FREQUENCY AND TIME BROADCAST SERVICES OF THE NATIONAL BUREAU OF STANDARDS

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ABSTRACT

A brief description of the NBS standard frequency and time broadcasts at HF, LF, and VLF is given, including some discussion of the US Frequency Standard (USFS). Some future plans in the area of the accurate dissemination of frequency and time standards are also given.

INTRODUCTION

There are many standardizing laboratories that require frequency and time calibrations that are directly traceable to the National Bureau of Standards. For these laboratories, and others, the various standard radio broadcasts[1] of the National Bureau of Standards are readily available. Extremely precise audio and radio frequency standards, including accurate time signals and radio propagation forecasts, are placed at the disposal of anyone having a receiver capable of tuning to one of the broadcast carriers. The latter include frequencies at HF (WWV) and (WWVH); LF (WWVB), and VLF (WWVL).

The effective utilization of these services depends upon a knowledge of the accuracy of the controlling standards, the broadcasting schedules of each station, the carrier frequencies, suitable methods of comparison, received accuracies possible and avoidance of pitfalls involved in their use. Due to the limited space here, the last three topics will be covered in a future paper.

FREQUENCY AND TIME STANDARDS

There is no fundamental difference between a time standard and a frequency standard. The scientific unit of time is determined astronomically with an uncertainty of a few parts in 10^9. Since frequency is related inversely to time by definition, this uncertainty, strictly speaking, must be transferred to the frequency derived from it. In practice, however, atomic frequency standards with stabilities of one or two parts in 10^{11} form the basis for very precise frequency measurements.

The present definition of the second[2] is the fraction $\frac{1}{31,556,925.9747}$ for January 0, 1900 at 1200 hours, Ephemeris time (ET). Because of the length of time (many years) required to determine ET to an accuracy of a few parts in 10^9, the relationship between the atomic transition frequency of cesium and the Ephemeris second was determined[3] in 1958 to be 9,192,631,770±20 c/s, which is the best value available at the present time. Because of the difficulty of determining Ephemeris time to any higher accuracy, it is generally agreed that the Ephemeris second will never match atomic standards for accuracy and precision. The Consultative Committee[4] for the Definition of the Second met in Paris in April 1961 to consider the question of basing the unit of time on an atomic or molecular transition frequency. It is highly probable that this will be done at the meeting of the International Committee of Weights and Measures scheduled for 1966.

The cesium beam frequency standards serving as the United States Frequency Standard[5] (USFS) are among the most stable, reproducible, and thoroughly evaluated frequency standards in the world. They are considered as having an accuracy of ±1.1 parts in 10^{11} and capable of being used in frequency measurements to a precision of a few parts in 10^{12}. In order to carry out its statutory responsibility and to make these high quality standards and their corresponding time scale readily available to those who wish to use them, the National Bureau of Standards maintains radio broadcasts at several carrier frequencies based upon them.

PRESENT STANDARDS FREQUENCY BROADCASTS OF THE NATIONAL BUREAU OF STANDARDS

(1) Standard HF Broadcasts

The first use of standard frequency transmissions occurred when the National Bureau of Standards, in 1923, transmitted various frequencies between 75 kc/s and 2 Mc/s at regular intervals. This service, using the call sign WWV, was gradually extended to higher power, and to include other carrier frequencies, tone modula-

tion, time intervals, time signals, radio propagation notices, etc.; and by 1939 a continuous operation schedule was put into effect. Near the end of 1948 a sister station with similar services, call sign WWVH, was installed in Maui, Hawaii, to serve the Pacific area and western North America.

Both of these stations broadcast the following technical services: (1) standard radio frequencies, (2) standard audio frequencies, (3) standard time intervals, (4) standard musical pitch, (5) time signals, and (6) radio propagation forecasts. All the carrier and modulation frequencies at WWV are derived from a common oscillator with a stability (but not accuracy) of better than one part in 10^{11} per day. Since January 1960 this oscillator has been offset intentionally from the USFS by a small, but precisely known, amount in order to reduce the departure between the time signals broadcast and astronomical time, UT2. Although UT2 time is subject to unpredictable changes observable at this level of precision, it is nevertheless expected that a particular offset, which is left unchanged throughout each calendar year, will provide not only a constant frequency but also a very uniform time scale.

For the above reasons, corrections to the actual carrier frequencies as transmitted are determined with respect to the USFS and are published in the Proceedings of the IRE[7] each month. This service was begun in May 1958 with the data extending back to December 1, 1957. The values are given to one part in 10^{11} with an uncertainty of 5 parts in 10^{11}. The time signals and carrier frequencies of WWV, WWVH, WWVB, and WWVL are coordinated with those of Argentina, Australia, Canada, England, Japan, South Africa, and Switzerland, as well as those from the US Navy stations. The time signals are emitted so that they are simultaneous to around one millisecond and the controlling frequencies are the same to about one part in 10^{10}. More details regarding all the NBS Standard Frequency and Time Signal Broadcasts are given in the appendices and in figure 1.

(2) Standard LF Broadcasts

In 1959 the National Bureau of Standards began an experimental standard frequency broadcast at 60 kc/s (former call sign KK2XEI, now WWVB) with less than 2 watts of radiated power. By utilizing special receiving equipment, the signal has been received from coast-to-coast in the continental United States for use in high precision frequency calibration work. One reported[8] result indicated that frequency calibrations may be made with a precision of three parts in 10^{11} in a period of about one day. This has also been verified[9] by similar measurements made at WWV by NBS personnel. At present the carrier frequency of WWVB is directly controlled by the US Working Frequency Standard (USWFS) at the Boulder Laboratories and is stable to about three parts in 10^{11}.

Work is underway to relocate this station within the next six months to a site near Fort Collins, Colorado, and increase the radiated power from the present one to two watts to approximately seven kilowatts.

(3) Standard VLF Broadcasts

In April 1960 a standard frequency broadcast was begun at 20 kc/s, with the call letters WWVL, from a site near the Boulder Laboratories (Sunset, Colorado) with a radiated power of about 15 watts. Beginning in October 1961 the carrier frequency was phase-locked[10] to the USWFS, so that the daily stability is the same as the USWFS. Reports of the reception of these signals using phase-lock receiving techniques have been received from many places in the continental US, and as far away as New Zealand[11]. Work is under way to relocate this station near Fort Collins and also to increase the radiated power to about one kilowatt. Further details are given in appendix II.

NBS TIME SIGNAL BROADCASTS

(1) Time Broadcasts at HF

For those interested in the NBS time signal broadcasts the following information is provided. Highly precise time signals, consisting of 5 cycles of 1,000 c/s at WWV and 6 cycles of 1,200 c/s at WWVH, are broadcast as a pulse at intervals of precisely one second. The pulse at the 59 second of each minute is omitted but two time pulses separated by 0.1 sec. are transmitted on the 60th second. Universal time, referenced to the zero meridian, is announced in International Morse code every five minutes at both stations. The twenty four hour clock is used starting with 0000 at midnight at the longitude zero. At station WWV a voice announcement of Eastern Standard Time is given before and after each International Morse code announcement. The time signals are kept in close agreement with UT2 by making a step adjustment of precisely 50 milliseconds whenever it is necessary. The time intervals as broadcast are accurate to about 5 parts in 10^{11} plus or minus one microsecond. Corrections in terms of UT2 of the time signals as finally determined by the US Naval Observatory are published periodically by them.

(2) Pulse Time Code on WWV

Station WWV also carries a pulse timing code which was tried out on an experimental basis for several months in 1960. The 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. Refer to Time Code on WWV, in appendix 1, for further details.

(3) Time Signal Broadcasts at LF and VLF

The LF and VLF stations, WWVB and WWVL, do not at present broadcast time signals; however, when relocated near Fort Collins, the 60 kc/s signals will carry very precise time signals which should be usable over most of continental USA. The time modulation will consist of 5 cycles of 1,000 cycles transmitted once per second. The 20 kc (WWVL) component of the station will be an experimental facility to test out various methods of providing accurate time with very narrow band signals. One possible system that will be tested has been described briefly in the literature[12].

APPENDIX I

BROADCASTS OF STANDARD FREQUENCIES AND TIME SIGNALS

Services provided by stations WWV and WWVH:

1. Standard Radio Frequencies
2. Standard Audio Frequencies (includes Standard Musical Pitch)
3. Standard Time Intervals
4. Time Signals
5. Radio Propagation Forecasts
6. International World Day Service ("State of Warning" signals)

NBS STANDARD BROADCAST STATIONS

STATION	LOCATION	CARRIER FREQUENCIES	RADIATED POWER	ANTENNAS AND MODULATION
WWV	NBS Station WWV Greenbelt, Maryland Coordinates: Lat. 38° 59' 33" N. Long. 76° 50' 52" W.	2.5 Mc/s 5 Mc/s 10 Mc/s 15 Mc/s 20 Mc/s 25 Mc/s	1 kw 8 kw 9 kw 9 kw 1 kw 0.1 kw	Radiation from all antennas is omnidirectional. The 2.5 Mc/s antenna at WWV and the 5 Mc/s antenna at WWVH are vertical quarter-wave; all others are vertical half-wave dipoles.
WWVH	Box 578, Puuene Maui, Hawaii Coordinates: Lat. 20° 46' 02" N. Long. 156° 27' 42" W.	5 Mc/s 0 Mc/s 5 Mc/s	2 kw 2 kw 2 kw	Percent amplitude modulation, double sideband: 440 and 600 c/s signals - 75%; voice and seconds pulses, peak - 100%. The audio frequencies, 440 and 600 c/s, on WWV are transmitted by means of a single upper sideband with full carrier, except on 25 Mc/s. Power output from the sideband transmitter is about 1/3 of the carrier power.
WWVB	National Bureau of Standards, Boulder, Colorado Coordinates: Lat. 39° 59' 30" N. Long. 105° 15' 55" W.	60 kc/s	1.5 w	Radiation is omnidirectional from a top-loaded vertical antenna.

WWVL	Sunset, Colorado (National Bureau of Standards, Boulder, Colorado) Coordinates: Lat. 40° 02' 15" N. Long. 105° 27' 05" W.	20 kc/s	14 kw	Radiation is omnidirectional from a top-loaded vertical antenna.

STANDARD RADIO FREQUENCIES

STATION	CARRIER FREQUENCIES*	NORMAL TRANS. STAB.	MAX. DAILY DEV.	REMARKS
WWV	2.5, 5, 10, 15, 20 and 25 Mc/s	±5 pp. in 10^{11}	±1 pp. in 10^{10}	As necessary, adjustments of frequency not exceeding one part in 10^{10} are made at 1900 UT. The carrier frequencies are interrupted from 45 to 49 minutes past each hour.
WWVH	5, 10 and 15 Mc/s	±1 pp. in 10^{10}	±1 pp. in 10^{9}	As necessary, adjustments of frequency not exceeding one part in 10^{9} are made at 1900 UT. The carrier frequencies are interrupted 15 to 19 minutes past each hour.
WWVB	60 kc/s	±3 pp. in 10^{11}	±3 pp. in 10^{11}	The carrier frequency is normally controlled by an atomic standard. Station identification is by International Morse Code keyed carrier on the hour and at 20 minute intervals. Transmission from WWVH and WWVB is continuous except for unscheduled interruptions.
WWVL	20 kc/s	±3 pp. in 10^{11}	±1 pp. in 10^{10}	The carrier frequency is phase-locked to the US Working Frequency Standard.

* The carrier frequencies of WWV and WWVH were offset -150×10^{-11} from the United States Frequency Standard beginning January 1960, WWVL in April 1960, and WWVB in July 1960. During 1962 the offset will be -130 parts in 10^{11}. This offset enables the time signals, which are locked to the carrier frequency, to maintain close agreement with UT2 time.

Corrections to all the carrier frequencies as broadcast are available on a weekly basis from National Bureau of Standards, Boulder, Colorado upon request; for WWV, they are also published monthly in the Proceedings of the Institute of Radio Engineers.[7]

STANDARD AUDIO FREQUENCY

STATION	AUDIO FREQUENCIES	REMARKS
WWV	440 c/s* 600 c/s	Changes in the transmitting medium (Doppler effect, etc.) may produce fluctuations in the audio frequencies as received.
WWVH	440 c/s* 600 c/s	Standard Audio Frequencies are broadcast alternately from both WWV and WWVH during two or three minutes of each five minute interval.

* Standard Musical Pitch - A above middle C.

STANDARD TIME INTERVALS

WWV time intervals, as transmitted, have the same accuracy as the carrier ±1 microsecond. The frequency offset mentioned above under Standard Radio Frequencies applies. Pulses are transmitted at one second intervals. Received pulses have random phase shifts or jitter due to changes in the propagation medium. The magnitude of these changes range from practically zero for the direct or ground wave to about 1,000 microseconds when received via a changing ionosphere.

Adjustments of precisely 50 milliseconds may be made in the time-interval markers at the WWV transmitters at 1900 UT 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 milliseconds.

WWVH time-interval markers (one second pulses) are adjusted, if necessary, each day during the interval 1900 to 1935 UT to be emitted simultaneously with WWV time pulses within ±1/2 millisecond.

TIME SIGNALS

Signal schedule: Standard audio frequencies are interrupted at precisely three minutes before each hour at WWV, and two minutes before each hour at WWVH. They are resumed exactly on the hour. Except for scheduled silent periods, seconds pulses are broadcast continuously except for the 59th pulse of each minute which is omitted. The beginning of a minute is identifed by a double pulse consisting of two regular 5 millisecond pulses spaced by 100 milliseconds. International Morse code announcements of Universal Time (referenced to the zero meridian) are made each five minutes from WWV and WWVH. Voice announcements of Eastern Standard Time are made each five minutes from WWV.

Adjustments of precisely 50 milliseconds may be made in the time pulses when necessary to maintain close agreement with UT2. (See note under Time Intervals.)

Corrections in terms of UT2 of the time signals as finally determined by the US Naval Observatory are published periodically by them.

RADIO PROPAGATION FORECASTS

A forecast of radio propagation conditions is broadcast in International Morse code from WWV at 19.5 and 49.5 minutes after each hour and from WWVH at 9.4 and 39.4 minutes after each hour. WWV broadcasts information relating to the North Atlantic radio path and WWVH broadcasts information relating to the North Pacific radio path. Quality is graded in steps ranging from W-1 to N-9 as follows:

W-1 Useless	U-5 Fair	N-6 Fair-to-Good
W-2 Very Poor		N-7 Good
W-3 Poor		N-8 Very Good
W-4 Poor-to-Fair		N-9 Excellent

INTERNATIONAL WORLD DAY SERVICE

A symbol indicating the geophysical "state of warning" as declared under the international program of the International Council of Scientific Unions is broadcast in International Morse Code from WWV at 4.5 and 34.5 minutes after each hour and from WWVH at 14.4 and 44.4 minutes after each hour.

The following symbols are broadcast to indicate the geophysical conditions:

SYMBOL	CONDITION	REMARKS
AGI AAAA	Alert	Magnetic Storm with K-index over 5 Outstanding Auroral Display Outstanding increase in Cosmic Ray flux
AGI — — —	Special World Interval in Progress	Geophysical activity of sufficient interest to warrant attention of experimenters throughout the world
AGI EEEEE	No significant Geophysical events.	

TIME CODE ON WWV

On January 1, 1961, WWV began broadcasting a 36-bit, 100-pulse-per-second time code, obtained by amplitude modulation of a 1,000 c/s signal. The code has the following characteristics (see Figure I).

The code is broadcast for one minute intervals and 10 times per hour. Except at the beginning of each hour, it immediately follows the standard audio frequencies of 440 and 600 c/s.

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.

Use is made of binary coded decimal (BCD) groups, nine of which occur each second in the following order: two groups for seconds, two groups for minutes, two groups for hours, and three 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.

A complete time frame is one second.

The least significant binary group and the least significant binary digit in each group occur first. The binary groups follow the one second reference marker.

The leading edge of all pulses is the reference time in all cases.

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

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.

The one-sec reference marker consists of five "1" pulses followed by a "0" pulse. The second begins at the leading edge of the "0" pulse.

Spaced code format is used; that is, a binary decimal group follows each of the 10-per-second index markers. The last index marker is followed by an unused four-bit group of "0" pulses just preceding the one second reference marker.

The blank four-bit group may be used in the future to transmit other types of coded information.

width coding:

"0" pulse is two milliseconds wide (two cycles of 1,000 c/s)

"1" pulse is six milliseconds wide (six cycles of 1,000 c/s)

The amplitude modulation of the 1,000 c/s signal is controlled so that the leading edges of the time code pulses coincide with a positive-going zero-axis-crossing of the 1,000 c/s.

APPENDIX II

STANDARD FREQUENCY BROADCASTS AT 60 KC (WWVB) AND 20 KC (WWVL)

The National Bureau of Standards Boulder Laboratories provides two standard frequency broadcasts, one in the LF band (60 kc) and the other at VLF (20 kc). Both carrier frequencies are continuously monitored and directly controlled by the US Working Frequency Standard (USWFS) at the Boulder Laboratories. At 60 kc (WWVB) the carrier frequency is derived from the USWFS, while at 20 kc (WWVL) the carrier is phase-locked by a VHF radio link. The frequencies transmitted are 130 parts in 10^{10} below the US Frequency Standard (USFS). Corrections to the broadcasts in terms of the USFS are mailed weekly upon request to interested users.

The call signs, WWVB and WWVL are given in International Morse Code on the hour and each 20 minutes thereafter by keying the carrier for purposes of identification.

Present plans are to relocate both stations near Fort Collins, Colorado, within the next year and to increase their effective radiated power (ERP) to: WWVL (20 kc) to 1 KW and WWVB (60 kc) to 7 KW. Station WWVB will also have highly precise time signals.

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Figure 1. **Chart of time code transmissions from NBS radio station WWV.**