STANDARD FREQUENCY AND TIME SERVICES OF THE NATIONAL BUREAU OF STANDARDS

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Here's a must for your reference file—a complete description of the eight technical services provided by NBS stations WWV, WWVH, WWVB and WWVL.

STANDARD RADIO FREQUENCIES

Program

Station WWV broadcasts on standard radio frequencies of 2.5, 5, 10, 15, 20, and 25 Mc/s. Broadcasts are continuous, night and day, except for an interruption of approximately four minutes each hour. The silent period commences at 45 minutes (plus 0 to 15 seconds) after each hour.

WWVH broadcasts on standard radio frequencies of 5, 10 and 15 Mc/s. The broadcast is also interrupted for approximately four minutes each hour, but the silent period commences at 15 minutes (plus 0 to 15 seconds) after each hour. Service is continuous on station WWVB which broadcasts on the standard radio frequency of 60 kc/s, and station WWVL which operates at 20 kc/s.

Accuracy

Since December 1, 1957 standard radio transmissions from stations WWV and WWVH have been held as nearly constant as possible with respect to the atomic frequency standards constituting the United States Frequency Standard (USFS) which is maintained and operated by the Radio Standards Laboratory of the National Bureau of Standards. Carefully-made atomic standards realize the idealized Cs resonance frequency f_{Cs} to a few parts in 10^{11}. The present USFS obtains this resonance to 1 part in 10^{11}. In terms of the second, measured $f_{Cs} = 9{,}192{,}631{,}770 \pm 20$ c/s (Markowitz, Hall, Essen, and Parry, "Frequency of Cesium in Terms of Ephemeris Time," *Phys. Rev. Letters*, 1, 105, 1958). The uncertainty of 2 parts in 10^9 with which frequency can be expressed in terms of the second has been avoided in practice by provisionally taking f_{Cs} exactly equal to the previous number, or to some other stated number before this number was available.

On January 1, 1960 the USFS was brought into agreement with f_{Cs} by arbitrarily increasing its assigned value by 74 parts in 10^{10}. Frequencies measured in terms of the USFS 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 (National Standards of Time and Frequency in the United States, *Proc. IRE*, 48, 105, 1960).

Frequencies transmitted by WWV are held stable to 5 parts in 10^{11} at all times. Deviations at WWV are normally 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}.

Changes in the propagation medium causing Doppler effect, diurnal shifts, etc., at times result in fluctuations of the received carrier frequencies which may be very much greater than the uncertainties described previously. WWVB and WWVL frequencies are normally stable to 2 parts in 10^{11}. Deviations from day to day are within 1 part in 10^{11}. Effects of the propagating medium on the received frequencies are much less at LF and VLF where full transmitted accuracy may be obtained using appropriate receiving techniques.

Corrections

All carrier and modulation frequencies at WWV and WWVH are derived from precision quartz oscillators. These oscillators are intentionally offset from the USFS by a small, but precisely known, amount to reduce departure between the time signals as broadcast and astronomical time UT2. Offset for 1960 was -150 parts in 10^{10}; in 1962 and 1963 -130 parts in 10^{10}; and in

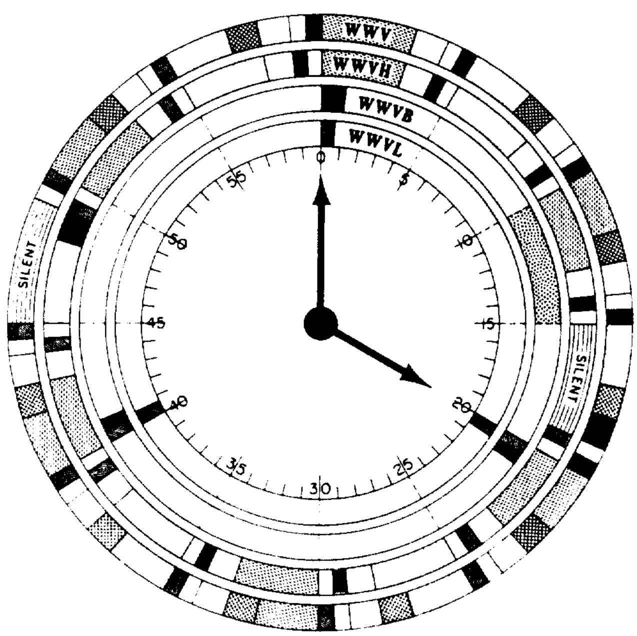
1964 and 1965 — 150 parts in 10^{10}. Although UT2 is subject to unpredictable changes readily noted at this level of precision, you can expect that a particular offset from the USFS will remain in effect for the entire calendar year.

The carrier frequency at WWVL (20 kc/s) is also offset from the USFS by the same amount indicated before. While WWVB (60 kc/s) has been transmitting with the offset frequency, beginning January 1, 1965 the frequency transmitted was that of the USFS. Thus, one of the NBS transmissions made the standard of frequency available to users so that absolute frequency comparisons could be performed directly. This frequency is not subject to annual offset change as are the other station frequencies.

STANDARD AUDIO FREQUENCIES

Program

Standard audio frequencies of 440 c/s and 600 c/s are broadcast on each radio carrier frequency at WWV and WWVH. The audio frequencies are transmitted alternately at five-minute intervals starting with 600 c/s on the hour. WWV's first tone period (600 c/s) is of three minute duration while the remaining periods are two minutes. At WWVH all tone periods are 3 minutes in duration. WWVB and WWVL do not transmit standard audio frequencies.



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

WWVB - CONTINUOUS WWVL - NONE

- STATION ANNOUNCEMENT
  - WWV - MORSE CODE - CALL LETTERS, UNIVERSAL TIME, PROPAGATION FORECAST
    - VOICE - EASTERN STANDARD TIME
    - MORSE CODE - FREQUENCY OFFSET (ON THE HOUR ONLY)
  - WWVH - MORSE CODE - CALL LETTERS, UNIVERSAL TIME,
    - VOICE - HAWAIIAN STANDARD TIME
    - MORSE CODE - FREQUENCY OFFSET (ON THE HOUR ONLY)
  - WWVB - MORSE CODE - CALL LETTERS
  - WWVL - MORSE CODE - CALL LETTERS, FREQUENCY OFFSET
- 100 PPS 1000 c/s MODULATION WWV TIMING CODE
- TONE MODULATION 600 c/s
- TONE MODULATION 440 c/s
- GEOALERTS
- IDENTIFICATION PHASE SHIFT
- UT-2 TIME CORRECTION

Fig 1—Hourly broadcast schedules.

Accuracy

Accuracy of the audio frequencies—as transmitted—is the same as that of the carrier. The frequency offset mentioned earlier applies. Similarly, changes in the propagation medium will sometimes result in fluctuations in the audio frequencies as received. Although 1000 c/s is not considered one of the standard audio frequencies, the time code which is transmitted 10 times an hour does contain this frequency and may be used as a standard with the same accuracy as the audio frequencies.

STANDARD MUSICAL PITCH

440 c/s for the note A, above middle C, is the standard in the music industry in many countries, and in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. Transmission periods of 440 c/s from WWV and WWVH appear in Fig 1. Standard pitch is maintained with this broadcast, and musical instruments are manufactured and adjusted in terms of this unvarying standard. Most musical instruments manufactured can be tuned to this frequency.

STANDARD TIME INTERVALS

Program

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 million cycles of the 5 Mc/s carrier. They are given by means of double-sideband amplitude modulation on each radio carrier frequency. Intervals of one minute are marked by the omission of the pulse at the beginning of the last second of every minute, and by commencing each minute with two pulses spaced by 0.1 second.

The first pulse marks the beginning of the minute. Two-minute, three-minute and five-minute 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. Pulse duration is 5 msec (Fig 2).

At WWV each pulse contains five cycles of 1000 c/s frequency. For WWVH the pulse consists of six cycles of 1200 c/s frequency. The pulse spectrum is composed of discrete frequency components at intervals of 1 c/s. Components have maximum amplitudes at approximately 995 c/s for WWV and 1194 c/s for WWVH pulses. Tone is interrupted 40 msec for each seconds pulse, with the pulse starting 10 msec after the interruption begins.

WWVB transmits seconds pulses continuously consisting of five cycles of 1000 c/s double-sideband amplitude modulation. Because of the narrow bandwidth of the antenna system, the modulation percentage is quite low. WWVL does not transmit seconds markers although accurate time intervals may be obtained directly from the carrier using appropriate techniques.

TIME SIGNALS

Program

Audio frequencies are interrupted at precisely three minutes before each hour at WWV, and two minutes before each hour at WWVH. They are resumed on the hour at WWV and WWVH, and at five- and ten-minute intervals throughout the hour as indicated in Fig 1.

WWV and WWVH announce Universal Time, referenced to the zero meridian at Greenwich, England, in International Morse Code every five minutes. This provides a ready reference to correct time where a timepiece may be in error by a few minutes. 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 UT, 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 resume.

At station WWV a voice announcement of Eastern Standard Time is given during the last half of every fifth minute during the hour. At 10:35 a.m., EST, for instance, the voice announcement given in English is: National Bureau of Standards, WWV; when the tone returns, Eastern Standard Time will be ten hours, thirty-five minutes. At WWVH a similar voice announcement of Hawaiian Standard Time occurs during the first half of every fifth minute during the hour. WWVB and WWVL do not give time-of-day information.

Corrections

Time signals broadcast from WWV and WWVH are kept in close agreement with UT2 (astronomical time) by making step adjustments of 100 msec as necessary. These adjustments are made at 0000 UT on the first day of a month. Advance notice of such adjustments is given to the public upon advice by the Bureau International de l'Heure in Paris. 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 depart from UT2 at a different rate due to the fact that WWVB broadcasts 60 kc/s derived from the USFS with no offset. Step time adjustments of 200 msec are made at 0000 UT on the first day of a month with appropriate advance notice. The National Bureau of Standards directs such step adjustments at intervals which maintain the seconds pulses within about 100 msec of UT2.

UT2 CORRECTIONS

Since the majority of time users do not require UT2 information to better than 100 msec, the systems described in the previous section are quite satisfactory. However, NBS provides an additional service in cooperation with the U. S. Naval Observatory which makes available the best values of UT2 on a daily basis. Corrections to the time signals as broadcast are given in International Morse Code during the last half of the 19th minute of each hour from WWV, and during the last half of the 49th minute of each hour from WWVH. Similar information is given from WWVB following the station identification during the 1st, 21st and 41st minute of each hour. Here are the symbols which are broadcast: UT2, then AD or SU, followed by a three digit number. This number is the correction in milliseconds. To obtain UT2, you 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 is fast with respect to UT2 if "SU" is the symbol used.

Corrections are extrapolated values of the difference UT2 minus Time Signal furnished by the U. S. Naval Observatory. Probable error is ±3 msec. Final correc-

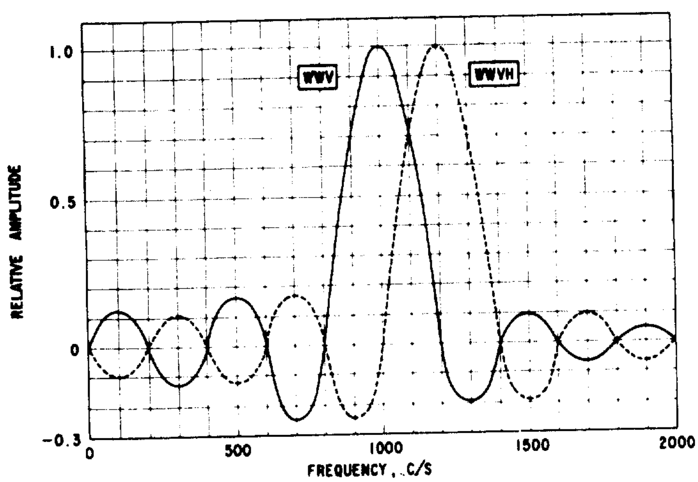


Fig 2—Sample characteristics of time pulses broadcast from WWV and WWVH. Spectra consist of discrete frequency components at intervals of 1.0 c/s. Components at the spectral maxima have amplitudes of 0.005 volt for a pulse amplitude of 1.0 volt. The WWV pulse consists of five cycles of 1000 c/s. The WWVH pulse consists of six cycles of 1200 c/s.

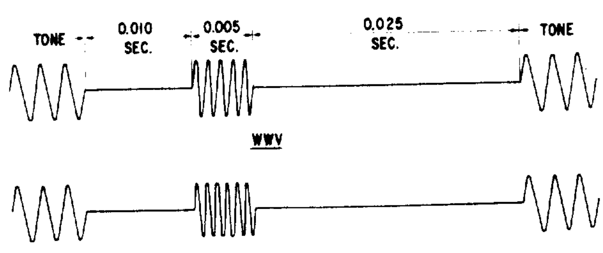


Table I—NBS Services and Locations

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	1963	√			√	√	√		
WWVL	1963	√							

WWV —Greenbelt, Maryland
(38°59′33″ N, 76°50′52″ W)
Leo Honea, Engineer-in-Charge
Telephone—301-552-1122

WWVH—Box 578, Puunene, Maui, Hawaii
(20°46′02″ N, 156°27′42″ W)
Sadami Katahara, Engineer-in-Charge
Telephone—79-4111

WWVB—Box 83-E, Route 2, Fort Collins, Colorado
(40°40′28.3″ N, 105°02′39.5″ W)
Richard Carle, Engineer-in-Charge
Telephone—303-484-2372

WWVL—Box 83-E, Route 2, Fort Collins, Colorado
(40°40′51.3″ N, 105°03′00.0″ W)
Richard Carle, Engineer-in-Charge
Telephone—303-484-2372

tions, with a probable error of ±1 msec, are published in the Time Service Bulletins of the Naval Observatory. These corrections are revised daily, the new value appearing for the first time during the hour after 0000 UT, and remaining unchanged for the following 24-hour period.

PROPAGATION FORECASTS

Forecasts of radio propagation conditions are 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, with the five minute announcement commencing on November 15, 1963. The present type of propagation forecast has been broadcast from WWV since July 1952, and was broadcast by WWVH from January 1954 until November 1964.

A forecast announcement tells users the condition of the ionosphere at the regular time of issue and the expected radio quality during the next six hours. NBS 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.

The forecast announcements from WWV refer to propagation along paths in the North Atlantic Area, such as Washington, D.C. to London or New York City to Berlin. Announcements are the short-term forecasts prepared by the NBS-CRPL Forecast Center, Box 178, Fort Belvoir, Virginia. Regular issue times for the forecasts are 0500, 1200 (1100 in summer), 1700 and 2300 UT.

An announcement of the forecast is broadcast as a letter and a number. The letter portion identifies the radio quality at the time of the forecast. Letters denoting quality are "N," "U" and "W" signifying, respectively, that radio propagation conditions are either normal, unsettled or disturbed. The number portion is the forecast of radio propagation quality on a typical North Atlantic path (from WWV) during the next six hours. Radio quality is based on the CRPL 1-to-9 scale shown in Table II. If, for example, propagation conditions are normal at the time of the forecast, 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.

Table II—Radio Quality

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

GEOPHYSICAL ALERTS

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

To experimenters and researchers in radio, geophysical and solar sciences, the symbol indicates the content of the IUWDS Geoalert message which is issued daily at 0400 UT to identify days on which outstanding solar or geophysical events are expected or have occurred in the preceding 24-hour period. There are six types of Geoalerts which may be issued; thus there are six letter symbols used to identify them plus a seventh symbol to signify that there is no Geoalert. Here are the various letter symbols with the type of Geoalert to which each refers: M—Magnetic storm, N—Magnetic quiet, C—Cosmic ray event, E—No Geoalert issued, S—Solar activity, Q—Solar quiet and W—Stratospheric warming.

Geoalert broadcasts are identified by the letters GEO in International Morse Code preceding one of the above letter symbols. The letter symbol is repeated five times to insure proper identification. If, for example, solar activity has been outstanding during the previous 24-hour period, the Geoalert broadcast would be GEO SSSSS. If a significant magnetic storm is expected (or exists), the broadcast would be GEO MMMMM. The no-alert symbol, sent as GEO EEEEE signifies than any preceding Geoalert may be considered finished and that there is no alert in progress. Since it is possible that two types of Geoalerts could be in effect at the same time, the symbols are broadcast in this priority order: C, M, W, S, Q, N, E.

WWV TIME CODE

On January 1, 1961 WWV began broadcasting the time code shown in Fig 3 for one minute out of each five, ten times an hour, as shown in Fig 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 with the time code. In this way subsequent analysis of the data is 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 broadcast is generally known as the NASA 36-Bit Time Code. It is produced at a 100 pps rate and is carried on 1000 c/s modulation. The code contains time-of-year information (Universal Time) in seconds, minutes, hours and day of year, and is synchronous with the frequency and time signals.

Here, WWV uses the binary coded decimal (BCD) system. Each second contains nine BCD groups in this 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 binary groups follow the one-second reference marker. Also, "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. 1000 c/s is synchronous with the code pulses so that you can readily obtain millisecond resolution. The 10/second index markers consist of "binary one" pulses preceding each code group except at the beginning of the second where you use a "binary zero" pulse. 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.

This 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 four-bit group of "binary zero" pulses just preceding the 1/second reference marker. A "binary zero" pulse consists of two cycles of 1000 c/s amplitude modulation, and the "binary one" pulse consists of six cycles of 1000 c/s amplitude modulation. Leading edges of the time code pulses coincide with positive-going zero-axis-crossings of the 1000 c/s modulating frequency.

OFFSET FREQUENCIES

WWV, WWVH and WWVL transmit reminders of the fact that all transmitted frequencies are offset from the USFS by a fixed amount. International Morse Code symbols for M150 are transmitted from WWV and WWVH immediately following the "on-the-hour" voice announcement. WWVL transmits International Morse Code for Minus-150 following the station call sign repeated three times. This is transmitted during the 1st.

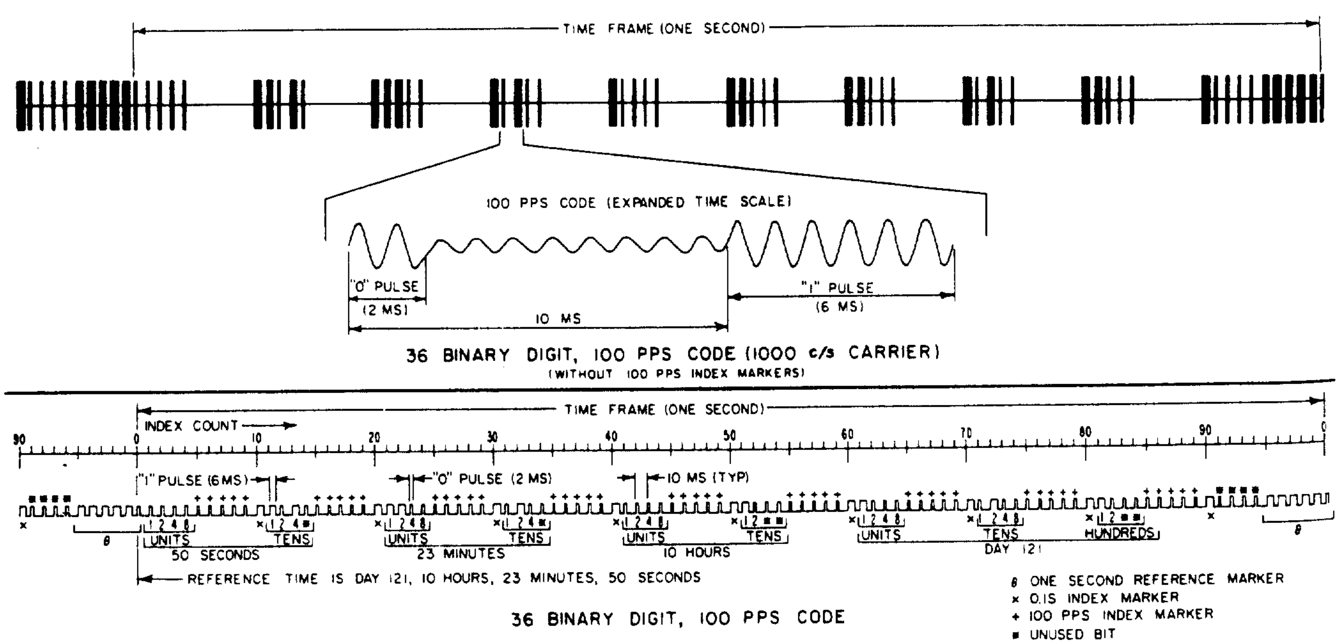


Fig 3—Time-code transmissions from WWV.

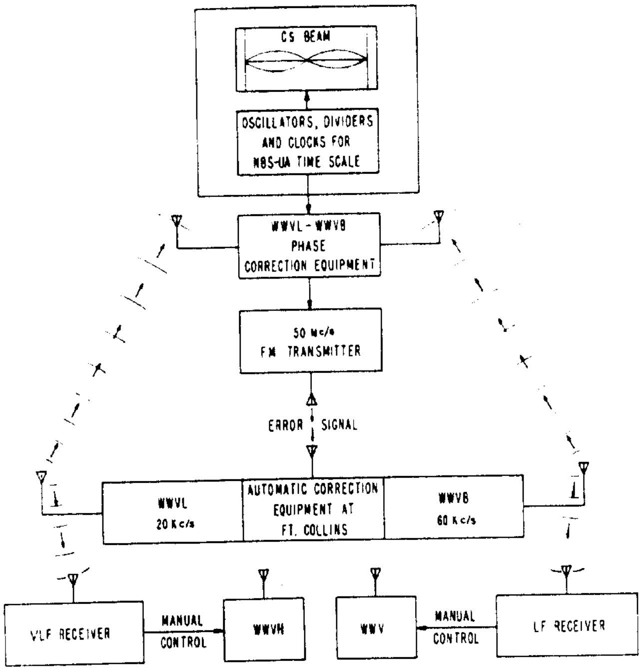


Fig 4—NBS frequency-control system.

21st, and 41st minute of each hour. Since WWVB transmits a frequency directly related to the USFS, there is no offset reminder.

STATION IDENTIFICATION

WWV and WWVH identify by International Morse Code and voice (in English) every five minutes. WWVL and WWVB identify by International Morse Code during the 1st, 21st, and 41st minute of each hour. WWVB further identifies for users of phase-tracking receivers by advancing the carrier phase 45° at 10 minutes after each hour and returning to normal phase at 15 minutes after each hour.

Table III—Radiated Power

Frequency (Mc/s)	Radiated power, kw			
	WWV	WWVH	WWVB	WWVL
0.020	—	—	—	1
0.060	—	—	7	—
2.5	1	—	—	—
5	8	2	—	—
10	9	2	—	—
15	9	2	—	—
20	1	—	—	—
25	0.1	—	—	—

ELECTRICAL CHARACTERISTICS

Transmitting Antennas

Broadcasts on 2.5 Mc/s from WWV and on 5 Mc/s from WWVH are from vertical quarter-wave antennas. Transmissions on all other frequencies from WWV and WWVH are from vertical half-wave dipoles. Antennas in both cases are omnidirectional: the antennas used by WWVB and WWVL are 400′ vertical antennas with capacity top-loading. Table III summarizes the radiated power of each station.

Modulation

At WWV the tone frequencies of 440 and 600 c/s are produced by single upper-sideband added to a full carrier on all frequencies except 25 Mc/s which is 75% double-sideband modulation. The sideband transmitters deliver one-third of the carrier power. Other signals than the steady tones are all produced by double-sideband amplitude modulation with 100% peak. At WWVH all modulation is double-sideband amplitude, with 75% on the steady tones and 100% peak for seconds pulses and voice.

WWVB employs double-sideband amplitude modulation for the seconds pulses and for the call sign. Seconds pulses are about 20% modulation and the call sign is about 40% modulation. Low modulation percentages are a consequence of the very narrow bandwidth of the transmitting antenna.

WWVL uses no amplitude modulation. Various experimental techniques are now under study in an attempt to develop a good timing system at VLF.

HOW NBS CONTROLS THE TRANSMITTED FREQUENCIES

Fig 4 shows a simplified diagram of the NBS frequency control system. The entire system depends upon the basic frequency reference (USFS) shown here 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 feeds receivers which monitor the WWVB-VL transmissions and compare the received phase with the standard phase. If an error exists between the reference and received phases, a 50 Mc/s transmitter sends a signal to the transmitting site at Fort Collins which in turn operates automatic phase correction equipment to correct the transmitted phase.

Control of the signals transmitted from WWV and WWVH is manual 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 using a very precise portable clock. With these clocks you can attain time synchronization to a few millionths of a second. □

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