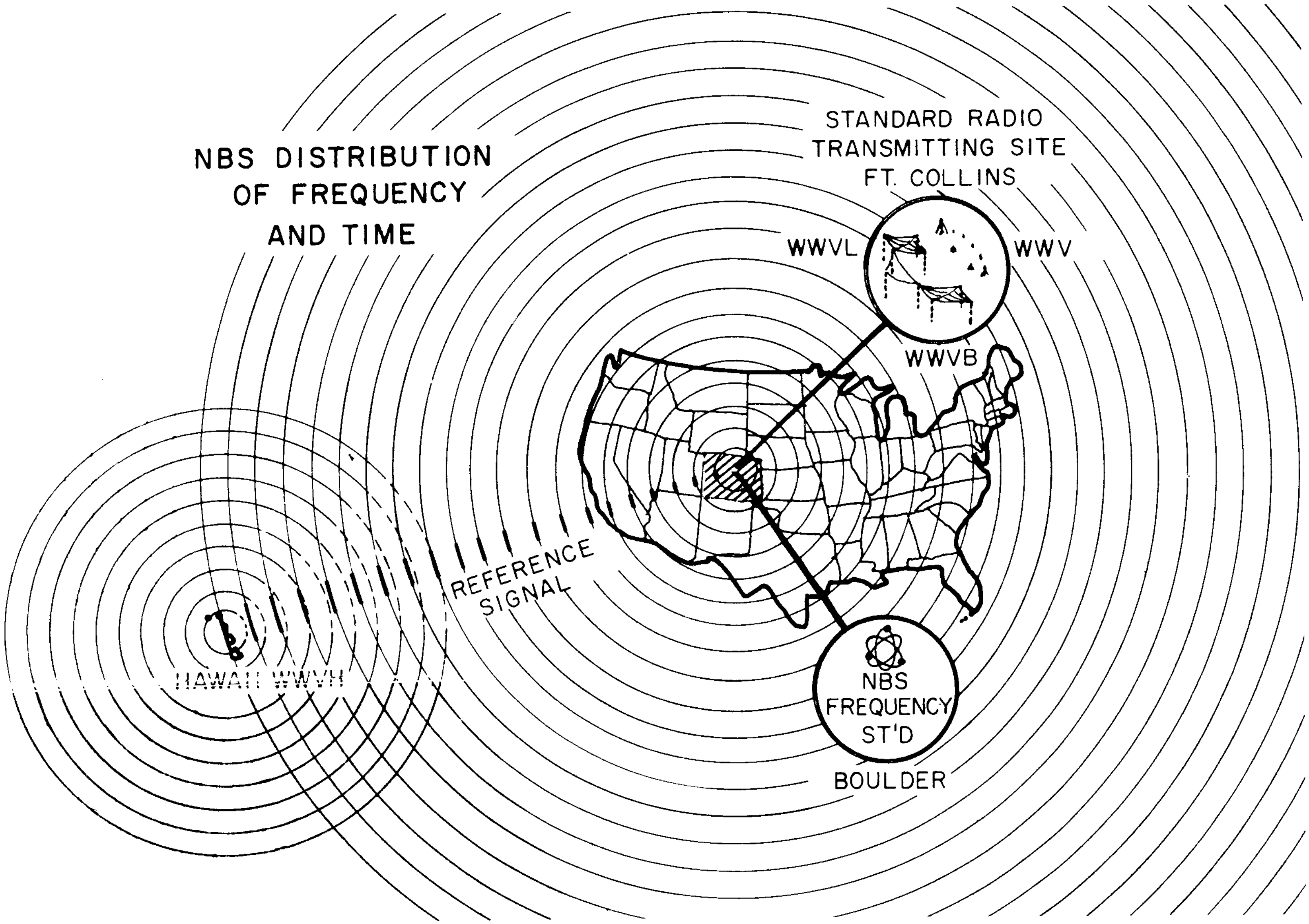
To supplement the coverage of WWV, broadcasts from station WWVH were instituted in 1948. These play an increasingly important role in various types of operations in the Pacific and Far East, both military and civilian.

On an experimental basis WWVB began broadcasting in Boulder, Colorado in 1956 and WWVL from Sunset, Colorado in 1960. Both of these stations have been in operation from Fort Collins, Colorado since July 1963. These stations, one transmitting on low frequency and the other on very low frequency, 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 45 years since the beginning of its radio broadcasts, NBS has expanded such services so that it is making major contributions today to the nation's space and defense programs, to worldwide transportation and communications, and to a multitude of industrial operations, as well as providing a convenient time service to thousands of listeners.

[1] Inquiries concerning this Bulletin may be addressed to the editor, Time and Frequency Division, NBS, Boulder, Colorado 80302.

[2] Inquiries concerning the broadcast services may be addressed to Frequency-Time Broadcast Services, NBS, Boulder, Colorado 80302 or to the Engineer-in-Charge at a particular station.


NBS DISTRIBUTION
OF FREQUENCY
AND TIME
STANDARD RADIO
TRANSMITTING SITE
FT. COLLINS
WWVL
WWV
WWVB
REFERENCE
SIGNAL
HAWAII WWVH
NBS
FREQUENCY
ST'D
BOULDER

1. Technical Services and Related Information

The standard frequency 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 Fort Collins, Colorado 80521
Telephone-303-484-3164
(40°40′49″N, 105°02′27″W)

WWVH Box 578, Puunene, Maui, Hawaii 96784
Telephone 79-4111
(20°46′02″N, 156°27′42″W)

WWVB Box 83-E, Route 2, Fort Collins, Colorado 80521
Telephone-303-484-2372
(40°40′28.3″N, 105°02′39.5″W)

WWVL Box 83-E, Route 2, Fort Collins, Colorado 80521
Telephone-303-484-2372
(40°40′51.3″N, 105°03′00.0″W)

1.1 Standard Radio Frequencies

(a) Program

Station WWV broadcasts on nominal radio frequencies of 2.5, 5, 10, 15, 20, and 25 MHz (see b and c, below.) The broadcasts are continuous night and day, except for an interruption of 4 min each hour. The silent period commences 45 min 15 sec after each hour, (fig. 1).

* Note: On 1 December 1966, WWV was relocated to Fort Collins, Colorado, from its former site at Greenbelt, Maryland

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 sec) after each hour.

Station WWVB broadcasts on the standard frequency of 60kHz and station WWVL on a nominal frequency of 20 kHz. These two stations have scheduled maintenance times on alternate weeks during some part of the period between 1300 GMT Tuesdays and 0100 GMT Wednesdays. Otherwise the service is continuous.

(b) Accuracy

Since December 1, 1957, the standard radio transmissions from stations WWV and WWVH have been held as nearly constant as possible with repect 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 standard realizes this resonance to 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 announced 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 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 5 parts in 10^{10}.

[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).

Changes in the propagation medium (causing Doppler effect, diurnal shifts, etc.) result in fluctuations (of the order of a part in 10^7) 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}. Deviations 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. 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 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, 1967 and 1968 -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 are continuously determined with respect to the NBS standard and are published monthly (since March 1966) in the NBS Time and Frequency Services Bulletin. The corrections also appear in the Proceedings of the IEEE, in which publication commenced in May 1958 and included data from December 1, 1957.[5]

The carrier frequency at WWVL (20 kHz) is also offset from standard frequency by the same amount as noted above.

Station WWVB (60 kHz) 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 standard of frequency so that absolute 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.

1.2. Standard Audio Frequencies

(a) Program

Standard audio frequencies of 440 Hz and 600 Hz are broadcast on each radio carrier frequency at WWV and WWVH. The audio frequencies are transmitted alternately at 5-min intervals starting with 600 Hz on the hour (fig. 1). This frequency is used by power companies for automatic setting of clocks. 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 audio 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 code information prior to the voice announcements are not standard frequencies.

1.3. Standard Musical Pitch

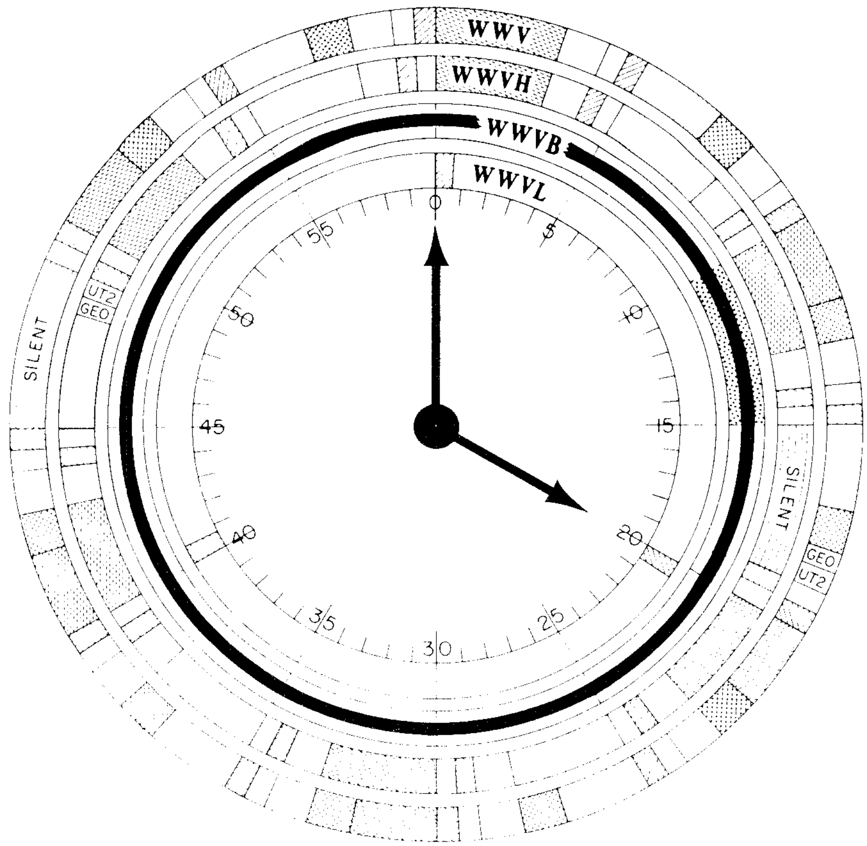
The frequency 440 Hz, for the note A above middle C, is the standard in the music industry in many countries and has been in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. The periods of transmission of 440 Hz from WWV and 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. Music listeners are thus benefited by the improvement in tuning accuracy.

1.4. Standard Time Intervals

Seconds pulses at precise intervals are derived from the same oscillator that controls the radio carrier frequencies, e.g., they commence at intervals of 5,000,000 cycles of the 5 MHz carrier. They are given by means of double-sideband amplitude-modulation on each radio carrier frequency. 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.

[5] W. D. George, WWV standard frequency transmissions, Proc. IRE **46**, 910 (1958) and subsequent issues.

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



SECONDS PULSES - WWV, WWVH - CONTINUOUS EXCEPT FOR 59th SECOND OF EACH MINUTE AND DURING SILENT PERIODS

WWVB - SPECIAL TIME CODE

WWVL - NONE

STATION ANNOUNCEMENT

WWV MORSE CODE - CALL LETTERS, UNIVERSAL TIME, PROPAGATION FORECAST

VOICE - GREENWICH MEAN TIME

MORSE CODE - FREQUENCY OFFSET (ON THE HOUR ONLY)

WWVH MORSE CODE - CALL LETTERS, UNIVERSAL TIME

VOICE - GREENWICH MEAN TIME

MORSE CODE - FREQUENCY OFFSET (ON THE HOUR ONLY)

WWVL MORSE CODE - CALL LETTERS, FREQUENCY OFFSET

100 PPS 1000 Hz MODULATION WWV TIMING CODE

TONE MODULATION 600 Hz

TONE MODULATION 440 Hz

GEO GEOALERTS

IDENTIFICATION PHASE SHIFT

UT2 UT2 TIME CORRECTION

SPECIAL TIME CODE

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

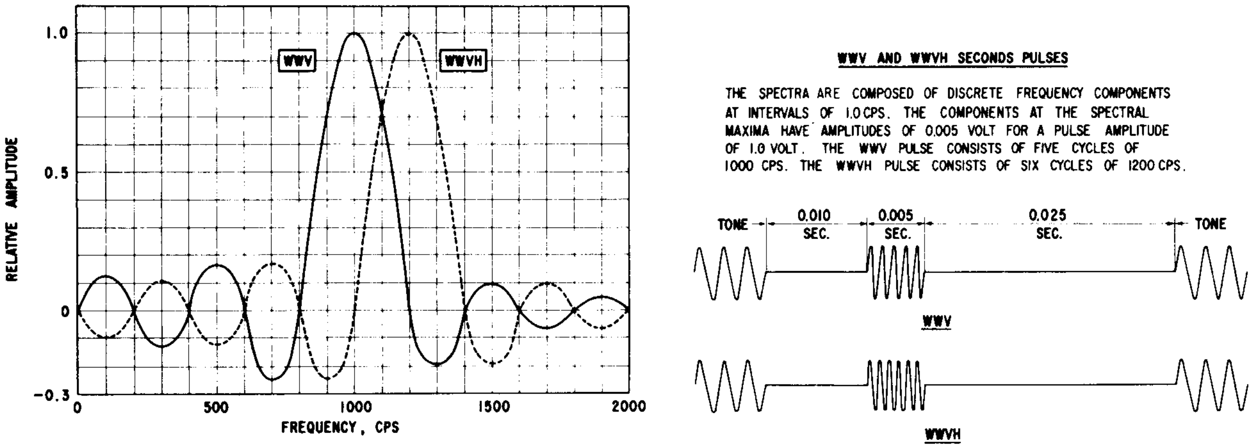


FIGURE 2. *Sample characteristics of time pulses broadcast from NBS radio stations WWV and WWVH.*

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 1.10.

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) 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. If 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 1.10. 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 GMT on the first day of a month. Advance notice of such adjustments is given to the public upon advice by the Bureau International de l'Heure in Paris 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. Corrections to the time signals 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 GMT on the first day of a month with appropriate advance notice. The Bureau International de l'Heure advises when such adjustments are to be made in order to maintain the seconds pulses within about 100 milliseconds of UT2.

1.6. UT2 Corrections

Since the 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 fast 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 GMT, 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 Naval Observatory.

1.7. 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 announcement each five minutes was commenced on November 15, 1963. The present type of propagation 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, Telecommunications Disturbance Forecast Center, Box 178, Fort Belvoir, Virginia 22060. The regular times of issue of the forecasts are 0500, 1100 (1200 from November 1-April 30), 1700, and 2300 GMT.

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 atmosphere, 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:

Disturbed grades (W)	*Unsettled grade* (U)	*Normal grades* (N)
1. useless	5. fair	6. fair-to-good
2. very poor		7. good
3. poor		8. very good
4. poor-to-fair		9. excellent

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.

1.8. 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. Previous codes were superseded. 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 GMT 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 GMT on station WWV, Fort Collins, Colorado, then at 0448 GMT on station WWVH, Maui, Hawaii. These broadcasts are repeated at hourly intervals until the new alert is issued. The new coding permits three types of information at each broadcast—each in the form of letters repeated three times in slow Inernational Morse Code.

The first set concerns either FORECASTS a solar or geophysical event for the next day, and/or the observation of a stratospheric warming (STRATWARM). Letters which may occur in the first set and their meaning are as given in the table below

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 time and type of event is shown in the table given below.

1st letter	EEE	(.)	No alert (NIL)
	III	(..)	FLARES expected
	SSS	(...)	PROTON FLARE expected
	TTT	(—)	MAGSTORM expected
	UUU	(..—)	FLARES and MAGSTORM expected
	VVV	(...—)	PROTON FLARE and MAGSTORM expected
	HHH	(....)	STRATWARM observed
	DDD	(— ..)	STRATWARM plus FLARES expected
	BBB	(—...)	STRATWARM plus PROTON FLARE expected
	MMM	(— —)	STRATWARM plus MAGSTORM expected

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

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

signifies: GEO SSS EEE DDD

GEO=Solar geophysical message

SSS =PROTON FLARE expected

EEE=No PROTON EVENT between 0000 GMT yesterday and 0400 GMT today

DDD=GEOMAGNETIC STORM occurred (began) between 1800 and 2400 GMT yesterday.

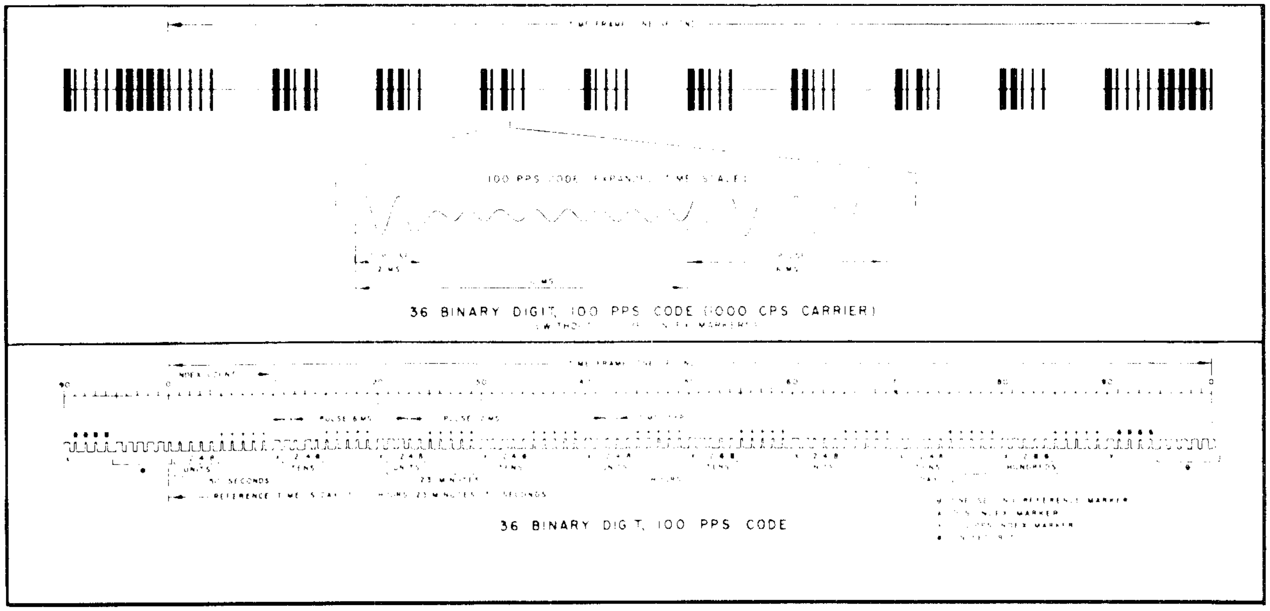


FIGURE 3. *Chart of time code transmissions from NBS radio station WWV.*

1.9. WWV Time Code

On January 1, 1961 WWV commenced broadcasting the time code shown in figure 3 for one minute of 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 (Greenwich Mean Time) 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 completed 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 obtained readily.

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.

1.10. 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, since the characteristic phase advance by 45° at 10 minutes after every hour followed by a similar phase retardation 5 minues later continues to serve to identify the station.

(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 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 Order 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 second after a periodically uncoded marker are shaded; other signal pulses following uncoded markers are labeled with a U.

Save for the uncoded and reference markers specifically expected in the foregoing, 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 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 "slow" with respect to the code time, the 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 "fast" 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 of the third group by 1.

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 $40 + 2 = 42$d 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 $35.000 - 0.041 = 34.959$.

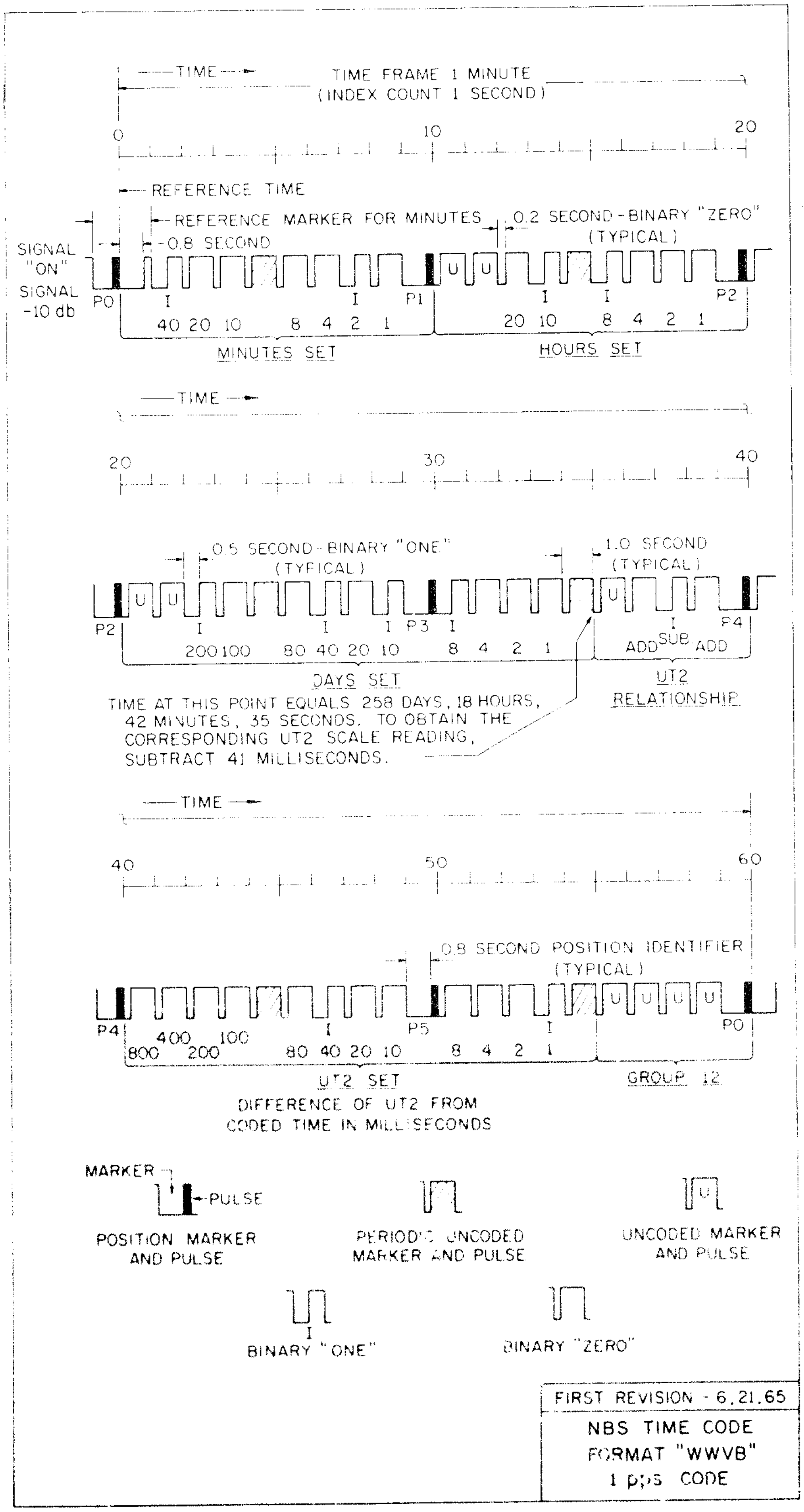


FIGURE 4. *Chart of time code transmissions from NBS station WWVB.*

1.11. 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, and 1968 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 frequently alternate between 20.0 kHz and 19.9 or 20.5 kHz, the change being made every 10 seconds. During these experiments code transmissions are not given. Otherwise International Morse Code for M300 is transmitted following the station call sign repeated three times, during the 1st, 21st, and 41st min of each hour. All three of the above stations are coordinated under the UTC (Universal Time Coordinated) system by the Bureau International de l'Heure (BIH).

Since WWVB transmits standard frequency without offset, no reminder is needed. 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.

1.12. Station Identification

WWV and WWVH identify by International Morse Code and voice (in English) every five minutes. The voice announcements are automatically synchronized recordings, not live broadcasts.

WWVL identifies by International Morse Code during the 1st, 21st and 41st min of each hour. WWVB identifies by its unique Time Code (see section 1.10.) and by advancing the carrier phase 45° at 10 min after each hour and returning to normal phase at 15 min after each hour.

1.13. Radiated Power, Antennas and Modulation

(a) Radiated Power

Frequency, MHz	Radiated power, kw			
	WWV	WWVH	WWVB	WWVL
0.020	—	—	—	2
0.060	—	—	12	—
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 quarterwave antennas. The broadcasts on all other frequencies from WWVH and all frequencies from WWV are from vertical half-wave dipoles. WWV antennas are omnidirectional. 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 high vertical antennas with capacity toploading.

(c) Modulation

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

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

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

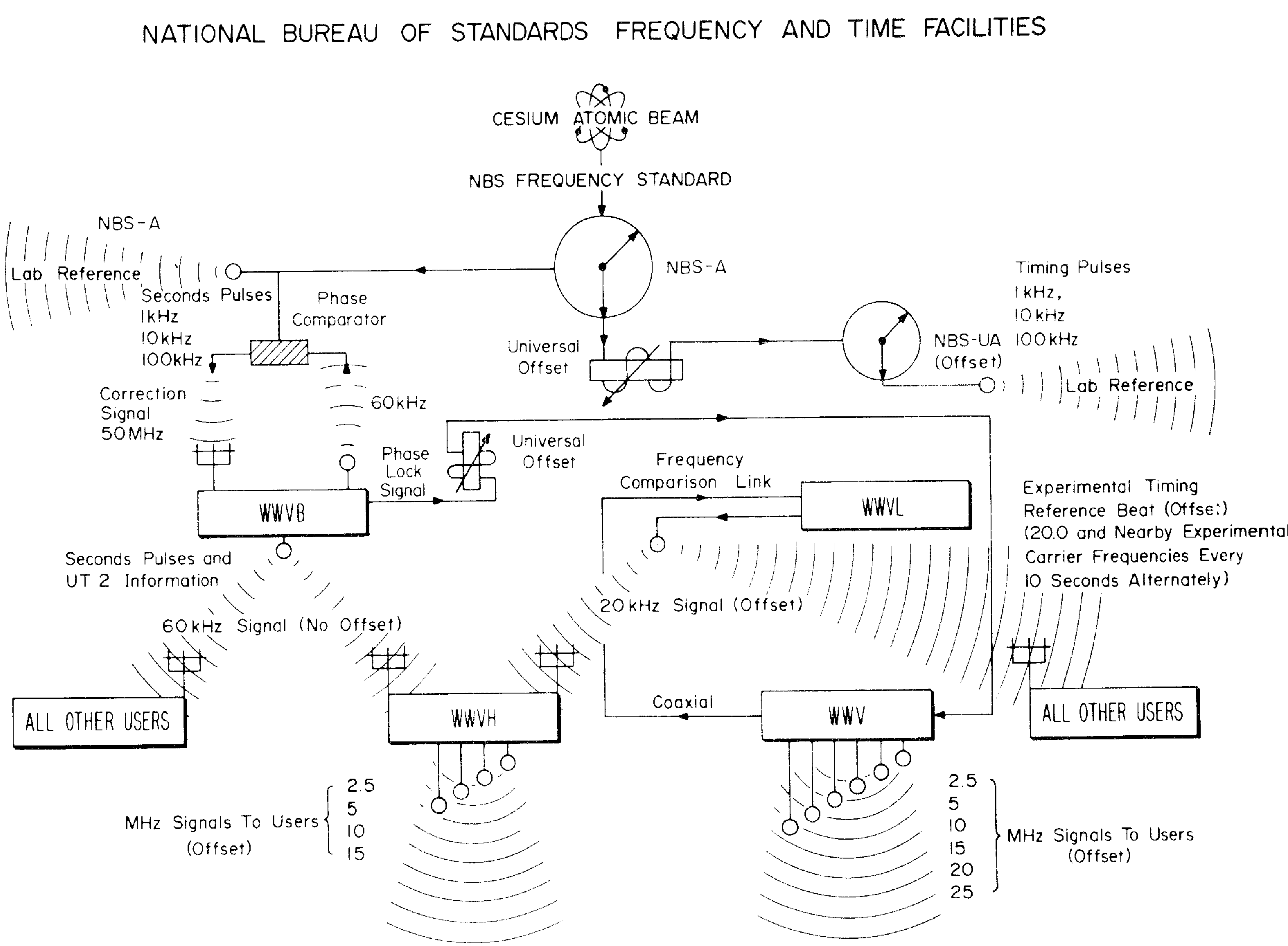


FIGURE 5. *NBS frequency control system.*

2. How NBS Controls the Transmitted Frequencies

In figure 5 a simplified diagram of the NBS frequency control system 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. Information from this reference is provided to receivers which monitor the WWVB transmissions and compare the received phase with the standard phase. If an error exists between the reference and received phases a signal is then transmitted by a 50 MHz transmitter to the transmitting site at Fort Collins which in turn operates automatic phase correction equipment to correct the transmitted phase.

The transmissions from WWV are controlled by three cesium standards located at that site. To insure accurate time transmission from WWV, the standards are compared via coaxial cable with the corrected standard which controls WWVB.

Control of the signals transmitted from WWVH is performed manually at present based upon signals from WWVB and WWVL which are received by LF and VLF phase-lock receivers. The oscillator controlling the transmitted frequencies and time signals is continuously compared with the LF and VLF signals. Adjustments are then made to the controlling oscillator manually which compensate for the characteristic drift of 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. With these clocks time synchronization to a few millionths of a second can be attained.

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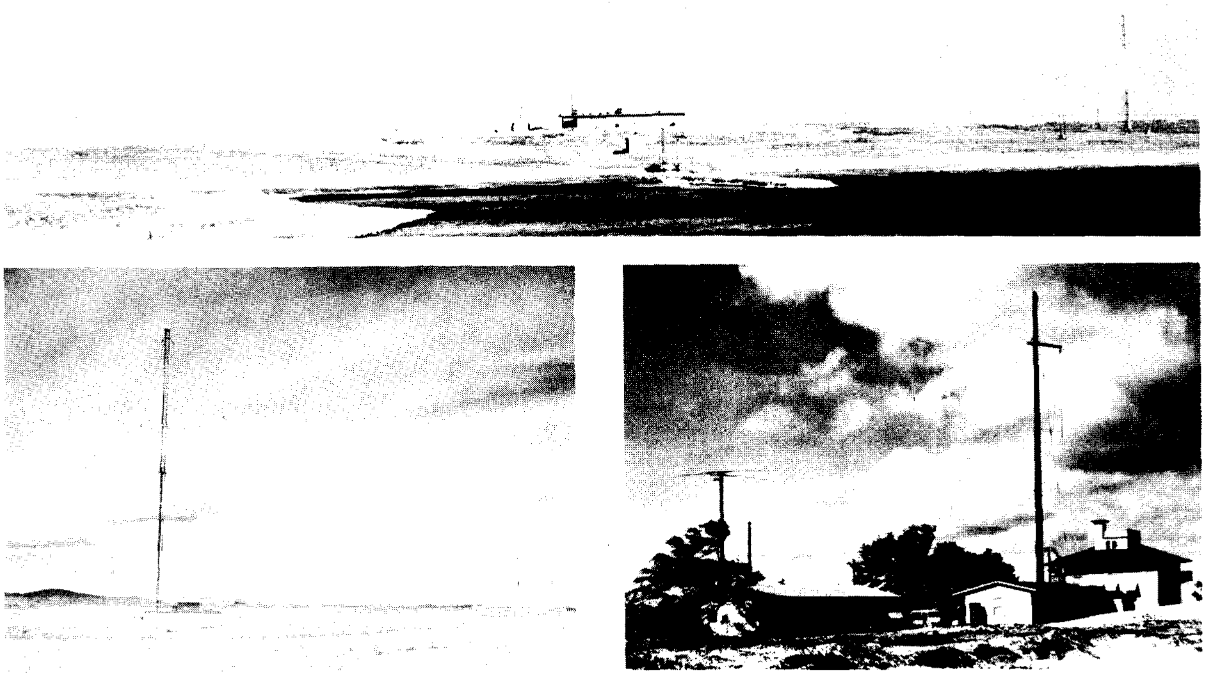

NBS Fort Collins facility in upper photo, showing the WWVB and WWVL transmitter building in the center, new 470-foot standby antenna mast in center, and 400-foot main masts on each side which are part of the two, four-mast antenna systems, WWVL to the left and WWVB to the right. At lower left are WWV transmitter building and antennas at Ft. Collins, Colorado. At lower right are antennas, transmitter building, and administrative buildings for WWVH, Maui, Hawaii.

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