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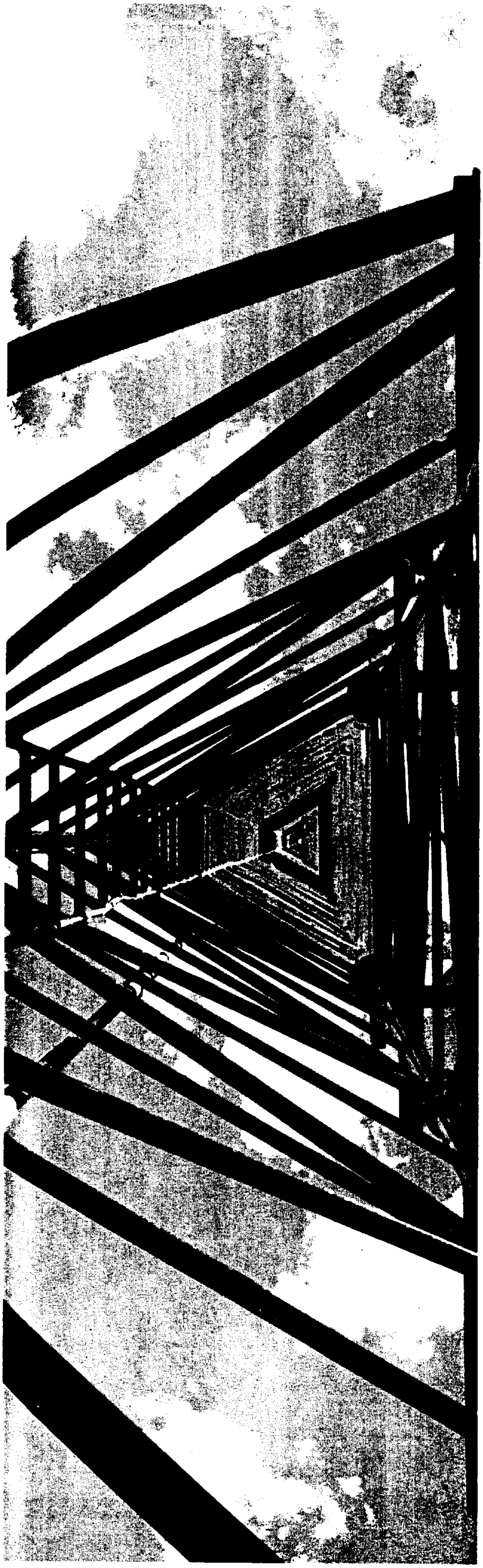

Time and Frequency Broadcasting

A 40-year-old service of NBS that might just be coming of age

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THERE are many standardizing laboratories requiring frequency and time calibrations that are directly traceable to the National Bureau of Standards (NBS). For these and other laboratories, the various standard NBS radio broadcasts[1] are readily available. Extremely precise audio and radio frequency standards, including accurate time signals and radio propagation forecasts, are available to anyone having a receiver capable of being tuned to one of the broadcast carriers.

The effective utilization of these services depends upon a knowledge of the accuracy of the controlling standards, the broadcast schedules of each station, the carrier frequencies, suitable methods of comparison, possible receiver accuracies, and avoidance of pitfalls involved in their use.

NBS STANDARD BROADCAST STATIONS

Station and 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 5 Mc 10 Mc 15 Mc 20 Mc 25 Mc	1 kw 8 kw 9 kw 9 kw 1 kw 0.1 kw	Radiation from all antennas is omnidirectional. The 2.5-Mc antenna at WWV and the 5-Mc 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 10 Mc 5 Mc	2 kw 2 kw 2 kw	Percent amplitude modulation, double sideband: 440- and 600-cps signals — 75%; voice and seconds pulses, peak — 100%. The audio frequencies, 440 and 600 cps, on WWV are transmitted by means of a single upper sideband with full carrier, except on 25 Mc. 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	1.5 w	Radiation is omnidirectional from a top-loaded vertical antenna.
WWVL Sunset, Colorado (NBS, Boulder, Colorado) Coordinates: Lat. 40° 02′ 15″ N. Long. 105° 27′ 05″ W.	20 kc	14 kw	Radiation is omnidirectional from a top-loaded vertical antenna.

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 by definition frequency is related inversely to time, strictly speaking, this uncertainty must be transferred to the frequency derived from it. In practice, however, atomic frequency standards having 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 1/31,556,925.9747 of the tropical year for January 0, 1900, at 1200 hours, Ephemeris time (ET). Because of the many years of time required to determine ET to an accuracy of a few parts in 10^9, however, some other more convenient method of measuring time was sought. Consequently, in 1958, a relationship was determined[3] between the Ephemeris second and the atomic transition frequency of cesium. It was found that cesium atoms "tick" 9,192,631,770 ± 20 times per Ephemeris second. Since it is generally agreed that the Ephemeris second will never match atomic standards for accuracy and precision, a move is already under way to base a new international definition of the second on an atomic or molecular transition frequency[4].

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 to be accurate to ± 1.0 part in 10^{11}, and capable of being used in frequency measurements to a precision of a few parts in 10^{12}. To carry out its statutory responsibility, and make these high-quality standards and their corresponding time scale readily available, NBS maintains radio broadcasts at several carrier frequencies based upon them.

Standard HF Broadcasts

The first use of standard frequency transmissions occurred in 1923, when NBS transmitted various fre-

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. Excluding scheduled silent periods, seconds pulses are broadcast continually, except for the 59th pulse of each minute which is omitted. The beginning of a minute is identified 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 every five minutes from WWV and WWVH. Voice announcements of Eastern Standard Time are made every 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 Standard Time Intervals.)

Corrections (in terms of UT2) of the time signals as finally determined by the U.S. Naval Observatory are published periodically by them.

STANDARD RADIO FREQUENCIES

Station	Carrier Frequencies*	Normal Trans. Stab.	Max. Daily Dev.	Remarks
WWV	2.5, 5, 10, 15, 20, and 25 Mc	± 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	± 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. Continuous transmission except for unscheduled interruptions.
WWVB	60 kc	± 3 pp. in 10^{11}	± 3 pp. in 10^{11}	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. Continuous transmission except for unscheduled interruptions.
WWVL	20 kc	± 3 pp. in 10^{11}	± 1 pp. in 10^{10}	Carrier frequency is phase-locked to the U.S. 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 was -130 parts in 10^{10}. 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 NBS, Boulder, Colorado upon request; for WWV, they are also published monthly in the Proceedings of IEEE.[7]

quencies between 75 kc and 2 Mc at regular intervals. This service, using the call sign WWV, was gradually extended to include higher power, other carrier frequencies, tone modulation, time intervals, time signals, radio propagation notices, etc. By 1939, a continuous operating schedule was put into effect. Near the end of 1948, a sister station providing similar services

STANDARD TIME INTERVALS

WWV time intervals, as transmitted, have the same accuracy as the carrier ± 1 microsecond. The frequency offset mentioned 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 ranges 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 so that they are emitted simultaneously with WWV time pulses within $\pm$ ½ millisecond.

(call sign WWVH) was installed in Maui, Hawaii to serve the Pacific area and western North America.

Both stations now broadcast these technical services:

1. standard radio frequencies
2. standard audio frequencies (including standard musical pitch)
3. standard time intervals
4. time signals
5. radio propagation forecasts
6. international world day service ("state of warning" signals).

All the carrier and modulation frequencies at WWV are derived from a common oscillator having 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 variance between the time signals broadcast and astronomical time, UT2.

The time scale, UT2, on which we base the time of day, is determined by the period of the earth's rotation on its axis. We subdivide this period into hours, minutes, and seconds. Inasmuch as the period of the earth's rotation is not constant — in fact, varies from day to day — the length of the second as given by atomic standards does not exactly coincide with the second determined from the earth's rotation. The broadcast signals therefore are offset from the scientific scale by as much as is necessary to keep them in close agreement.

During 1962, the International Bureau of Time consulted observatories throughout the world and compared astronomical and atomic measurements of time. From this comparison was determined the

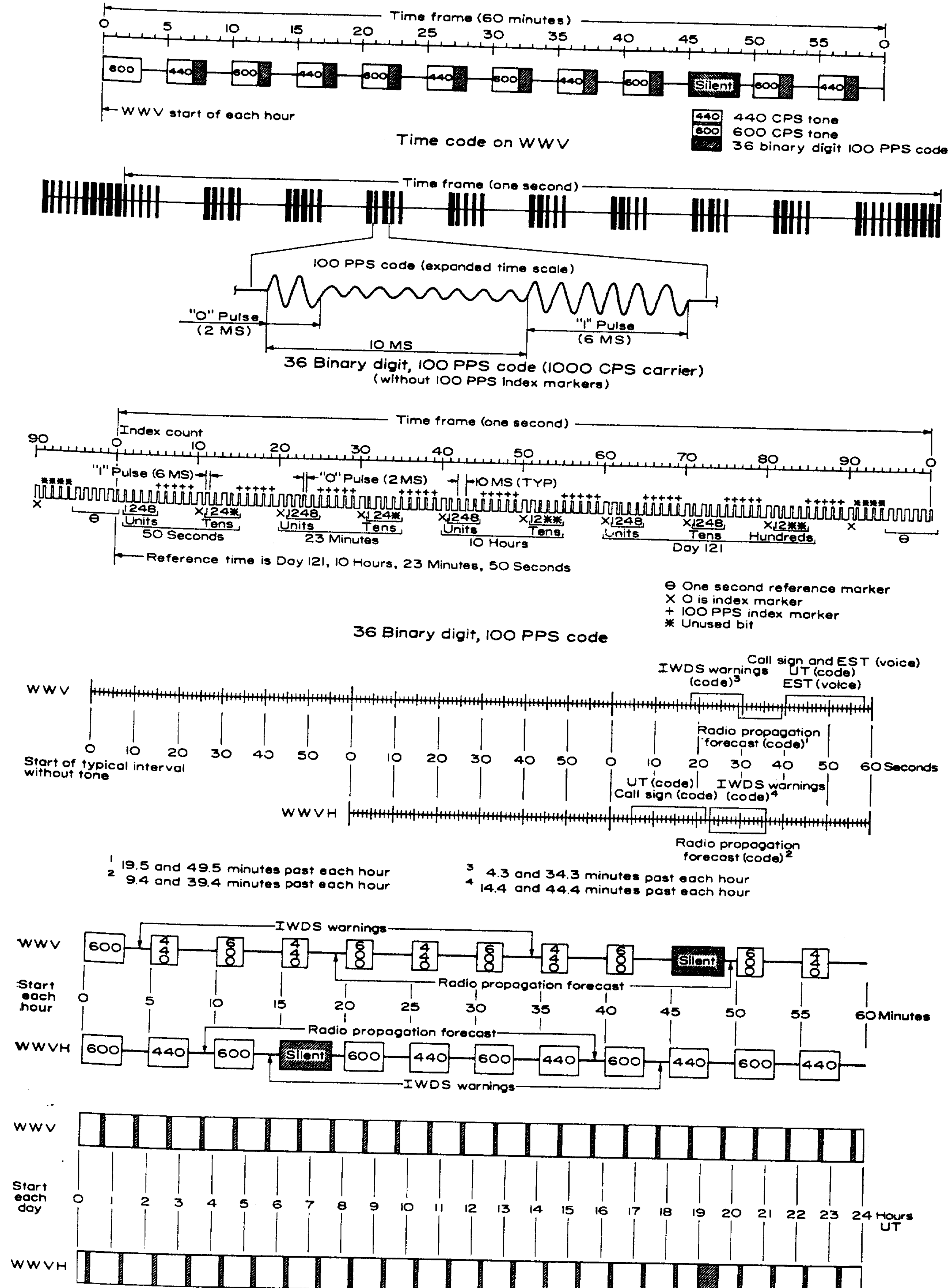

Chart of time code transmissions from NBS radio station WWV.

STANDARD AUDIO FREQUENCIES

Station	Audio Frequencies	Remarks
WWV	440 cps* 600 cps	Changes in transmitting medium (Doppler effect, etc.) may produce fluctuations in the audio frequencies as received.
WWVH	440 cps* 600 cps	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.

average variation from Ephemeris time expected in the speed of the earth's rotation during 1963. The findings indicated a difference of about 13 parts in a billion — the same value as was used in 1962. The correct frequency on the Ephemeris scale can be determined then by adding 13 parts in a billion to the frequency signal as received.

Corrections to the actual carrier frequencies as transmitted are determined with respect to the USFS and are published in the Proceedings of the IEEE[7] each month. This service was begun in May 1958, with the data extending back to December 1, 1957. Values are given to one part in 10^{11}, with an uncertainty of five parts in 10^{11}. 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 U. S. Navy stations. Time signals are emitted so that they are simultaneous to approximately one millisecond; and controlling frequencies are the same to about one part in 10^{10}.

Standard LF Broadcasts

In 1956, NBS began an experimental standard frequency broadcast at 60 kc (former call sign KK2XEI, now WWVB) with less than 2 watts of radiated power. With the aid of 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 report[8] 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 U.S. Working Frequency Standard (USWFS) at the Boulder Laboratories, and is stable to about three parts in 10^{11}.

Presently in the process of being relocated, WWVB is scheduled to begin operations at its new site near Fort Collins, Colorado about the end of June 1963. Radiated power is being increased from the present 1 or 2 watts to approximately 7 kw. Because of the better transmission characteristics of LF as compared to VHF or HF, the new facility is expected to increase greatly the practicability of receiving timing signals at any time and any location in the continental U.S.

Standard VLF Broadcasts

In April 1960, a standard frequency broadcast was begun at 20 kc (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 that for USWFS. Reports of the reception of these signals, using phase-lock receiving techniques, have been received from many places in the continental U.S. and as far away as New Zealand.[11]

Like Station WWVB mentioned previously, the

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	

WWVL facility is being relocated near Fort Collins, Colorado, and also is expected to be in operation about the end of June 1963. Its radiated power will be increased to about one kilowatt.

HF Time Broadcasts

Highly precise time signals, consisting of five cycles of 1,000 cps at WWV, and six cycles of 1,200 cps at WWVH, are broadcast as pulses at intervals of precisely one second. The pulse at the 59th second of each minute is omitted, but two time pulses separated by 0.1 second 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 24-hour clock is used starting with 0000 midnight at 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 five parts in 10^{11} $\pm$ one microsecond. Time-signal corrections (in terms of UT2), as finally determined by the U.S. Naval Observatory, are published periodically.

WWV Pulse Time Code

Station WWV also carries a pulse timing code which 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. The code was tried out on an experimental basis for several months in 1960. Then on January 1, 1961, WWV began broadcasting a 36-bit, 100-pulse-per-second (pps) time code, obtained by amplitude modulation of a 1,000 cps signal. The code has the characteristics shown on page 52. It is broadcast ten times per hour for one-minute intervals. Except at the beginning of each hour, it immediately follows the standard audio frequencies of 440 and 600 cps. 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 for seconds, two for minutes, two for hours, and three 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 in length.

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. In all cases, the leading edge of each pulse is the reference time.

The code has a 100-per-second clocking rate, 10-per-second index markers, and a 1-per-second reference marker. The 1,000 cps signal 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-second 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.

A "0" pulse is two milliseconds wide (two cycles of 1,000 cps). A "1" pulse is six milliseconds wide (six cycles of 1,000 cps).

The amplitude modulation of the 1,000 cps 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 cps signal.

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