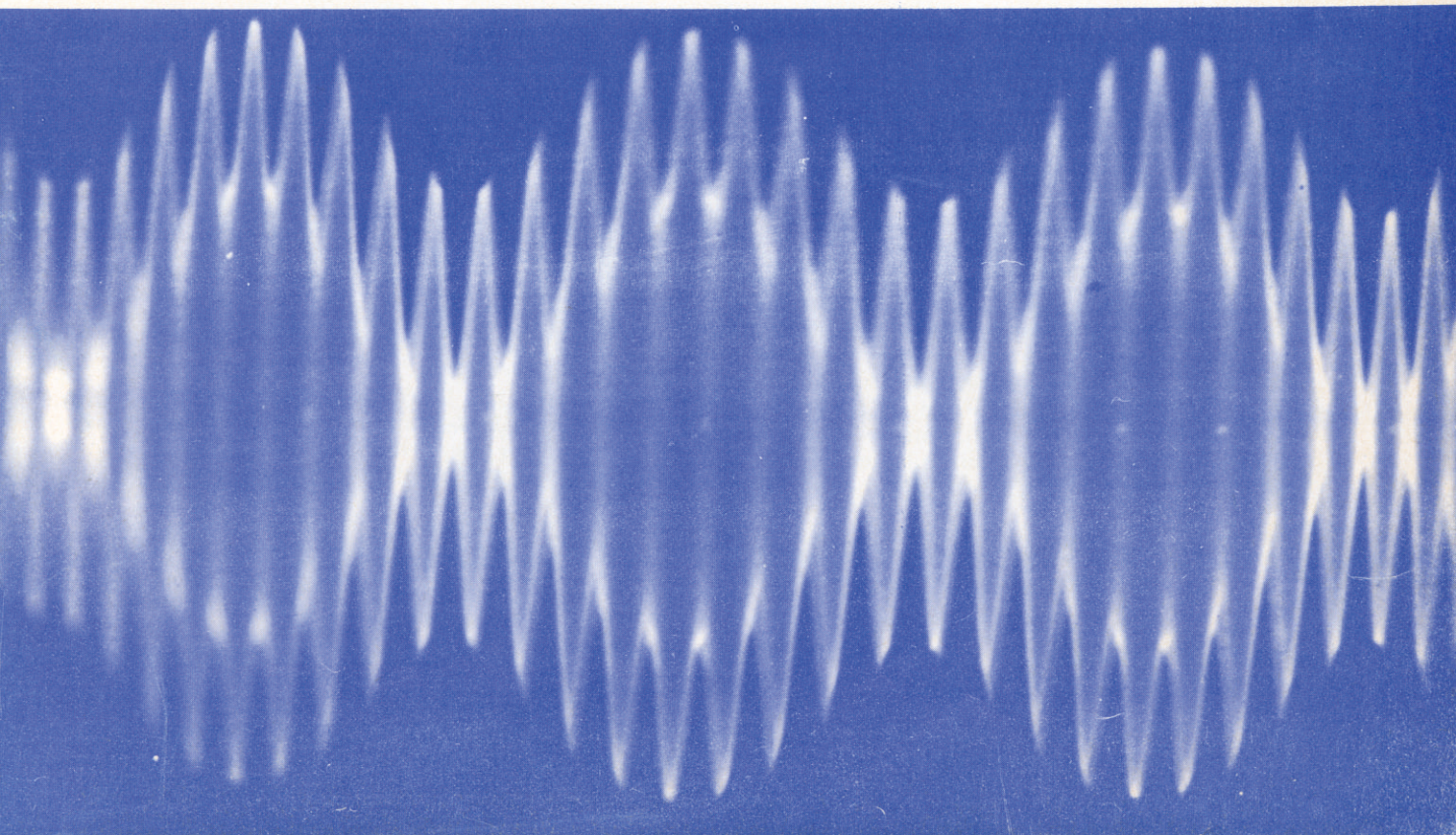
Miscellaneous Publication 236

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Standard Frequencies and Time Signals from NBS Stations WWV and WWVH



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Standard Frequencies and Time Signals From NBS Stations WWV and WWVH

National Bureau of Standards Miscellaneous Publication 236

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Detailed descriptions are given of six technical services broadcast by National Bureau of Standards radio stations WWV and WWVH. The services include 1, standard radio frequencies; 2, standard audio frequencies; 3, standard time intervals; 4, standard musical pitch; 5, time signals; and 6, radio propagation forecasts. Other domestic and foreign standard frequency and time signal broadcasts are tabulated.

1. Technical Services and Related Information

The National Bureau of Standards' radio stations WWV (in operation since 1923) and WWVH (since 1948) broadcast six widely used technical services: 1, Standard radio frequencies; 2, standard audio frequencies; 3, standard time intervals; 4, standard musical pitch; 5, time signals; 6, radio propagation forecasts.[1]

The radio stations are located as follows: WWV, Beltsville, Maryland (Box 182, Route 2, Lanham, Maryland); WWVH, Maui, Hawaii (Box 901, Punnene, Maui). Coordinates of the stations are: WWV (lat. 38°59′33″ N, long. 76°50′52″ W); WWVH (lat. 20°46′02″ N, long. 156°27′42″ W).

1.1. Standard Radio Frequencies

(a) Program

Station WWV broadcasts on standard radio frequencies of 2.5, 5, 10, 15, 20, and 25 Mc. The broadcasts are continuous, night and day, except WWV is interrupted for approximately 4 min each hour. The silent period commences at 45 min (plus 0 to 15 sec) after each hour. (See fig. 1.)

Station WWVH broadcasts on standard radio frequencies of 5, 10, and 15 Mc. The broadcast is interrupted for 3 min commencing on the hour (plus 0 to 15 sec) and on each quarter hour thereafter, and for periods of 34 min each day beginning at 1900 UT (Universal Time, UT, is the same as GMT and GCT).

(b) Accuracy

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 which constitute the United States Frequency Standard (USFS), maintained and operated by the Radio Standards Laboratory of the National Bureau of Standards. Carefully made atomic standards have been shown to realize the idealized Cs resonance frequency, f_{Cs}, to a few parts in 10^{10} or better; and the present USFS is believed to realize this resonance to 1.5 parts in 10^{11}. The frequency f_{Cs} has been measured in terms of the second [2] to be $f_{Cs}=9{,}192{,}631{,}770 \pm 20$ cps. This uncertainty of 2 parts in 10^9, with which frequency can be expressed in terms of the second, has usually been avoided in practice by provisionally taking f_{Cs} exactly equal to the above number (or to some other stated number before the above was available).

On January 1, 1960, the USFS was brought into agreement with f_{Cs} as quoted above by arbitrarily increasing its assigned value by 74 parts in 10^{10}. Frequencies measured in terms of the USFS be-

[1] All inquiries concerning the technical radio broadcast services should be addressed to: Radio Standards Laboratory, National Bureau of Standards, Boulder, Colo.

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

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.
Price 10 cents

tween 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.[3]

The frequency of the transmissions from WWV normally are held stable to 1 part in 10^9, at all times. Deviations at WWV are normally less than 2 parts in 10^{10} from day to day. When necessary, frequency adjustments not exceeding 5 parts in 10^{10} are made at WWV at 1900 UT. Frequency adjustments at WWVH do not exceed 3 parts in 10^9.

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

(c) Corrections

All carrier and modulation frequencies at WWV are derived from a common 2.5-Mc quartz oscillator, the stability of which is described above. In addition, since January 1, 1960, this oscillator has been intentionally offset from the USFS by a small but precisely known amount in order to reduce departure between the time signals broadcast and astronomical time UT2. For example, the offset for 1960 is about 150 parts in 10^{10}, and is low with respect to the USFS, since the unit of UT2 is about this much longer than the (Ephemeris) second. Although UT2 is subject to unpredictable changes observable at this level of precision, it is nevertheless expected that a particular offset can be left unchanged throughout each calendar year, thus providing as constant a frequency as possible for the year.

For the above reasons, corrections to the actual oscillator frequency are continuously determined with respect to the USFS and are published in the *Proceedings of the IRE*. These were begun in May, 1958 with data extending back to December 1, 1957.[4]

1.2. Standard Audio Frequencies

(a) Program

Two standard audio frequencies, 440 cps and 600 cps, are broadcast on each radio carrier frequency. The audio frequencies are given alternately at 5-min intervals starting on the hour with 600 cps, as shown in figure 1. At WWV, the first tone period (600 cps) of each hour is of 3-min duration; the remaining periods are of 2-min duration. At WWVH, all tone periods are of 3-min duration.

(b) Accuracy

The accuracy of the audio frequencies, as transmitted, is the same as for the carrier. The frequency offset mentioned under 1.1(c) applies. Changes in the propagation medium (causing Doppler effect, etc.) result at times in fluctuations in the audio frequencies as received.

1.3. Standard Time Intervals

(a) Program

Seconds pulses at precise intervals are derived from the same oscillator which controls the radio carrier frequencies, e.g., they commence at intervals of 5,000,000 cycles of the nominal 5 Mc/s carrier. They are given by means of double-sideband amplitude-modulation on each radio carrier frequency. Intervals of 1 min are marked by omitting the pulse at the beginning of the last second of every minute and by commencing each minute with *two pulses spaced by 0.1 sec;* the first pulse is used to mark 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 off. The pulse duration is 0.005 sec. The pulse wave form is shown in figure 2. At WWV each pulse consists of five cycles of a 1,000-cps frequency. At WWVH each pulse consists of six cycles of a 1,200-cps frequency. The pulse spectrum is composed of discrete frequency components at intervals of 1.0 cps. The components have maximum amplitudes at approximately 995 cps and 1,194 cps for the WWV and WWVH pulses, respectively. The tone is interrupted 0.040 sec for each seconds pulse. The pulse starts 0.010 sec after commencement of the interruption.

(b) Accuracy

The accuracy of the time intervals, as transmitted, is the same as for the carrier with an additional limitation of ± 1 μsec. The frequency offset mentioned under 1.1(c) applies. (See note concerning time adjustments under section 1.5(b), Time Signals.)

1.4. Standard Musical Pitch

The frequency 440 cps 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 cps 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 an unvarying standard. Practically no instruments are manufactured which cannot be tuned to 440 cps. Listeners of music are benefited because there are fewer instruments not in tune.

[3] National standards of time and frequency in the United States, Proc. IRE **48**, 105 (1960).
[4] W. D. George, WWV standard frequency transmissions, Proc. IRE **46**, 910 (1958) and subsequent issues.

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 at 5- and 10-minute intervals at both stations as shown in figure 1.

Universal Time (referenced to the zero meridian) is announced in International Morse Code each 5 min from WWV and WWVH. This provides a quick reference to correct time where a timepiece may be in error by a few minutes. The 0-to-24-hr 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 UT, four figures (1, 6, 5, and 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 *Eastern* Standard Time is given before and after each International Morse Code announcement. For example, at 9:10 a.m., EST, the voice announcement in English is: "National Bureau of Standards, WWV; when the tone returns, Eastern Standard Time is 9:10 a.m."

(b) Corrections

The time signals are kept in close agreement with UT2 by making step adjustments of precisely 50 msec when necessary. Such adjustment will be made on the first of the month following the month in which the transmitted time departs from UT2 by more than 50 msec. Corrections to the time signals are published periodically by the U.S. Naval Observatory.

1.6. Radio Propagation Forecasts

A forecast of radio propagation conditions is broadcast in International Morse Code on each of the standard radio carrier frequencies; from WWV at approximately 19.5 and 49.5 min past each hour, and from WWVH at approximately 9.4 and 39.4 min past each hour, as shown in figure 1. Propagation notices were first broadcast from WWV in 1946; the present type of announcement has been broadcast from WWV since July, 1952, and from WWVH since January, 1954.

The forecast announcement tells users the condition of the ionosphere at the regular time the forecast is made and how good or bad communication conditions are expected to be in the succeeding six or more hours. The NBS forecasts are based on information obtained from a worldwide network of geophysical and solar observatories, including radio soundings of the upper atmosphere, short wave reception data, and similar information. Trained forecasters digest the information and formulate the predictions.

From WWV the forecasts refer only to North Atlantic radio paths, such as Washington to London or New York to Berlin. The times of issue are 0500, 1200 (1100 in summer), 1700, 2300 UT. These are the short-term forecasts prepared by NBS-CRPL North Atlantic Radio Warning Service, Box 178, Ft. Belvoir, Va.

From WWVH the forecasts are for North Pacific radio paths, such as Seattle to Tokyo, or Anchorage to San Francisco. As of March 1, 1959, the times of issue are 0600 and 1800 UT, and the forecasts are first broadcast at 0639 and 1839 UT, respectively. These are the short-term forecasts prepared by NBS-CRPL North Pacific Radio Warning Service, Box 1119, Anchorage, Alaska.

The forecast is broadcast as a letter and a digit. The letter portion of the announcement 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 normal, unsettled, or disturbed. The digit portion is the forecast of the radio propagation quality on a typical North Atlantic (from WWV) or a typical North Pacific (from WWVH) transmission path during the 6 or more hours after the forecast is made. Quality is graded in steps ranging from 1 (useless) to 9 (excellent) 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 at the time the forecast is made are normal but are expected to be only "poor-to-fair" within the next 6 or more hours, the announcement would be broadcast as N4 in International Morse code.

1.7. Geophysical Alerts

A symbol indicating the geophysical "state of warning" as declared under the international program of the International Council of Scientific Unions, is broadcast in very slow International Morse Code on each of the standard radio carrier frequencies; from WWV at approximately 4.5 and 34.5 min past each hour, and from WWVH at approximately 14.4 and 44.4 min past each hour, as shown in figure 1. Such notices were first broadcast during the International Geophysical Year 1957–58 and are continuing under the similarly organized program, International World Day Service (IWDS).

The "state of warning" symbol indicates to experimenters in radio, geophysical, and solar sciences the content of the IWDS Warning Message issued at 1600 UT by the World Warning

Agency on days when outstanding geophysical events have occurred in the preceding 24 hr. The information in each such message is first broadcast from WWV at 1604.5 UT and from WWVH at 1714.4 UT.

If the IWDS Warning Message declares an *alert*, the symbol AGI AAAA is broadcast for 24 hr. This means that a significant magnetic storm has started, with K-index reaching 5 or higher at a midlatitude station. It can also mean that an outstanding auroral display has been reported (or inferred, because the K-index has reached at least 7) or that an outstanding increase in cosmic ray flux has been observed. The IWDS Warning Message itself, distributed through other channels including the meteorological communication networks coordinated by the World Meteorological Organization, specifies whether the alert is Magnetic Storm, Aurora, or Cosmic Ray; the "state of warning" symbol broadcast from WWV and WWVH does not make these distinctions at the present time.

A Special World Interval in progress is indicated by the symbol AGI and three extra long dashes. This means that an alert, as above, has been declared and, further, that the geophysical activity is of sufficient interest to warrant special attention and intensified observations by experimenters throughout the world. A Special World Interval will usually last two or three days. The Interval is considered to extend until 2359 UT on the final day even though the symbol "Special World Interval in progress" is not broadcast after 1600 UT (WWV) or 1700 UT (WWVH).

When the "state of warning" is neither alert nor Special World Interval in progress, the symbol broadcast is AGI EEEEE

1.8. Radiated Power, Transmitting Antennas, Modulation

(a) Radiated Power

Frequency, Mc	*Power, kw* WWV	*Power, kw* WWVH
2.5	1	- - - - - -
5	8	2
10	9	2
15	9	2
20	1	- - - - - -
25	0.1	- - - - - -

(b) Transmitting Antennas

The broadcast on 2.5 Mc from WWV and on 5 Mc from WWVH is from a vertical quarter-wave antenna. The broadcasts on all other frequencies are from vertical half-wave dipoles. The antennas are omnidirectional.

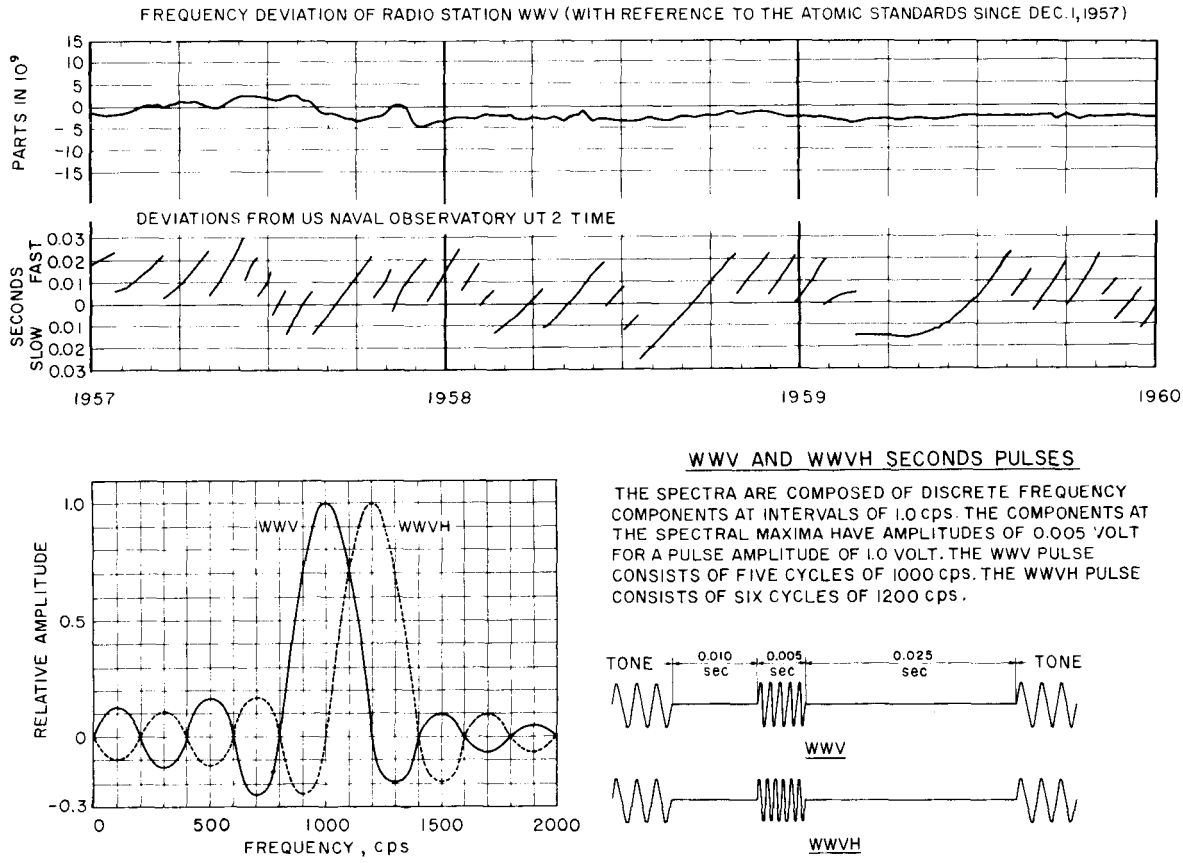


FIGURE 1. *Sample characteristics of time and frequency broadcasts from NBS stations WWV and WWVH.*

(c) Modulation

The amplitude modulation, double sideband, is:

Audio frequencies 440 or 600 cps—75 percent, voice and seconds pulses, peak—100 percent.

At WWV, the tone frequency 440 or 600 cps, except on 25 Mc, is normally operated as a single upper sideband with full carrier. Power output from each sideband transmitter is about one-third the carrier power. Single sideband tone modulation on 25 Mc may be added at a later date. Other signals (announcements and seconds pulses) are double sideband, 100-percent amplitude modulation.

1.9. Other Standard Frequency and Radio Time Signal Services

Standard frequencies and time signals broadcast include the stations indicated in the following table:

Call sign	Location	Carrier frequency	Modulation	Carrier power
	(a) *HF Broadcasts*	*Mc*	*xps*	*kw*
ATA	New Delhi, India	10	1, 1000	1.
FFH	Paris, France	2. 5, 5, 10	1, 440, 1000	0. 3
HBN	Neuchatel, Switzerland	2. 5, 5	1, 500	0. 5
IAM	Rome, Italy	5	1, 440, 600, 1000	1.
IBF	Turin, Italy	5	1, 440, 1000	0. 3
JJY	Tokyo, Japan	2. 5, 5, 10, 15	1, 1000	2.
LOL	Buenos Aires, Argentina	2. 5, 5, 10, 15, 20, 25	1, 440, 1000	2.
MSF	Rugby, England	2. 5, 5, 10	1, 1000	0. 5
OMA	Prague, Czechoslovakia	2. 5	1, 1000	1.
ZLFS	Lower Hutt, New Zealand	2. 5		0. 03
ZUO	Olifantsfontein, South Africa	5	1	4.
	Moscow, USSR	10, 15	1	20.
	(b) *VLF Broadcasts*			
WWVL	Sunset, Colorado	20 Kc		0. 02

2. Stations Operating Outside the Exclusive Bands

2.1. LF and VLF

Call sign	Location	Carrier frequency	Modulation	Carrier power
		kc	*cps*	*kw*
WWVB [1]	Boulder, Colorado	60		0. 0015
DCF77	Federal German Republic	77. 5	1, 200, 440	12
CHU	Ottawa, Canada	3330, 7335, 14670	1	0. 3, 3, 5
OMA	Czechoslovakia	50		5
GBR	Rugby, England	16		300
MSF	Rugby, England	60	1, 1000	10
NBA	U.S. Navy, Canal Zone	18	1	100

[1] National Bureau of Standards station WWVB (formerly KK2XEI) broadcasts continuously and the call letters are keyed approximately on the hour and each 20 min thereafter. The frequency is normally controlled by an atomic standard. Present plans are to increase the radiated power to about 3 kw as soon as possible.

2.2. Other Broadcasts

The U.S. Naval Observatory, Department of the Navy, broadcasts time signals continuously or at regular intervals from a number of stations including NSS (Annapolis, Md.), NPG (Mare Island, Calif.), NPM (Pearl Harbor, Hawaii), and NBA (Balboa, C.Z.). Detailed information may be obtained from the U.S. Naval Observatory, Washington 25, D.C.

A comprehensive list of United States and foreign radio time signals is given in chapters 3 and 9 of *Radio Navigational Aids*, Hydrographic Office Publication No. 117 (formerly H.O. Pub. No. 205), for sale by local and foreign authorized sales agents of the U.S. Navy Hydrographic Office or direct from the U.S. Navy Hydrographic Office, Washington 25, D.C. Price of the publication, with a binder, is $5.00; contents only (without binder), $3.50.

BOULDER, COLO.

Changes in WWV/WWVH Standard Broadcasts

ON January 1, 1961, at 0000 UT, the Bureau retarded the time signals broadcast from radio stations WWV and WWVH by 5 msec,[1] and at the same time resumed broadcasting a special timing code [2] which gives the day, hour, minute, and second (UT) coded in binary form. The 5-msec retardation brought the time signals of WWV/WWVH into closer agreement with other standardized frequency broadcasting stations throughout the world. The pulse timing code, tried out on an experimental basis for several months during 1960, has now been returned to the air on a permanent basis.

The United Kingdom and the United States began coordinating their time and frequency transmissions early in 1960. This coordination is the result of an agreement announced by Dr. James H. Wakelin, Jr., Assistant Secretary of the Navy (Research and Development), Dr. Allen V. Astin, Director of the U.S. National Bureau of Standards, and in the United Kingdom by the Astronomer Royal, Royal Greenwich Observatory, and the Director of the National Physical Laboratory.

Coordination was begun to help provide a more uniform system of time and frequency transmissions throughout the world, needed in the solution of many scientific and technical problems in such fields as radio communications, geodesy, and the tracking of artificial satellites.

Participating in the project are the Royal Greenwich Observatory, the National Physical Laboratory, and the Post Office Engineering Department in the United Kingdom, and, in the United States, the U.S. Naval Observatory, the Naval Research Laboratory, and the National Bureau of Standards. This program follows previous cooperative efforts of these agencies to achieve uniformity and simplification in procedures.

The transmitting stations which are included in the coordination plan are GBR and MSF at Rugby, England; NBA, Canal Zone; WWV, Beltsville, Maryland; and WWVH, Hawaii.

Although the signals emitted by all these stations are kept on as uniform a basis as is feasible, occasional corrections are necessary. The last previous time adjustment for WWV/WWVH, a retardation of 20 msec, was made on December 16, 1959. It is expected that such adjustments in the time signals will be made as infrequently as possible and preferably at the beginning of each calendar year when necessary. The time signals are locked to the broadcast frequency.

In 1961 it is planned to maintain the frequency stable to 1 part in 10^{10} and at the same offset value as before, i.e., -150 parts in 10^{10} with reference to the United States Frequency Standard.[3]

The timing code provides a standardized timing basis for use when scientific observations are made simultaneously at widely separated locations. It can be used for example, where signals telemetered from a satellite are recorded along with these pulse-coded time signals; 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.

This 36-bit, 100-pulse/sec time code, carried on 1,000-c/s modulation, is being broadcast from radio station WWV (2.5, 5, 10, 15, 20, and 25 Mc/s). Starting date was January 1, 1961.

1. The code is broadcast for 1-min intervals and 10 times per hour. Except at the beginning of each hour, it immediately follows the standard audiofrequencies of 440 c/s and 600 c/s.

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

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

4. A complete time frame is 1 sec.

5. The least significant binary group and the least significant binary digit in each group occur first. The binary groups follow the 1-sec reference marker.

6. "On time" occurs at the leading edge of all pulses.

7. The code contains 100-per-second clocking rate, 10-per-second index markers, and 1-per-second reference marker. The 1,000 c/s is locked to the code pulses so that millisecond resolution is easily obtained.

8. The 10-per-second index markers consist of "1" pulses preceding each code group except at the beginning of the second where it is a "0" pulse.

9. The 1-sec reference marker is made up of five "1" pulses followed by a "0" pulse. The second begins at the leading edge of the "0" pulse.

10. The code is a spaced code format; that is, a binary group (BCD) follows each of the 10-per-second index markers. The last index marker is followed by an unused 4-bit group of "0" pulses just preceding the 1-second reference marker.

11. The unused 4-bit group may be used in the future to transmit other types of coded information, such as the last digit of the year, station number, etc.

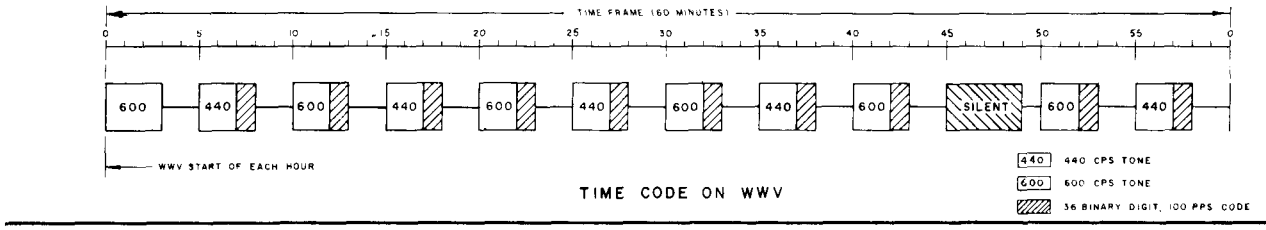
12. Width coding:

"0" pulse, 2 msec wide (2 cycles of 1,000 c/s)
"1" pulse, 6 msec wide (6 cycles of 1,000 c/s)

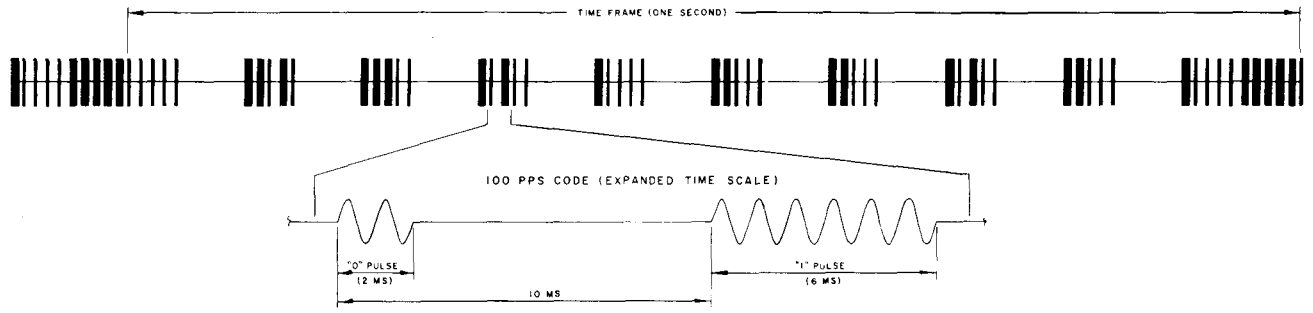
13. The time code is amplitude modulated on 1,000 c/s. The leading edges of the time code pulses coincide with a positive-going zero-axis-crossing of the 1,000 c/s.

[1] National standards of time and frequency in the United States, *Proc. IRE* **48**, *105–106 (Jan. 1960)*.
[2] Experimental timing code added to WWV broadcasts, *NBS Tech. News Bul.* **44**, *114 (July 1960)*.
[3] Atomic frequency standards, *NBS Tech. News Bul.* **45**, *8 (Jan. 1961)*.

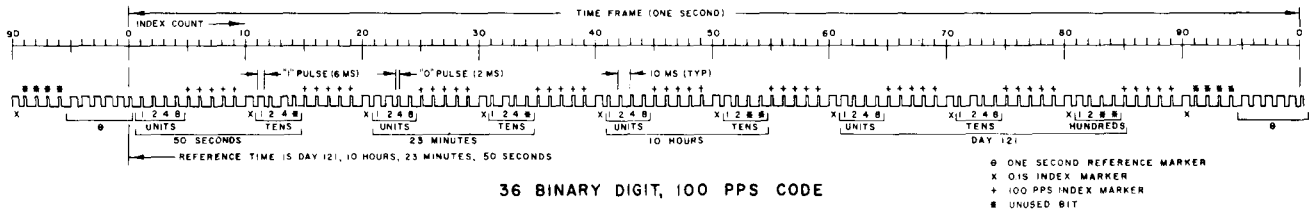
FIGURE 2. Chart of time code transmissions from NBS radio station WWV.



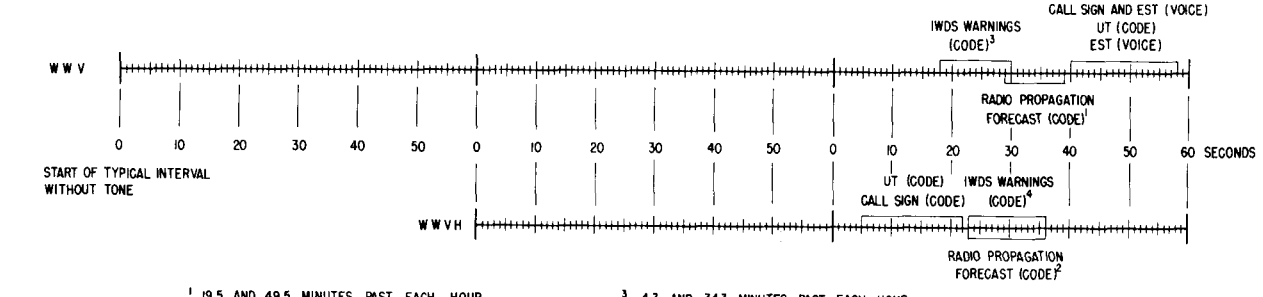
TIME CODE ON WWV



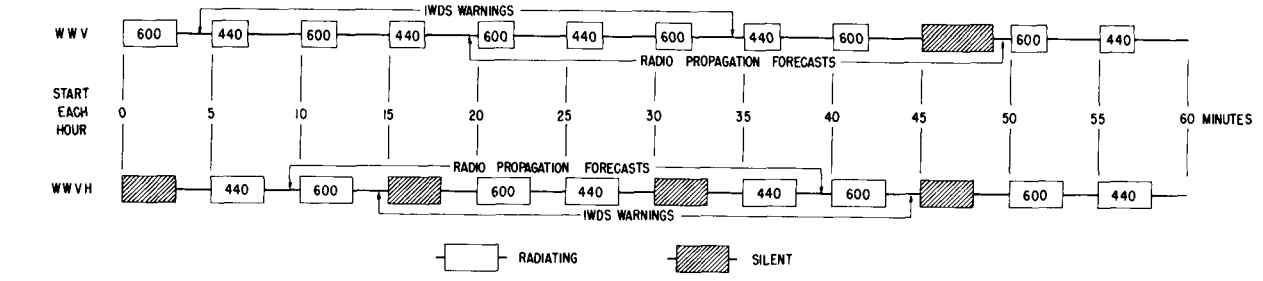
36 BINARY DIGIT, 100 PPS CODE (1000 CPS CARRIER)
(WITHOUT 100 PPS INDEX MARKERS)

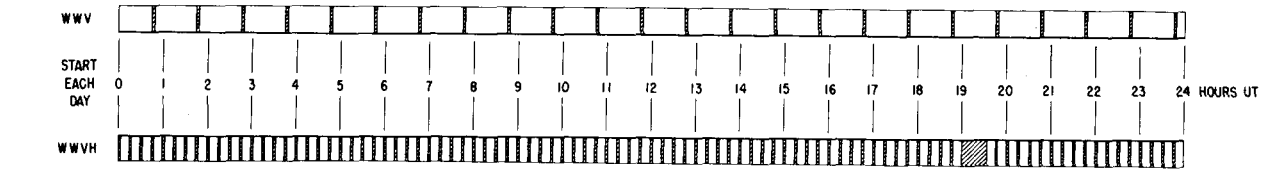


36 BINARY DIGIT, 100 PPS CODE



[1] 19.5 AND 49.5 MINUTES PAST EACH HOUR
[2] 9.4 AND 39.4 MINUTES PAST EACH HOUR
[3] 4.3 AND 34.3 MINUTES PAST EACH HOUR
[4] 14.4 AND 44.4 MINUTES PAST EACH HOUR





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