Errata

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HP References in this Application Note

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INTRODUCTION

GENERAL

This application note explains the basic principles of precision time and frequency standards. Timekeeping and instrument calibration are discussed in Application Note 52-2, while Application Note 52-3 deals with the stability of frequency and time standards and methods of measuring stability.

In 1943, the first HP crystal-controlled frequency standard was produced. Since then, Hewlett-Packard has placed major emphasis on development of high performance frequency and time standards. This emphasis on development was needed to meet the needs of basic research and advanced technology. Today, the HP cesium beam standard typifies advanced state-of-the-art in frequency and timekeeping. The cesium beam frequency standard takes advantage of a most significant development, the utilization of an atomic transition, and provides a time interval of far greater uniformity than any previously available in the long history of timekeeping. This compact and portable self-contained unit has been flown around the world as a "passenger" on regularly scheduled airlines to compare time-of-day standards of the United States to those of other countries. The 1967 flight successfully correlated time between 53 locations in 18 countries to an accuracy of about 0.1 microsecond. (33)*

Hewlett-Packard time-and-frequency-standard systems are used for frequency and time control or calibration at manufacturing plants, physical research laboratories, and calibration centers. They are also used at astronomical observatories, missile and satellite tracking stations, and radio monitoring and transmitting stations. System applications include:

Distribution of standard frequencies in factories or research facilities ("house standards").
Control of standard frequency and time broadcasts.
Synchronization of electronic navigation systems.
Investigation of radio transmission phenomena.
Frequency synthesizer control.
Single-sideband communications equipment.
Data communications network synchronization.

Because units of time or frequency cannot be kept in a vault for reference purposes, frequency and time standards require regular comparisons to a recognized primary standard to maintain their accuracy. Hewlett-Packard offers time and frequency standard systems which not only provide locally generated frequencies and time intervals, but also include means for relating these frequencies and time intervals to time/frequency standards such as the National Bureau of Standards (NBS).

While accuracy may be the fundamental concern, the degree to which a high-accuracy system is useful is a direct function of system reliability. For this reason, increased accuracy and increased reliability are considered inseparable design objectives. Necessary equipment characteristics are:

Oscillator stability.
High accuracy comparison capability.
Reliability.
Operational simplicity.

Compatible design of a complete range of equipment makes it easy to arrange a system to meet the user's needs for frequency standard work, timekeeping, or both.

This application note provides a brief introduction to frequency and time standards. Appendices provide detailed information on definitions of time, on international standards of time and frequency, and on worldwide broadcasts of time and frequency.

**Numbers in parenthesis indicate references contained in the Bibliography.*

FREQUENCY STANDARDS

Worldwide comparison of local standards to national standards, coordinated through the BIH, is possible through time and frequency standard broadcast stations. Stations of this type in the United States are operated by the National Bureau of Standards, the Unites States Coast Guard, and the United States Navy.

Fast and precise frequency calibrations are possible through comparisons of a local standard against phase-stable low frequency standard signals transmitted by the National Bureau of Standards (NBS). The low-frequency broadcast (60 kHz) from the NBS transmitter at WWVB, Ft. Collins, Colorado, is capable of yielding comparison precisions as high as a few parts in 10^{12} in the continental U.S. under good propagation conditions. Even at great distances, the frequency comparison accuracy that can be achieved in a 24-hour period using low frequencies exceeds that which could be realized in several months, using high frequency transmissions.

The stability of the local standard is a primary consideration in achieving a high level of accuracy and precision. An increase in a local standard's long-term stability makes it possible to increase the length of time between recalibrations.

A level of absolute accuracy is possible in a local standard system which incorporates atomic controlled oscillators. Outstanding examples are the Cesium Beam Frequency Standard which can provide an accuracy of 7 parts in 10^{12}, and the Rubidium Vapor Frequency Standard, which can be calibrated to within parts in 10^{12} of the reference frequency.

The cesium beam standard uses an invariant atomic frequency to stabilize a high-quality quartz oscillator. It, thus, combines the excellent short-term characteristics of a quartz oscillator with the long-term stability of an atomic resonator. The long-term stability of the High Performance Cesium Beam Frequency Standard is generally better than 3 parts in 10^{12} for the life of the cesium beam tube. Cesium beam standards are absolute standards of frequency within their specified bounds and as such do not require calibration to establish their accuracy.

The rubidium vapor frequency standard is an atomic-type frequency standard and uses a rubidium vapor resonance cell as the stabilizing element. It has an extremely low drift rate of less than 1 part in 10^{11} per month and a short-term stability of better than 5 parts in 10^{12}, averaged over 1-second.

The long-term stability of the quartz oscillator is rated conservatively at better than 5 parts in 10^{10} per day. Substantially better performance is experienced under normal operating conditions. Such performance results from use of a carefully tested high-quality crystal as well as precision temperature control, inherently stable circuitry, and low power dissipation in the crystal.

In addition to good long and short-term stability, many applications also require a signal having a high spectral purity. This is essential where frequency multiplication to microwave frequencies is performed. HP quartz oscillators are designed to specifically include these applications.

TIMEKEEPING — TIME INTERVAL AND EPOCH

Timekeeping has two distinct aspects: determination of epoch and determination of time interval. Epoch is when an event occurred; interval is the time between events and is independent of a starting point.

The search for a uniform time interval unit has lead to adoption of an atomic standard as was done for the unit of length (a meter is defined in terms of wavelengths of the orange-red line of krypton 86). The fundamental unit of time used is the second. The 1967 redefinition of the second, in terms of a certain hyper-fine transition in the Cs-133 atom, has realized a time scale more uniform than any previous scale. Prior to this redefinition, the time interval unit was based solely upon astronomical observations. The rates have been kept the same to insure continuity between time scales.

Time or epoch (sometimes referred to as time-of-day) is another matter. Time is currently measured in terms of the Coordinated Universal Time Scale (UTC) (22). The UTC Scale uses the atomic second (as of January 1, 1972) as its time interval and is adjusted as necessary to keep it within 0.7 seconds (may be raised to .95 as an upper limit) of the Universal Time Scale (UT1). The UT1 scale is based upon the rotation of the earth and is not a uniform scale since the earth's rotation is not uniform. This scale is used in applications involving the rotation of the earth such as celestial navigation by sea or air, the tracking of satellites and geodesy.

NBS and USNO provide the official basis for Standard Times for the United States (21). Local Standard Times usually differ from mean solar time (currently from UTC) by an integral number of hours. The United States Naval Observatory determines Universal Time and Ephemeris Time from astronomical observations referenced to UTC (USNO) and publishes weekly data which enables several different kinds of time used in scientific work to be obtained.

RADIO TIME SIGNALS

By its nature, time interval is not a standard which can be kept in a vault for reference purposes. Regular comparison to a recognized primary standard is a necessity.

Radio transmissions provide both data and time interval. Time signal emissions are broadcast by several VLF, LF, and HF stations around the world. A listing of these broadcast stations is contained in Appendix II. Time Interval Signals are received with greater precision from LORAN C and OMEGA stations. Time transfer techniques using these facilities, as well as other methods, are discussed in detail in AN 52-2.

If radio wave energy were propagated at a constant velocity and constant path with a noise-free background, frequency and time signals could be received with essentially the stability and accuracy of the primary source. Frequency would be received just as sent and time signals would have a constant delay, depending on distance from source, for which a simple correction could be applied. Actual propagation does not realize these ideal conditions, so systems must be designed to overcome or minimize limitations.

The high (3-30 MHz) and low (30-300 kHz) frequency ranges have different characteristics because of the way these signals travel around the earth. High frequency signals propagate in a complex manner between the ionosphere and the earth to arrive at distant points. Variations of the ionosphere's ionic-profile and height above earth cause the propagation time of a signal to change continuously. Instabilities of high frequency propagation make it necessary to record data from stations such as WWV. Many days of data recordings are needed to average out the propagation anomalies and even approach a precision better than 1 part in 10^8. WWV signals are considered to be stable to 2 parts in 10^{11}, as transmitted. (Additional information is contained in AN 52-2.)

Transmission paths of low frequency and very low frequency (3-30 kHz) signals are far more stable. They follow the earth's curvature as though being guided by a duct having the ionosphere as a boundary rather than a reflector. Ionospheric variations have a much reduced influence. The resultant high phase-stability plus the long range coverage of the lower frequencies makes them valuable for standard frequency transmissions.

Many users still rely upon a high frequency service (for example, WWV) to set their clocks accurately. While it is relatively easy to control the rate of a clock by reference to low frequency signals, information bandwidth characteristics have limited, to some extent, the use of lower frequencies for time-of-day information and for time comparison measurements. To achieve high precision in clock synchronization, fast rise-time pulses are often used as precise time markers. At the lower frequencies, pulse rise-time is degraded by the time constants of the antenna systems and the receiving equipment. Research continues on improvement in the ability to synchronize accurately from VLF time signals.

LOCAL TIME REFERENCE

A precision time reference must be capable of providing the two basic aspects of time. First, it must provide a uniform time interval. This is derived from a very stable frequency source such as a cesium beam frequency standard. Secondly, it must have some way of providing time or time-of-day. To determine time or time-of-day is relatively easy. It requires the summing of uniform time intervals from a known starting point. The accurate initial setting of the clock is the difficult task. To set a local clock correctly, it must be referenced to a master clock. This initial setting is termed synchronization or time-transfer.

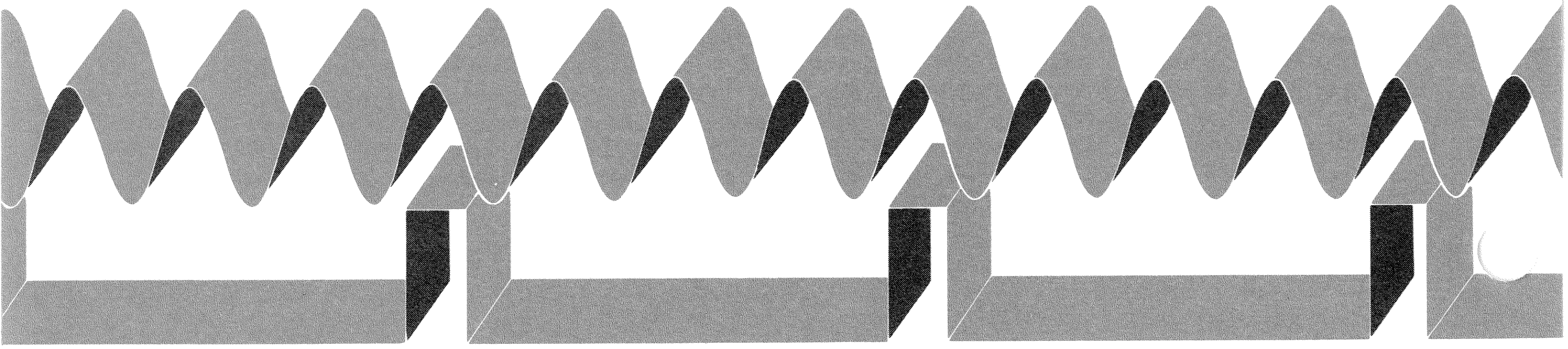
Precision time synchronization at great distances has been the subject of much study. HF radio time signal broadcasts are generally received worldwide to an accuracy of about one millisecond. Radio propagation time uncertainties make it difficult to improve very much upon this value, except by use of a specialized service such as LORAN C. This navigation service makes possible microsecond synchronizations within the area served by the ground wave of its radio transmitters.

Other ways found to yield microsecond accuracies using radio transmissions include the use of active relay satellities, clock-carrying satellites (Transit and Timation), passive reflectors such as the surface of the moon and meteor trails, microwave relay, and commercial television synchronizing pulses.

A unique method of correlating time over great distances, with better than microsecond accuracies, was demonstrated by the Hewlett-Packard series of "flying clock" experiments. The last experiment by HP, performed in autumn of 1967, utilized two 5061A Cesium Beam Frequency Standards to correlate time between 53 locations in 18 countries to about 0.1 microsecond. (33)

Both standards were initially phase-compared to the Hewlett-Packard "house frequency standard". One standard had no offset but the "C" field of the second standard was adjusted to bring its frequency into closer agreement (1 to 2 parts in 10^{13}) with the "house standard". At the end of the 41-day trip, the two flying clocks were found to have operated within 5 parts in 10^{13} of each other's average frequency. Compared to the Hewlett-Packard "house standard", one clock operated at an average of within 5 parts in 10^{13}, the other clock operated within 10 parts in 10^{13} of the average "house standard frequency". Flying clocks are now used by many operational groups to synchronize remote stations.

The improved portability, accuracy, and stability of the HP Cesium Beam Frequency Standard makes it relatively easy to correlate distant stations to better than microsecond accuracies.



SECTION II

TIME AND FREQUENCY STANDARDS

GENERAL

The demand continues for ever greater precision and accuracy in frequency control. Basic to such control is the atomic resonance standard with unprecedented frequency stability.

Atomic resonance standards use quantum mechanical effects in the energy states of matter, particularly transitions between states separated by energies corresponding to microwave frequencies. Transitions having properties well suited to use in standards occur in atoms of cesium, rubidium, thallium, and hydrogen.

Considerable attention has been directed to three devices: The cesium beam tube, the rubidium gas-cell resonator, and the hydrogen maser. The cesium and rubidium devices utilize passive atomic resonators to steer conventional oscillators, usually quartz crystal, via feed back control circuits. The hydrogen maser, an active device, derives its signal from stimulated emission of microwave energy, which may be amplified by electronic means to a useful power level, or used to steer a quartz oscillator.

Other devices which have been investigated as frequency standards are the ammonia maser, the methane stabilized laser, the rubidium gas-cell maser, and the thallium beam tube. The ammonia maser was attractive because of the high spectral purity and excellent short-term stability it offered. The rubidium maser is a more recent development which offered the prospect of exceptional spectral purity. The thallium beam tube offered greater relative precision and reduced magnetic field dependence. However, the cost, size, and complexity of these devices has limited their current use to the laboratory. The methane stabilized laser offers low cost, easy fabrication and excellent short-term stability. Disadvantage currently is that it operates in the infrared region and hence is difficult to use.

The cesium and hydrogen atomic standards are frequency standards which do not require a reference to insure that they are "on frequency" and as such are considered absolute standards of frequency. Frequency standards which must be referenced to an accepted source such as a cesium standard are the rubidium gas cell and quartz crystal oscillators.

Certain applications do not require the precision and accuracy available from quartz oscillators referenced directly to a primary atomic standard. Quartz oscillators referenced to national frequency standards by phase-comparisons with low frequency radio signals offer high accuracy at moderate cost. For example, the HP Model 117A VLF Comparator phase-compares a local frequency standard against the 60 kHz signal received from NBS station WWVB. A self-contained strip chart recorder plots the phase difference of the two frequencies, and provides a link between "house" frequency standards and NBS. Special versions of the HP 117A VLF Comparator are available to receive European stations. The H44-117A is designed to receive HBG (75 kHz) at Prangins, Switzerland, and the H88-117A is designed to receive MSF (60 kHz) at Rugby, United Kingdom.

ATOMIC FREQUENCY STANDARDS

In general, atomic frequency standards make use of an atomic resonance device to phase-lock a frequency source such as a voltage-controlled crystal oscillator. The atomic resonators are classified as being either passive or active devices. Cesium beam tubes and rubidium vapor gas cells are passive atomic resonators, whereas the hydrogen maser is an active resonator.

HYDROGEN MASER

The hydrogen maser as a frequency standard provides a frequency which is well defined without reference to any external (reference) standard. (1,8,10). A beam of atomic hydrogen is directed through a highly inhomogeneous magnetic field which selects atoms in states of higher energy and allows them to proceed into a quartz bulb (Figure 2-1). The quartz bulb confines the atoms to the uniform magnetic field region in a tuned microwave cavity set to the transition frequency of the hydrogen atom between the F=1, m_f=0, and F=0, m_f=0 energy levels. The quartz bulb has teflon coated walls to reduce perturbation of the energy states. However, a small perturbation of the atoms still occurs during collision with the wall and produces a frequency shift. This wall-shift can be accurately determined by careful frequency measurements.

Inside the coated quartz storage bulb the hydrogen atoms make random transits and are reflected at each encounter with the walls. The atoms undergo many collisions with the walls while in the bulb, and their effective interaction time with the microwave field is lengthened to about 1-second. During this interaction process, the atoms tend to relax and give up their energy to the microwave field within the tuned cavity. This field also tends to stimulate more atoms to radiate, thus building in intensity until steady-state maser operation is achieved.

The atomic hydrogen maser is the most stable of all known frequency sources for averaging times of a few seconds to about a day or more. It has proved to be a practical frequency source for a few specialized applications where these stabilities are critical and where its large size is not a consideration.

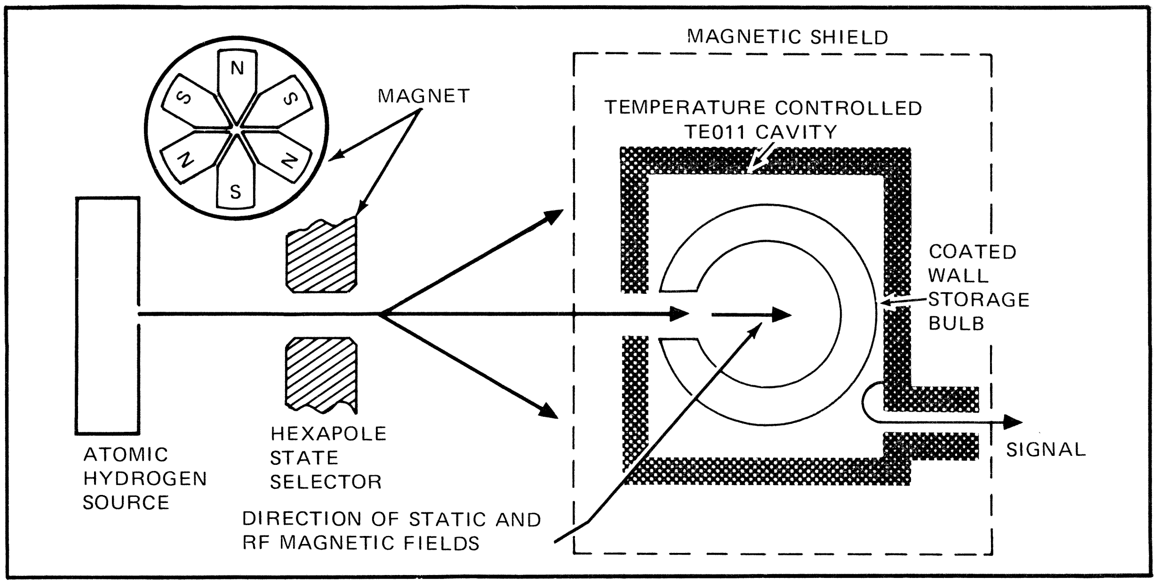


Figure 2-1. Diagram of the Hydrogen Maser

At the present time the hydrogen maser is primarily a laboratory-type device and has limited practical use as a commercial field instrument.

CESIUM BEAM STANDARDS

Cesium beam standards are in use wherever high precision and accuracy in time and frequency standards are the goals. Cesium beam units are the present basis for most of the national standards for frequency and time (see Appendix II).

For the cesium beam standard, the quantum effects of interest arise in the nuclear magnetic hyperfine ground state of the atoms. (1,11,12,13,14.) A particularly appropriate transition occurs between the F=4, m_f=0, and F=3, m_f=0 hyperfine levels in the cesium 133 atom. This transition arises from electron-spin, nuclear-spin interaction and is used for frequency control. The transition is relatively insensitive to external influences such as electric and magnetic fields and it has a defined frequency for unperturbed atoms at rest of 9, 192, 631, 770.0000 Hz.

A typical cesium beam device shown in Figure 2-2 takes advantage of this invariant transition. It is so arranged that cesium atoms in all sub-levels of states F=3 and F-4, leave an oven and are formed into a beam. The beam is deflected in a nonuniform magnetic field ("A" magnet) by a force component dependent upon F_0, m_f, the field, and the field gradient.

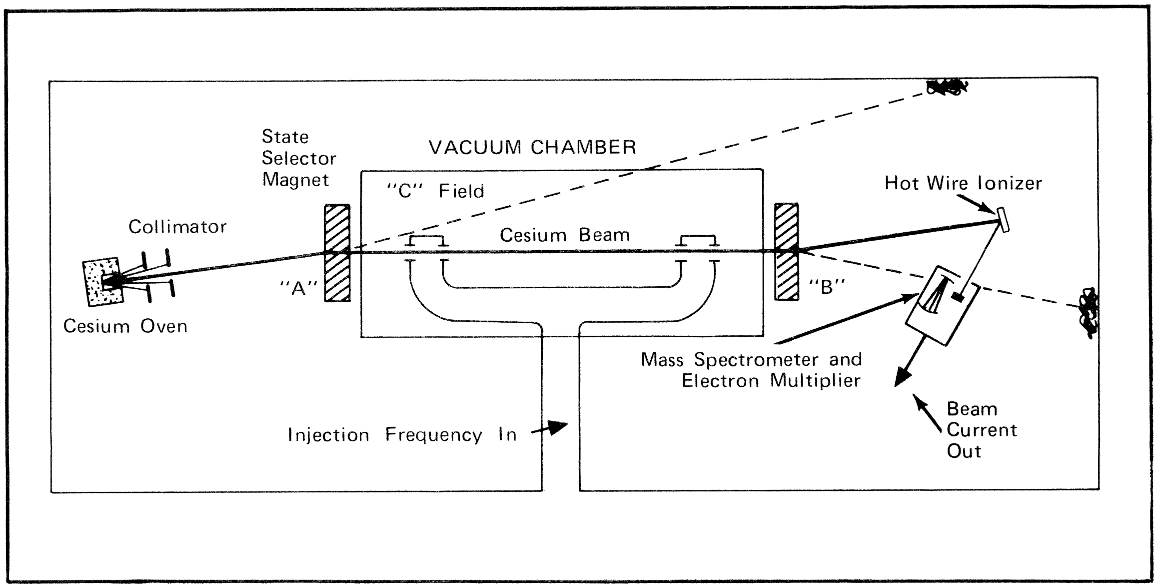


Figure 2-2. Beam Tube Schematic

The atoms in the F=3 sub-levels and the F=4, m_f=-4 sub-level are deflected into the microwave cavity while those in the remaining F=4 sub-levels are deflected out of the main beam (getters are used to capture the cesium atoms in the unwanted paths. The atoms in the F=3 sub-levels and F=4, m_f=-4 sub-level then pass through a low and uniform magnetic field space (C-Field) and are subjected to excitation by microwave energy.

For the control of frequency, the cesium atom is required to perform a resonance absorption of energy from the microwave exciting signal, corresponding to a transition from the 3,0 state to the 4,0 state. Upon passing through a second magnetic field (B magnet) identical to the first one, those atoms which have undergone the required transition are deflected toward the hot-wire ionizer. Cesium atoms, ionized by the hot wire, then pass through a mass spectrometer and are accelerated towards a multistage electron multiplier. Common contaminants which may cause noise bursts are removed by the mass spectrometer. Ion current is converted into electron current and amplified by the electron multiplier. Amplified current then passes through signal processing electronics which regulates the frequency of a voltage-controlled crystal oscillator. Oscillator output frequency is multiplied and fed back to the cesium beam through the wavequide, thereby closing the loop.

In the HP Model 5061A and 5062C Cesium Beam Standards, the microwave field is derived from a precision quartz oscillator by frequency multiplication and synthesis, and is phase-modulated at a low audio rate. When the microwave frequency deviates from the center of atomic resonance, the output current from the cesium beam tube contains a component alternating at the modulation rate. The amplitude of this component is proportional to the frequency deviation and also contains phase information which indicates the direction of deviation; that is, whether the frequency is above or below center frequency. This component is then filtered, amplified, and synchronously detected to provide a dc voltage used to automatically tune the quartz oscillator to zero error.

New cesium beam tubes exhibit frequency perturbations so small that independently constructed tubes compare within a few parts in 10^{12}. Outstanding reliability is obtained from these tubes with a presently guaranteed life of 3 years for the standard beam tube, and 14 months (10,000 hours) for the high performance beam tube.

Quartz crystal oscillators used exhibit superior characteristics even without control by the atomic resonator. Drift-rate is less than 5 parts in 10^{10} for 24 hours, and short-term stability is better than 5 parts in 10^{12} for a 1-second averaging time. The 5 MHz quartz crystal is housed in a proportionally-controlled oven. Output frequency variation due to temperature is less than 2.5 parts in 10^9 from 0°C to 50°C.

RUBIDIUM VAPOR STANDARD

The rubidium vapor standard, like the cesium beam standard, uses a passive resonator to stabilize a quartz oscillator. (1,15.) The rubidium standard offers excellent short-term stability in a relatively small and easily portable apparatus. It is not self-calibrating and during construction it must be calibrated against a reference standard such as the cesium beam frequency standard.

Operation of the rubidium standard is based on a hyperfine transition in rubidium 87 gas. The rubidium vapor and an inert buffer gas (to reduce doppler broadening among other purposes) are contained in a cell illuminated by a beam of filtered light (Figure 2-3). A photodetector monitors changes, near resonance, in the amount of light absorbed as a function of applied microwave frequencies. The microwave signal is derived by multiplication of the quartz oscillator frequency. A servo-loop connects the detector output and oscillator so that the oscillator is locked to the center of the resonance line.

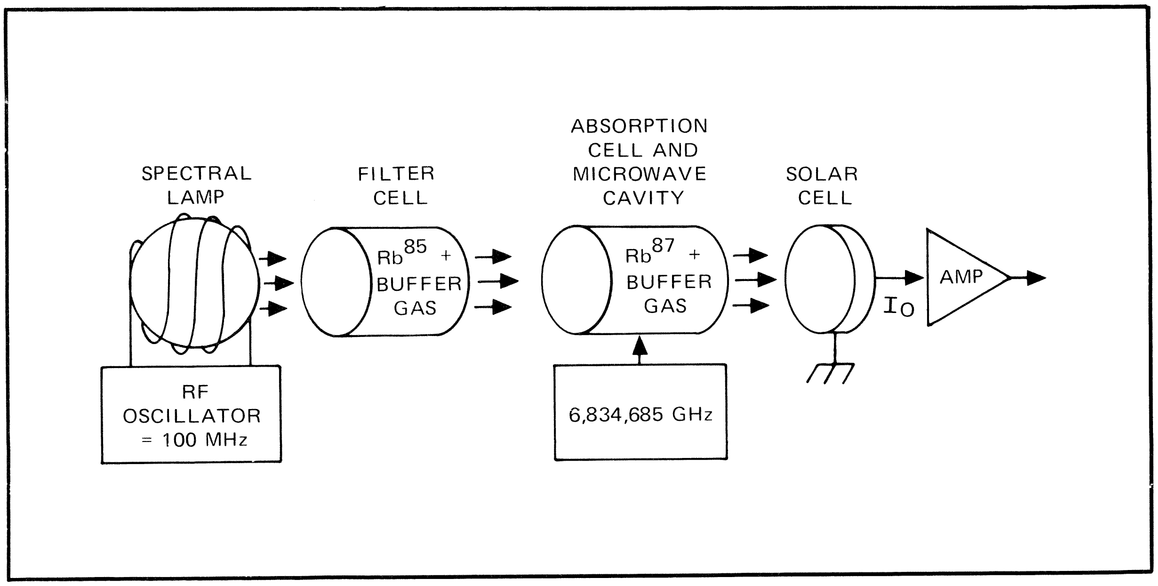


Figure 2-3. RVFR Assembly Block Diagram

By an optical pumping technique, an excess population is built up in one of the rubidium-87 ground-state hyperfine levels within the cell. Population of the F=2 level is increased at the expense of the F=1 level. Illuminated rubidium-87 atoms are optically excited into upper energy states from which they decay quickly into both the F=2 and the F=1 levels. Components linking the F=2 level to the upper energy states are removed by filtering the excitation light. Since the light excites atoms out of the F=1 level only, while they decay into both, an excess population builds up in the F=2 level. Because fewer atoms are in the state where they can absorb the light, the optical absorption coefficient is reduced.

Application of microwave energy, corresponding to that which separates the two ground state hyperfine levels F=2 and F=1, induces transitions from the F=2 to F=1 level so that more light is absorbed. In a typical system arrangement, photodetector output reaches a minium when the microwave frequency corresponds to the rubidium 87 hyperfine transition frequency of 6,834, 682,614 Hz.

Resonance frequency is influenced by the buffer gas pressure and to a lesser degree by other effects. For this reason, a rubidium vapor standard must be calibrated against a reference standard. Once the cell is adjusted and sealed, the frequency remains highly stable.

Hewlett-Packard's Model 5065A Rubidium Vapor Frequency Standard exhibits an extremely low drift-rate of less than 1 part in 10^{11} per month and a short-term stability of better than 5 parts in 10^{12} averaged over a 1-second period.

QUARTZ OSCILLATORS

The striking properties of the quartz crystal oscillator give it such an advantage over all earlier frequency stable systems, such as those relying on tuning fork resonators, that its use for exacting measurements of frequency and time quickly became almost universal in national and industrial laboratories around the world. (1,16,17.)

Crystalline quartz has great mechanical and chemical stability and a small elastic-hysteresis (which means that only a small amount of energy is required to sustain oscillation). These are most useful in a frequency standard. The piezoelectric properties of quartz make it convenient to use in an oscillator circuit. When quartz and certain other crystals are stressed, an electric potential is induced in nearby conductors; conversely, when such crystals are placed in an electric field they are deformed a small amount, proportional to field strength and polarity. This property by which mechanical and electrical effects are linked in a crystal is known as the "piezoelectric effect."

In use, a quartz resonator is mounted between conducting electrodes. Electrodes are thin, metallic coatings deposited directly on the crystal by an evaporation process. Mechanical support is provided on the crystal at places chosen to avoid any inhibition of the desired vibration. If possible, the mounting is such that unwanted vibration modes are suppressed. An alternating voltage applied across the crystal causes it to vibrate with a preference for the mechanical resonance frequency of the crystal.

When the resulting two-terminal resonator is connected into a circuit it behaves as though it were an electrical network. It is so located in the oscillator circuit that its equivalent electrical network becomes a major part of the resonant-circuit which controls the oscillator frequency.

Improvements in quartz-crystal oscillator-stability have been in three main areas:

1. Increased precision in temperature control.
2. Improved cutting, mounting, and sealing techniques.
3. Improved control to keep driving power to the crystal low and constant.

An inherent characteristic of crystal oscillators is that their resonant frequency changes with age. This "aging rate" of a well-behaved oscillator is almost constant. After the initial aging period of a few days to a month, the rate can be considered constant with small variations. Once the aging rate is measured, it is usually easy to apply corrections to remove its effects from data. However, over a long period, the accumulated error due to drift could become serious. For example: a unit with drift rate of 5 parts in 10^{10} per day could accumulate an error of several parts in 10^{8} in a year. Thus, periodic frequency checks and corrections are needed to maintain a quartz crystal frequency standard.

Long-term stability of Hewlett-Packard's Model 105A/B Quartz Oscillator and Model 10544 component quartz oscillator is conservatively rated at less than 5 parts in 10^{10}/day. Substantially better performance is experienced under normal operating conditions.

TIME INTERVAL STANDARDS (Clocks)

Clocks and Frequency Standards have no fundamental differences. They are based upon dual aspects of the same phenomenon: a clock counts the number of cycles in a given period.

As a practical matter, a standard of frequency can serve as the basis for time measurement, and vice-versa, with certain restrictions. To avoid errors, when a frequency standard is used to maintain time, either interval or epoch, care must be taken to reference the frequency to the time scale of interest (sidereal, UTC, etc. — see Appendix I).

A time interval standard or clock has to have two basic capabilities. It has to be able to provide a very stable and precise time interval as well as able to count the total number of (standard) time unit intervals from a preset condition or epoch (time-of-day). Application Note 52-2 discusses timekeeping in detail including the aspects of instrument calibration and time transfer.

POWER SUPPLY CONSIDERATIONS

Continuous operation is important to a frequency standard system and is **vital** to a time reference for without power time is lost and resynchronization is necessary. Hewlett-Packard power supplies designed for use with standards systems provide power for continued operation in the event of external power failure, or while the system is being transported. Nickel-cadmium or lead-acid batteries supply the standby power.

Two power supplies specifically designed for use with time and frequency standard systems are the HP Model 5085A and HP Model K02-5060A. The HP 5085A requires an input of 115 or 230 Vac and provides an output of 24 Vdc. The HP K02-5060A will operate with input of 6, 12, 24-30 Vdc, and 115 or 230 Vac, and provide appropriate power to frequency standard instruments.

Both the HP 5085A and HP K02-5060A Power Supplies are designed with internal standby nickel-cadmium batteries floating across the regulated dc output to assume the load automatically in case of external power failure. The frequency or time standard system is not affected by any transfer of the load from the power supply to batteries or back again since no switching is used. When external power is restored the power supply automatically resumes the load, and if the external power is 6 or 12 Vdc (HP K02-5060A only) or 115/230 Vac, recharges the standby batteries.

Front panel lights on the HP 5085A and HP K02-5060A Power Supplies indicate whether operating power is ac or dc. Meters indicate both the voltage and current being supplied by the internal batteries. Provision is also made in the HP 5085A for the connection of an independent external alarm system.

IN-PLANT DISTRIBUTION OF STANDARD FREQUENCIES

In many applications very stable frequencies must be provided to more than one location. In a manufacturing plant, for example, standard frequencies may be needed in the production area for calibration of counters, synthesizers, signal generators, etc. At the same time, standard frequencies may be needed in the R&D lab for testing designs. These applications could be handled by providing several frequency standards; or by using a master frequency standard and distribution amplifiers, the standard frequencies could be "piped" throughout the user's facility. Another application requiring the use of a distribution amplifier would be where several receivers or transmitters need to have their local oscillators controlled by the same frequency standard.

At Hewlett-Packard, Santa Clara, a distribution system carries the reference frequency to terminals at individual workbenches which are remote from the standards laboratory. A distribution system using HP 5087A Distribution Amplifiers designed specifically for this purpose, isolates and protects the reference standard from noise and spurious signals generated in the distribution lines.

While a distribution system of shielded cables can successfully deliver average frequency (the correct number of cycles for a long interval of time), it is quite difficult to maintain the delivered signal at a high level of spectral purity. Amplifiers may introduce noise and sometimes distortion.

Electrostatic and electromagnetic fields and ground-currents can introduce unbalance currents which appear at the far end of the system as phase changes in the signal. Even if use of carefully shielded and balanced lines have kept electrical interference to a minimum, phase changes can arise from temperature changes.

In work areas where signals of high spectral purity are required, Hewlett-Packard uses separate frequency standards. These standards are referenced to the "house" standard by signals carried over the distribution system. Such a comparison removes any short-term variations arising in the distribution system. Where signal purity requirements are moderate, crystal filters at the system output can reduce noise to a reasonable level.

Telephone lines and cables are generally not suitable to distribute standard frequencies because of the limitations previously discussed. Clocks, however, can be operated from a signal carried over wire lines. The clock mechanism serves as an integrator to remove the effects of noise. Carrier systems are not suitable for frequency standard work since most use a suppressed-carrier transmission. When the receiving terminal does not reinsert a carrier of the exact frequency used by the transmitter, errors are caused in all frequencies transmitted through the system.

SUMMARY

This application note provides an introduction to the various types of time and frequency standards as well as some of the considerations in setting up a time and frequency standard system. Additonal information can be obtained from the references listed in the Bibliography.

Table 2-1 lists several Hewlett-Packard precision frequency sources, their features, and characteristics.

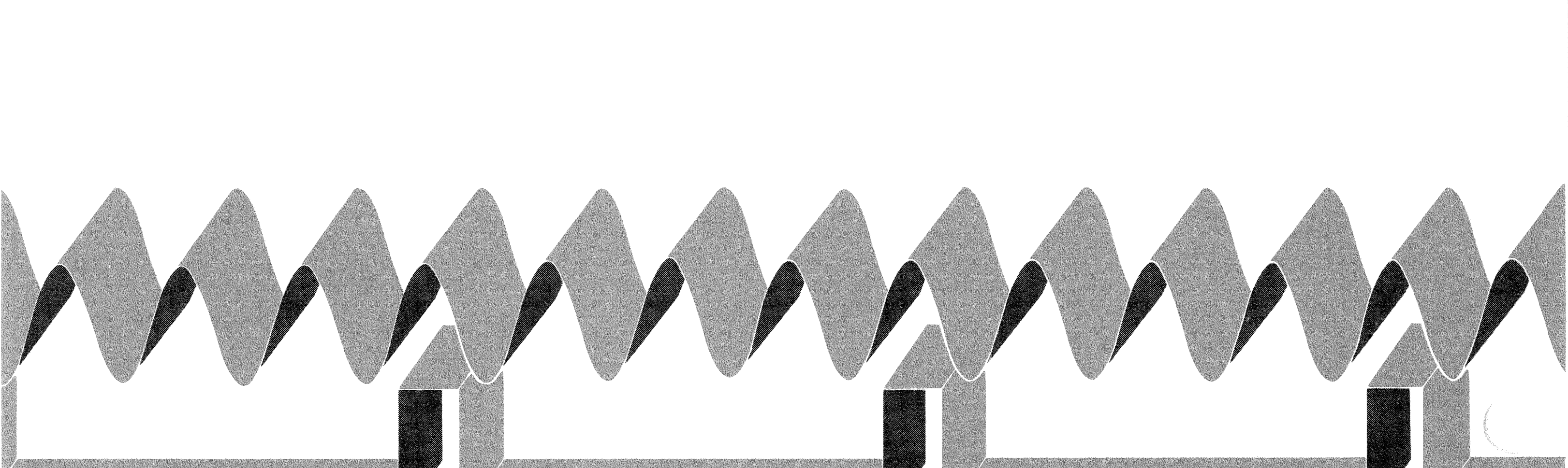
Table 2-1. HP Precision Frequency Sources

Instrument	**5061A with Option 004 (1)**	**5061A with Std. Tube**	**5062C**	**5065A**	**105A**
Type:	Cesium	Cesium	Cesium	Rubidium	Quartz
Drift: (Aging Rate)	Neglible	Neglible	Neglible	±1x10^{-11}/mo	±5x10^{-10}/day
Intrinsic Accuracy: (2)	±7x10^{-12}	±1x10^{-11}	±3x10^{-11}	NA	NA
Reproducibility:	±3x10^{-12}	±5x10^{-12}	±1x10^{-11}	—	—
Settability:	±1x10^{-13} (3)	±7x10^{-13}	±2x10^{-12}	±2x10^{-12}	—
Short Term Stability: (1 sec avg)	5x10^{-12}	5.6x10^{-11}	7x10^{-11}	5x10^{-12}	5x10^{-12}
Warm-up: from 25°C	30 min	45 min	20 min from -28°C	5x10^{-11} within 4 hr.	1x10^{-9} within 30 minutes
Operating Temperature:	0 to 50°C	0 to 50°C	-28°C to +65°C	0 to 50°C	0 to 50°C
Size:	8¾″ x 16¾″ x 18⅜″	8¾″ x 16¾″ x 18⅜″	5¼″ x 16¾″ x 21″	5-7/32 x 16¾″ x 18⅜″	3-5/32 x 16¾″ x 13¼″
Weight: (No Options)	70 lbs	67 lbs	50 lbs	34 lbs	16 lbs
Warranty:	3 yrs instrument 14 mos. on tube	3 years	1 year	1 year instrument 3 yrs. RVFR	1 year
Features:	High intrinsic reproducibility and long term stability.	Accepted and used worldwide as the basic unit in high accuracy systems.	Built to operate under tough environmental conditions.	Compact and light weight. Excellent spectral purity. Low cost Atomic frequency Std.	Compact, light, and rugged. Inexpensive.

NOTES: (1) Option 004 = High Performance Beam Tube.

(2) Maintained over operating temperature range and magnetic fields up to 2 gauss or any combination thereof.

(3) With HP 10638A Degausser.



APPENDIX I

TIME

INTRODUCTION

Mankind has long sought the ideal reference standard; one which would not only provide a uniform time scale, but also the means to extrapolate from it a small interval or an extended period. This search resulted in the adoption of the atomic second in 1967. This new standard far surpasses in excellence any previously known standard, not only for time, but for any physical parameters.

In 1958, Ephemeris Time (ET) was established, based on the orbital motion of the earth about the sun at the beginning of the year 1900. Ephemeris Time is the culmination of age-old attempts to discover an invariant astronomical reference, first in the earth's rotation on its axis and later in its motion about the sum. Ephemeris Time appears to give the desired uniform reference. However, for reasons still to be discussed, it is neither easy to arrive at nor practical to compare against.

A solution to this problem was arrived at by the General Conference of Weights and Measures. A hyperfine transition in the atom of Cesium 133 was tentatively adopted in 1964, then fully adopted in 1967 as the uniform time reference. A time interval of great uniformity based on this transition has been defined as the atomic second. Careful measurements have related this new second to Ephemeris Time, and the atomic second is today's universal time unit.

This appendix to Application Note 52-1 discusses, in some detail, standards of time in the context of their historical development. The various time scales — Apparent Solar Time, Mean Solar Time, Ephemeris Time and others — are described. Appendix II discusses National Standards of time and frequency, and how time-and-frequency standards are made available through radio broadcasts. Appendix II also includes a list of worldwide frequency and time standard broadcast stations.

APPARENT SOLAR TIME

For many centuries, the time reference used was the rotation of the earth about its axis with respect to the sun. A unit of time derived from observations of the apparent movement of the sun will be a constant value only if the sun reappears over a fixed point of observation at uniform intervals. As man has increased the precision with which astronomical observations can be made, it was found that the rotation of the earth does not represent a uniform time scale. Even after all possible corrections are made for the known regular variations in the measurement conditions there still remain secular and irregular variations in the rotational speed of the earth which cause corresponding changes in this type of time scale.

An apparent solar day is dependent upon the motion and orientation of the earth and the position of the sun. Measurements made with a sun dial, for example, give apparent time since it is in terms of the actual relative position of the sun. If the earth's orbit were a perfect circle and lay in the plane of the equator with uniform rotation, the length of an apparent day would remain fairly constant throughout the year.

Earth's orbit, however, is not circular; it is elliptical and the orbital plane does not coincide with the plane of the equator; it is at an angle of 23°27′ to it. Therefore, apparent days vary in length. The orbital speed of an object whose path describes an ellipse is constantly changing. The earth, as viewed from the sun, moves faster along that part of the orbit nearest the sun than at other times. Figure AI-1 shows how this affects solar measurements. The difference between Apparent Solar Time and Mean Solar Time is called the equation-of-time. It has its maximum value early in November when the difference is about 16 minutes.

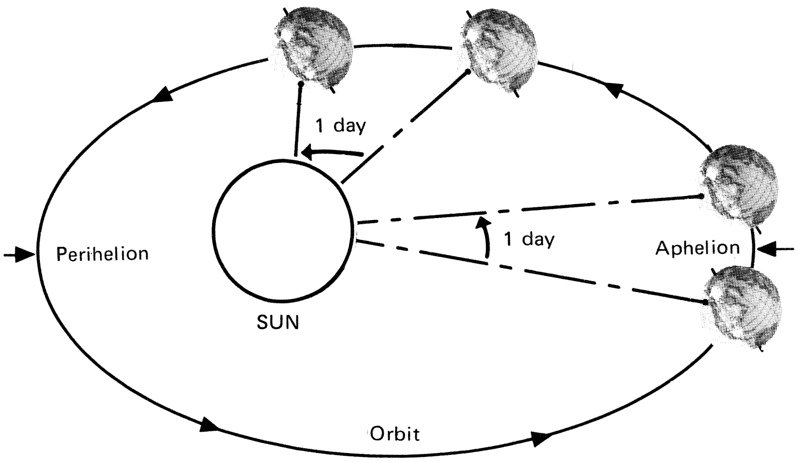


Figure AI-1. Earth's Orbital Motion Exaggerated to Show Varying Effects on Apparent-Solar-Day

MEAN SOLAR TIME

Mean Solar Time is simply apparent time averaged to eliminate variations due to orbital eccentricity and the tilt of the earth's axis. A mean solar day is the average of all the apparent days in the year and a mean solar second is equal to a mean solar day divided by 86,400. As a fundamental unit of time, the mean solar second is inadequate because it is still tied to the rotation of the earth which is now known to be nonuniform.

The solar, or tropical, year is a measure of the period of the earth's orbit, as defined by observation of the time from Vernal Equinox-to-Vernal Equinox. Vernal Equinox occurs about March 20, and is the time when the sun moves from the southern hemisphere to the northern hemisphere in its apparent motion along the ecliptic. If extended into space (see Figure AI-2), the earth's axis of rotation meets the apparent celestial sphere at two points called the "north celestial pole" and the "south celestial pole." Ninety degrees from these two points, is a great circle known as the "celestial equator" which is an extension of the plane of the earth's equator. During the annual revolution of the earth about the sun, the sun appears to move among the stars. The apparent path of the sun is called the "ecliptic." The ecliptic is inclined at an angle of 23° 27′ to the plane of the earth's equator. Time to travel from Vernal Equinox-to-Vernal Equinox along the ecliptic, then, is one solar year, as is shown in Figure AI-2. A solar year is presently equal, in Mean Solar Time, to 365 days, 5 hours, 48 minutes and 45.5 seconds, or in decimal form, 365.2422 mean solar days.

Because the solar year by which we reckon time is 365 days plus a fraction, corrections must be made to our calendar at various times in order to make the data correspond with the position of the sun.

UNIVERSAL TIME

As with Mean Solar Time, Universal Time (UT) is based on the rotation of the earth about its axis; the units UT were chosen so that on the average, local noon would occur when the sun was on the local meridian. UT, thus defined, made the assumption that the rotation of the earth was constant and that it would, therefore, be a uniform time scale. It is now known that the rotation

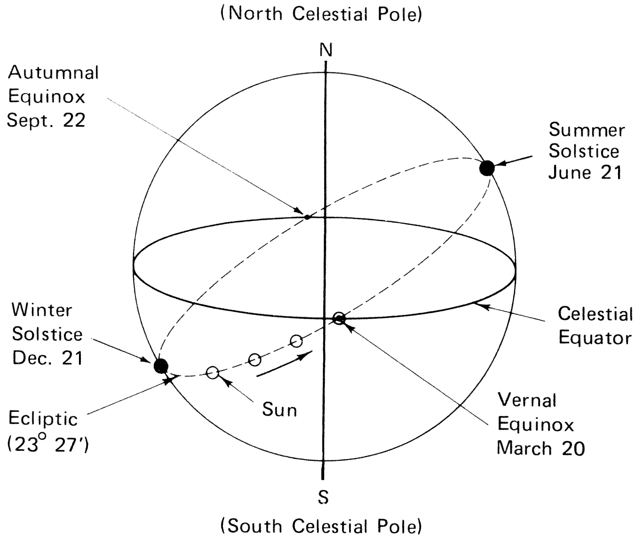


Figure AI-2. Path of Ecliptic Traced by Position of Sun as Earth Moves About It

of the earth is subject to periodic, secular, and irregular variations, and Universal Time is subject to these same variations. When uncorrected, the units of Universal Time are equivalent to the mean-solar-second, and are identified as a time scale by the designation UT_0 (UT_0 is mean solar time at Greenwich).

Correction to UT_0 has led to two subsequent universal time scales: UT_1 and UT_2. UT_1 recognizes that the earth is subject to polar motion. The effect of this polar motion produces an error to any uncorrected measurement of the earth's angular rotation. Figure AI-3 illustrates this. UT_1, then, is a time scale based on the true angular rotation of the earth about its axis.

The UT_2 time scale is UT_1 with an additional correction for seasonal variations in the rotation of the earth. These variations are apparently caused by seasonal displacement of matter over the earth's surface, such as changes in the amount of ice in the polar regions as the sun moves from the southern hemisphere to the northern hemisphere and back again through the year. This cyclic redistribution of mass acts on the earth's rotation since it amounts to seasonal changes in its moment of inertia.

COORDINATED UNIVERSAL TIME (UTC)

Prior to January 1, 1972, to approximate UT in laboratories, the frequency of a precision oscillator such as a cesium or rubidium clock was offset from its nominal frequency by an amount that allowed the clock rate to be nearly coincident with UT_2. Small differences were corrected periodically (called step-time adjustments) to maintain synchronism with UT_2. The changes in offsets and step-time adjustments were accomplished simultaneously throughout the world, through the announcements made by the "Bureau International de l'Heure" (BIH). This method of timekeeping is identified as Coordinated Universal Time (UTC).

On January 1, 1972, the UTC system was improved to allow UTC time to accumulate at the same rate as International Atomic Time, and thereby eliminate the problems of operating systems with frequency offsets. At the same time, the step-time adjustments were changed from .1 to 1-second.

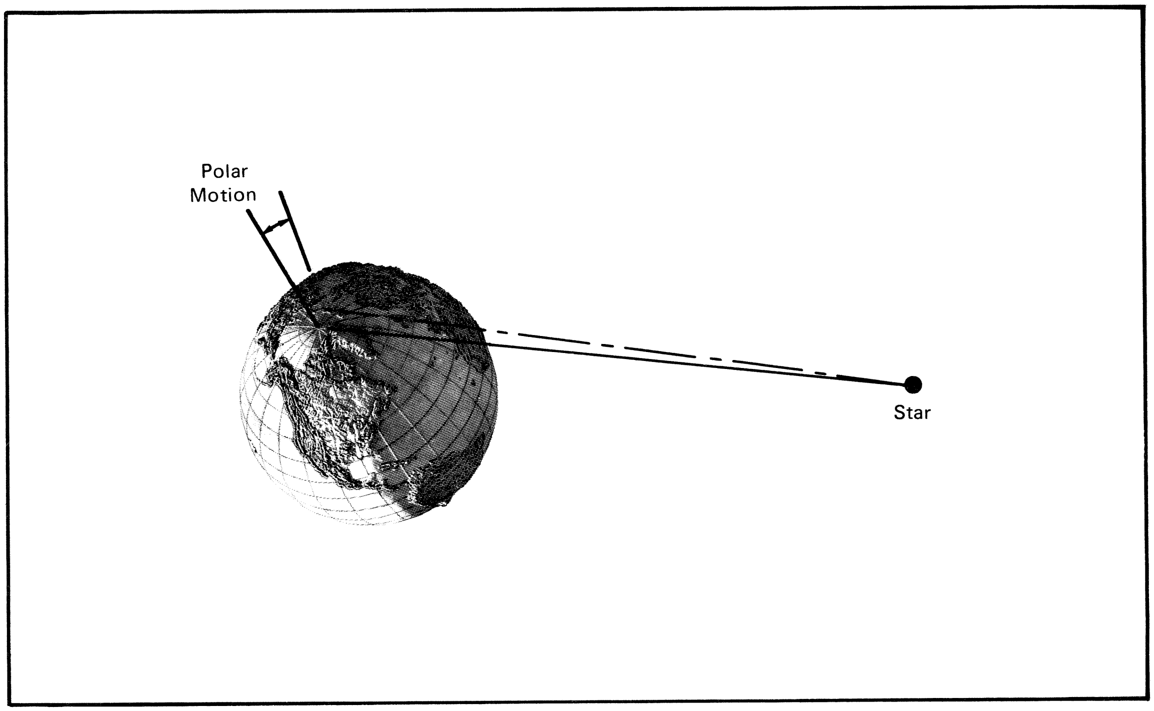


Figure AI-3. Polar Motion Changes the Apparent Position of a Fixed Point of Observation with Respect to a Celestial Body

The step-time adjustments are now called "leap seconds." The leap seconds are introduced into UTC time to keep synchronism with UT_1 to within ±0.7 seconds (this may be raised to ±0.95 seconds). These adjustments, when required, should be made on the last day of a UTC month, preferably December 31 and/or June 30. Table AI-1 provides a history of offsets and step-time adjustments in UTC since January 1, 1961.

Table AI-1. Offsets and Step Adjustments of UTC

Date (O h UT)	**Frequency Offset ($x10^{-10}$)**	**Steps (seconds) UTC (new) — UTC (old)**
1961 Jan 1	-150	
Aug 1	-150	+0.050
1962 Jan 1	-130	
1963 Jan 1	-130	-0.100
1964 Jan 1	-150	
Apr 1	-150	-0.100
Sep 1	-150	-0.100
1965 Jan 1	-150	-0.100
Mar 1	-150	-0.100
Jul 1	-150	-0.100
Sep 1	-150	-0.100
1966 Jan 1	-300	
1968 Feb 1	-300	+0.100
1972 Jan 1	0	-0.1077580
Jul 1	0	-1.0
1973 Jan 1	0	-1.0
1974 Jan 1	0	-1.0

APPARENT SIDEREAL TIME (EQUINOCTIAL)

For various astronomical applications it is desirable to have a time scale which is referenced to the relative position of the stars with respect to the rotation of the earth. Time defined in this manner is called Sidereal Time.

The intersection of the plane of the earth's equator with the ecliptic provides a fundamental reference point called the "true Vernal Equinox" or "first point of Aries" which is the first constellation of the Zodiac to transit the true equinox. The time interval between two successive meridian transits of the true Vernal Equinox is called a true sidereal day. The true equinox is not fixed with respect to the system of stars (constellations) against which it is measured. This point moves very slowly along the ecliptic in a retrograde direction in a period of 25 millenium. This secular or steady motion is called precession. The periodic or oscillating part of the motion is called nutation. By way of comparison, a mean-solar-day is also obtained, in practice, from observations of the stars, but the measurement of rotation is referenced to the sun.

A sidereal "day" contains 24 sidereal hours, each having 60 sidereal minutes of 60 sidereal seconds. In Mean Solar Time, a sidereal day is about 23 hours, 56 minutes, and 4.09 seconds. The time difference in the two "days" is due primarily to the earth's motion about the sun and from the motion of the equinox (precession).

What happens is that during the course of a day, orbital motion causes the sun to appear to move slightly to the east among the stars. Even if the earth did not rotate, the sun would appear to move eastward completely around the earth during one period of the earth's orbit. The effect of this apparent motion is that the day referenced to the sun is 3 minutes, 56.5 seconds longer than the day referenced to the stars. Figure AI-4 shows these relationships. For the same reason a solar year will contain 366.24+ sidereal days, or one more than the number of mean-solar-days.

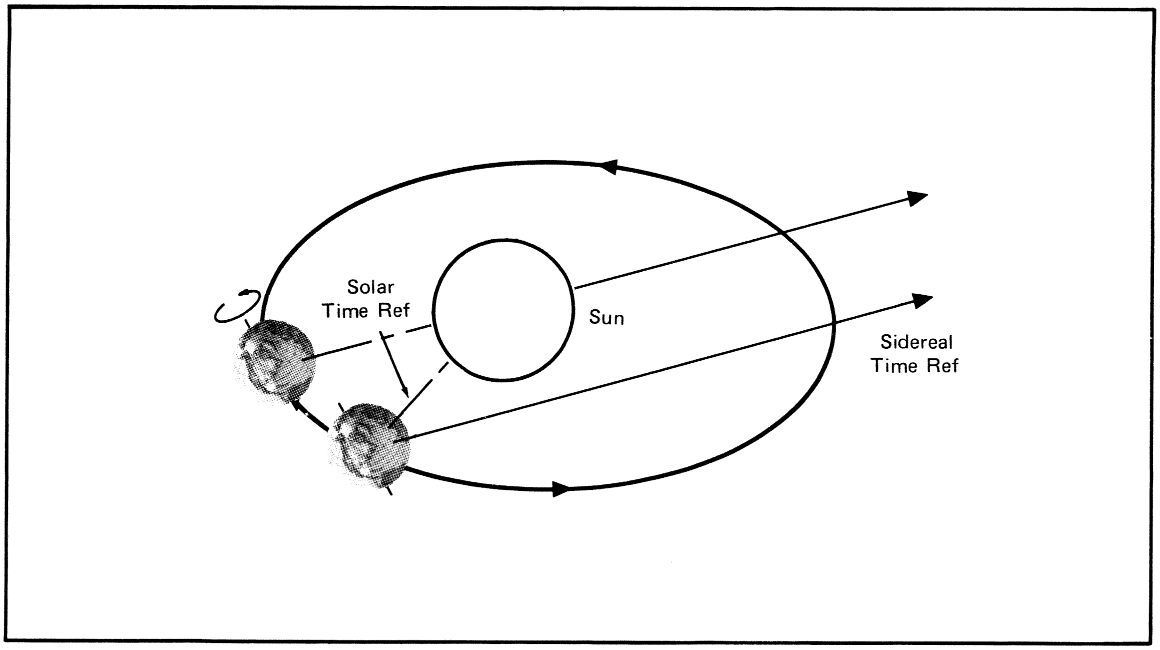


Figure AI-4. Since the length of the solar day is referenced to the sun, orbital motion lengthens the solar day over what it would be if the earth were fixed in position. Sidereal time is referenced to distant stars; orbital motion is of no consequence.

A sidereal year is a measure of the exact period of revolution of the earth around the sun. It is the true time interval required for the earth to move from a position of alignment with a given star as seen from the sun to the same position of alignment again. This is illustrated in Figure AI-5.

Compared to the length of the solar, or tropical, year of 365.2422 mean-solar-days, the sidereal year is longer by about 20 minutes. The reason is that the solar year is based on the Vernal Equinox, not on the period of the earth with respect to a fixed point on the orbit. Since the

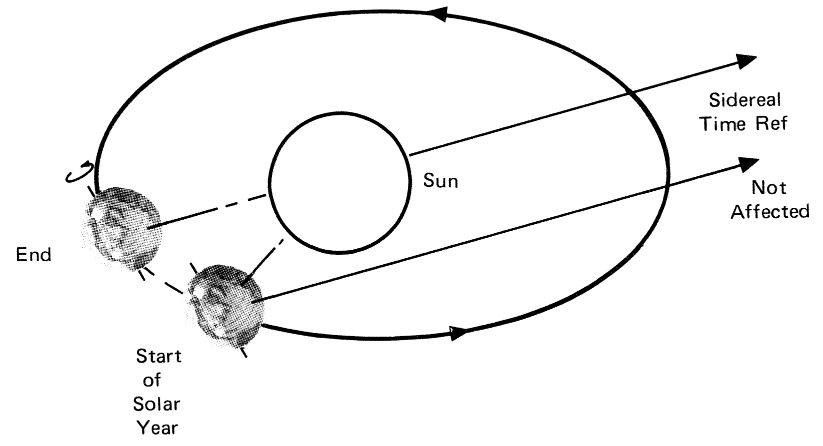


Figure AI-5 Precession of the Equinoxes Causes the Solar Year to be About 20 Minutes Shorter than the Sidereal Year

equinoxes are subject to precession, the true Vernal Equinox does not occur at precisely the same point on the orbital path from year-to-year. Therefore, the solar year differs from the sidereal year. Since the precession is westward, the equinox occurs sooner than it would if there were no motion of precession.

Precession of the equinoxes is due to change in the direction of the earth's axis of rotation. This movement is similar in nature to the precession of a spinning top when subjected to a lateral force. In the case of the earth, the force is the gravitational pull exerted by the sun and the moon upon the bulge in the earth about the equator. As shown in Figure AI-6, this force causes the poles to move in a circular, but wavy, path. The circular motion is precession; the superimposed wavy motion is nutation. Nutation results from the fact that the forces causing precession are not uniform and depend on the relative positions of the sun and moon to the earth. For example, when the sun is directly over the equator it can cause no precession since, under this condition, the sun can exert no net force outside the plane of orbit. Precession of the equinoxes takes place at a very slow rate having a period of about 25 milleniums.

MEAN SIDEREAL TIME

Mean Sidereal Time is defined as "the hour-angle of the mean-equinox" or the equinox freed of nutation. The mean sidereal day is the interval between successive transits of the mean equinox. The difference between Apparent and Mean Sidereal Time is called "the nutation in right ascension or the equation-of-equinoxes" and varies from 0 to slightly more than 1-second.

Mean Sidereal Time differs from Apparent Sidereal Time because of the nodding or nutation of the earth's axis. Sidereal time is not influenced by the orbital motion of the earth, since the stars that are observed are so very distant that their apparent positions do not vary as the earth moves about the sun.

Because the difference between Mean and Apparent Sidereal Time is so small, apparent sidereal time is the scale generally used by astronomers. Also, since sidereal time is based on the true rotation of the earth referenced to the stars, it provides a straight-forward unit by which to fix the position of stars for astronomical observations. In the course of a solar year, a clock keeping time in sidereal units will indicate 1 day more than it would indicate in mean solar units.

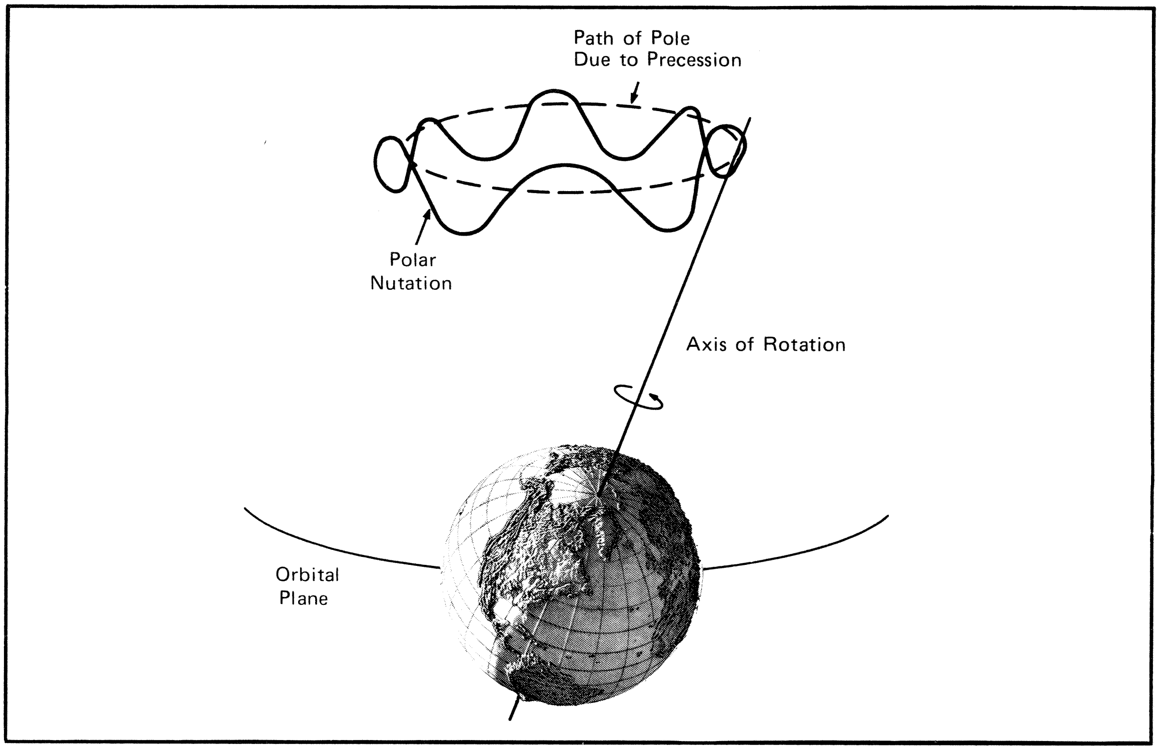


Figure AI-6. Nutation Superimposes a Seasonal Wavy Motion on the Circular Path of Precession

EPHEMERIS TIME

Ephemeris Time is time measured on the basis of orbital movements of planets, the moon, and other planetary bodies. An ephemeris is a table of coordinates which enables the prediction of position and movements of celestial objects. It is determined by mathematical formulae. Ephemeris is also the name given to the time value for the variable "t" in the equations of motion and their solution.

Earth's orbital motion about the sun is used as the standard to define the numerical measure of Ephemeris Time. Earth's position in orbit is obtained from observing the sun's position in relation to the stars. In practice, Ephemeris Time is based on the orbital motion of the moon by observing its position with respect to the stars. Coordinates of the moon, as a function of Ephemeris Time, are published. The lunar ephemeris contains a coefficient based on past observations, which is used to correct for the effects of lunar-solar tides on the earth.

In 1955, the International Astronomical Union adopted the definition of the Ephemeris Second as "1/31, 556, 925.9747 of the tropical year, for January 0, 1900 at 12 hours" (12 h, 0 m, 0 s ET January 0, 1900 = 24 h, 0 m, 0 s UT December 31, 1899). This definition was also adopted, in 1956, by the General Conference on Weights and Measures. The latter group, in 1967, officially adopted the transition between two energy levels of Cesium 133 as the new definition of the second. The tropical year for the moment of 12 hours, January 0, 1900, is the length the tropical year would be if the sun continued at its apparent instantaneous rate, corrected for orbital eccentricity and nutation of the earth's axis. The Ephemeris Second, thus defined, fulfilled the requirements for an invariant unit of time.

Tables published by Simon Newcomb of the USNO at the end of the 19th century gave the position of the sun for regular intervals. These intervals were originally thought to be in terms of UT until Newcomb discovered discrepancies. It is now recognized that ET is the actual scale and the tables may therefore be used at the basis for measuring ET. In other words, the Ephemeris Time scale places celestial bodies in repeatable astronomical relationship to each other, year after year.

INTERNATIONAL ATOMIC TIME (TAI)

The International Second was formally adopted in October, 1967, by the XIII General Conference of Weights and Measures. The Conference action based the definition on an invariant transition in the cesium atom.

The General Conference defined the second as "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom 133."

The atomic definition realizes an accuracy much greater than that achieved by astronomical observations. It results in a time base more uniform and much more convenient. Determinations can now be made in a few minutes, to a greater accuracy than was possible before in measurements that took many years. The new definition of the second is as close to agreement with the earlier Ephermeris definition as is experimentally possible.

International Atomic Time (TAI) therefore is the accumulation of atomic seconds from a particular date, January 1, 1958, when TAI was approximately in coincidence with UT2. On that day, the epoch of Atomic Time was made 0 h, 0 m, 0 s when UT_2 was 0 h, 0 m, 0 s.

TIME ZONES

The United States is divided into seven standard time zones. The time in each zone is an integral number of hours different from (earlier than) Mean Solar Time at Greenwich, which is almost (±1 sec) the same as UTC. The zones are: Eastern, 5 hours earlier; Central, 6 hours; Mountain, 7 hours; Pacific, 8 hours, Yukon, 9 hours; Alaska-Hawaii, 10 hours; Bering, 11 hours.

There are 24 world time zones based upon longitude. By international agreement, the central cross hair of an historic instrument called the Airy Transit Circle, in Greenwich, England, marks the Prime Meridian at 0° longitude. The Prime Meridian is an imaginary great circle, crossing both geographic poles. Standard time zones are established at intervals of 15° of longitude east and west of the Prime Meridian. Time zones in the United States are roughly centered along the meridians of 75°, 90°, 105°, 120°, 135°, 150°, and 165°. The exact boundaries of the time zones are modified by political and geographic considerations, but generally form a belt 7½°, on either side of the zone reference-meridian. A map, No. 76, depicting worldwide time zones is available from (current cost is $1.50):

United States Navy
Defense Mapping Agency
Hydrographic Center
Attn: MC2 Sales,
Washington, D.C. 20390

APPENDIX II

NATIONAL STANDARDS OF TIME AND FREQUENCY

A critical requirement for useful modern standards is that they be rigorously consistent along the entire chain of measurements traceable to international standards which represent fundamental units of mass, length, and time interval.

Numerous national and international organizations are responsible for maintaining national and international standards of time, time interval, and frequency. It is impossible in the space allocated in this appendix to adequately describe each agency and its relation to other agencies. Instead, a brief description of some of the services provided by a few agencies will be discussed. Additional information on other agencies can be found in the references listed in the Bibliography.

BUREAU INTERNATIONAL de l'HEURE (BIH)

The BIH was established in 1913 and is now one of the services of the Federation of Astronomical and Geophysical Services. The BIH acts as an international coordinating body for timekeeping services. Several monthly and annual publications are published by the BIH on time and time scale comparisons and other data on the various contributing national laboratories. The BIH Annual Report (3) is published in French in the odd years, and English in the even years. One of the major functions of the BIH is the establishment of UTC and TAI. TAI is computed by averaging the AT of individual instruments at several laboratories. UTC is an approximation of UT1 obtained from TAI as discussed in Appendix I.

Table AII-1 contains a list of the national laboratories collaborating with the BIH and the equipment in use at each laboratory. Additional information on periodicals of the BIH can be obtained by writing to:

United States

Superintendent
U.S. Naval Observatory
Washington, D.C. 20390

Other Countries

M. le Directeur
Bureau International de l'Heure
61, Avenue de l'Observatoire
75014 Paris, France

NATIONAL BUREAU OF STANDARDS (NBS)

The United States National Bureau of Standards (NBS) develops and maintains the atomic frequency and time interval standards for the U.S. The NBS also disseminates time and frequency via radio broadcasts. It additionally provides, by appropriate means, the calibration of corresponding standards of the United States' major scientific, commercial, and government agencies. Another NBS responsibility is cooperating in making scientific comparisons with standards of other nations.

The NBS, through the Frequency Time Broadcast Services Section of the Time and Frequency Division, operates four standard radio frequency transmitters. WWV (HF) and WWVB (LF) operate continously and are located in Fort Collins, Colorado. WWVL (VLF), also located in Fort Collins, now broadcasts experimental programs only on an intermittent basis. WWVH (HF) is located near Kekaha, Kauai, Hawaii, and operates continuously.

Information regarding NBS services is contained in an NBS publication:

NBS Special Publication 236
NBS Frequency and Time Broadcast Services
For Sale by the Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

Users of NBS frequency and time services may request to be placed on a mailing list for the "NBS Time and Frequency Services Bulletin" issued monthly to announce service changes and other useful information. Interested persons should write to:

Frequency-Time Broadcast Services Section, 273.02
Time and Frequency Division
National Bureau of Standards
Boulder, Colorado 80302

The NBS primary frequency standard has been maintained since 1920. Its precision has improved steadily and in 1960 markedly increased as a result of using the Atomic Cesium Beam as a frequency reference.

Arrays of secondary frequency and time standards at NBS consist of cesium beam standards and are referenced to the primary Atomic Cesium Beam Standard. To some of these secondary standards are added leap-seconds as determined by the "Bureau International de l'Heure" (BIH) as well as small rate adjustments for national and international coordination. These secondary frequency and time standards are used as a reference for the NBS Cesium Clock which provides UTC time.

The Fort Collins master cesium clock is compared daily to the NBS master clock by using the line-10 horizontal synchronizing pulses from a local television station. All other Fort Collins clocks and time-code generators are then compared with the Fort Collins master cesium clock. Frequency corrections to the Fort Collins oscillators are thus based on their phase-relation to the NBS master clock.

Transmissions from WWV, WWVB, and WWVH are controlled by three cesium beam frequency standards at each location. To insure accurate time-transmissions from each station, the time-code generators are compared with the Fort Collins station master clock, several times each day. Controls of the transmitted signals from WWVH is not only based on cesium standards, but also upon phase-locked signals received from WWVB. The cesium standards controlling the transmitted time signals and frequencies are continously compared with the NBS time scale with the transmitting station clocks. Figure AII-1 depicts the NBS frequency and time facilities.

UNITED STATES NAVAL OBSERVATORY (USNO)

The primary purpose of the United States Naval Observatory is to provide accurate time and astronomical data (Ephemerides) which are essential for safe navigation at sea, in the air, and in space. UTC (NBS) and UTC (USNO) are both coordinated with BIH to within ±5 μsec.

Continual observation of positions and motions of the sun, moon, planets, and principal stars is also maintained. From these observations and from "standard" cesium beam and hydrogen maser atomic clocks, precise time is determined. Additional observations are used in compilation of tables and star catalogues which are used in preparing annual navigational almanacs (Ephemeris) listing the predicted positions of celestial bodies.

The USNO controls distribution of precise time and time interval (frequency) from navy radio stations, satellites, and radio navigation (LORAN A&C) systems operated by the U.S. Coast Guard. The OMEGA VLF navigation system and the TRANSIT satellite navigation system are synchronized with the USNO master clock. Precise clock time is also distributed by the USNO to its time reference stations throughout the world. These stations are included in the list of transmitters in Table AII-4.

The USNO master clock is compared with observations in Washington, D.C. and Richmond, Fla. for Universal Time made by the Observatory on each clear night using photographic Zenith tubes (PZT). A PZT is a specialized telescope fixed in a vertical position and fitted for extremely accurate photographic observations of stars that transit near the Zenith.

As the stars transit the zenith of the (local) meridian, light from the star passes through the PZT lens and is reflected, by a mercury-filled container, onto a photographic plate. The photographic plate is secured by a motor-driven carriage to track the star being observed. Four 20-second exposures are made of each star, and between exposures the lens and plate are rotated 180°. The carriage motion during the exposures starts timing pulses which are read on a clock being compared to the stars. The clock reading, when the star transited the meridian, is determined by measuring the position of the star images. A comparison with the predicted time gives the clock correction. Data is published by the USNO on several different time scales.

The USNO publishes several periodicals relating to time services and dissemination. Additional information can be obtained by writing to:

Superintendent
U.S. Naval Observatory
Washington, D.C. 20390

TIME AND FREQUENCY BROADCASTS

Table AII-2 lists the national authorities and their addresses responsible for the time signal emissions. Table AII-3 lists the accuracies of the carriers of the standard frequency broadcasts. The last table in this section lists the national time signal broadcasts and their characteristics (Table AII-4). This data is extracted from the BIH 1972 Annual Report and is subject to change. The latest information on a particular station can be obtained by writing to the responsible authorities.

Table AII-1. National Laboratories Collaborating with BIH

ABBREVIATION	**LABORATORY**	**ATOMIC STANDARDS**		
		Qty.	**Mfr.**	**Type**
DHI	Deutsches Hydrographisches Institut, Hamburg, West Germany	1	HP	Cs Std
F*	Commission National de l'Heure, Paris, France	11 1	HP HP	CS Std CS Tube with lab electronics
FOA*	Research Institute of National Defence, Stockholm, Sweden	2	HP	Cs Std
IEN*	Instituto Elettrotecnico Nazionale, Torino, Ittaly	4	HP	Cs Std
IGMA	Instituto Geographico Militar Buenos Aires, Argentina	1	E	Cs Std
ILOM	International Latitude Observatory, Mizusawa, Japan	1	HP	Cs Std
MSO	Mount Stromlo Observatory Canberra, Australia	1	HP	Cs Std
NBS*	National Bureau of Standards, Boulder, Colorado	8 1	HP LAB	Cs Std Cs Std
NIS	National Institue for Standards, Cairo, U.A.R.	1	HP	Cs Std
NPL*	National Physical Laboratory Teddington, U.K.	4 1 1	HP Lab Hydrogen Maser	Cs Std Cs Std
NPRL	National Physical Research Laboratory, Pretoria, South Africa	1	HP	Cs Std
NRC*	National Research Council of Canada, Ottawa, Canada	3 1	HP Lab	Cs Std Cs Std

Table AII-1. National Laboratories Collaborating with BIH (Continued)

ABBREVIATION	**LABORATORY**	**ATOMIC STANDARDS**		
		Qty.	**Mfr.**	**Type**
OMSF*	Instituto y Observatorio de Marina, San Fernando, Spain	2	E	Cs Std
ON*	Observatoire de Neuchatel, Neuchatel, Switzerland	1 2	E HP	Cs Std Cs Std
ONBA	Observatorio Naval, Buenos Aires, Argentina	2		Cs Std
ONRJ	Observatorio National, Rio de Janeiro, Brazil			
OP*	Observatoire de Paris, Paris, France	4	HP	Cs Std
ORB*	Observatoire Royal de Belgique, Bruxelles, Belgique	1	HP	Cs Std
PTB*	Physikalisch-Technische Bundesanstalt Braunschweig, West Germany	6 1	HP Lab	Cs Std Cs Std
PTCH*	Direction generale des PTT Berne, Switzerland	1	E	Cs Std
RGO*	Royal Greenwich Observatory Herstmonceux, U.K.	5	HP	Cs Std
RRL	Radio Research Laboratories Tokyo, Japan	several	HP	Cs Std
TAO	Tokyo Astronomical Observatory, Tokyo, Japan	3	HP	Cs Std
TCL	Telecommunication Laboratories, Taiwan, Republic of China	2	HP	Cs Std
URE*	Ustav Radiotechniky a Electroniky, Prague, Czechoslovakia	1	HP	Cs Std
URSS	Laboratoire d'etat de l'etalon de temps et de frequence, USSR		Hydrogen Masers	
USNO*	United States Naval Observatory, Washington, D.C.	20** 1	HP Hydrogen Maser	Cs Std
ZIPE	Zentralinstitut Physik der Erde, Potsdam, East Germany			

NOTES: HP Cs Std = Hewlett-Packard Cesium Standard
E Cs Std = Ebauches S.A. Cesium Standard

*Laboratories contributing to TAI
**Selected from a large number of standards

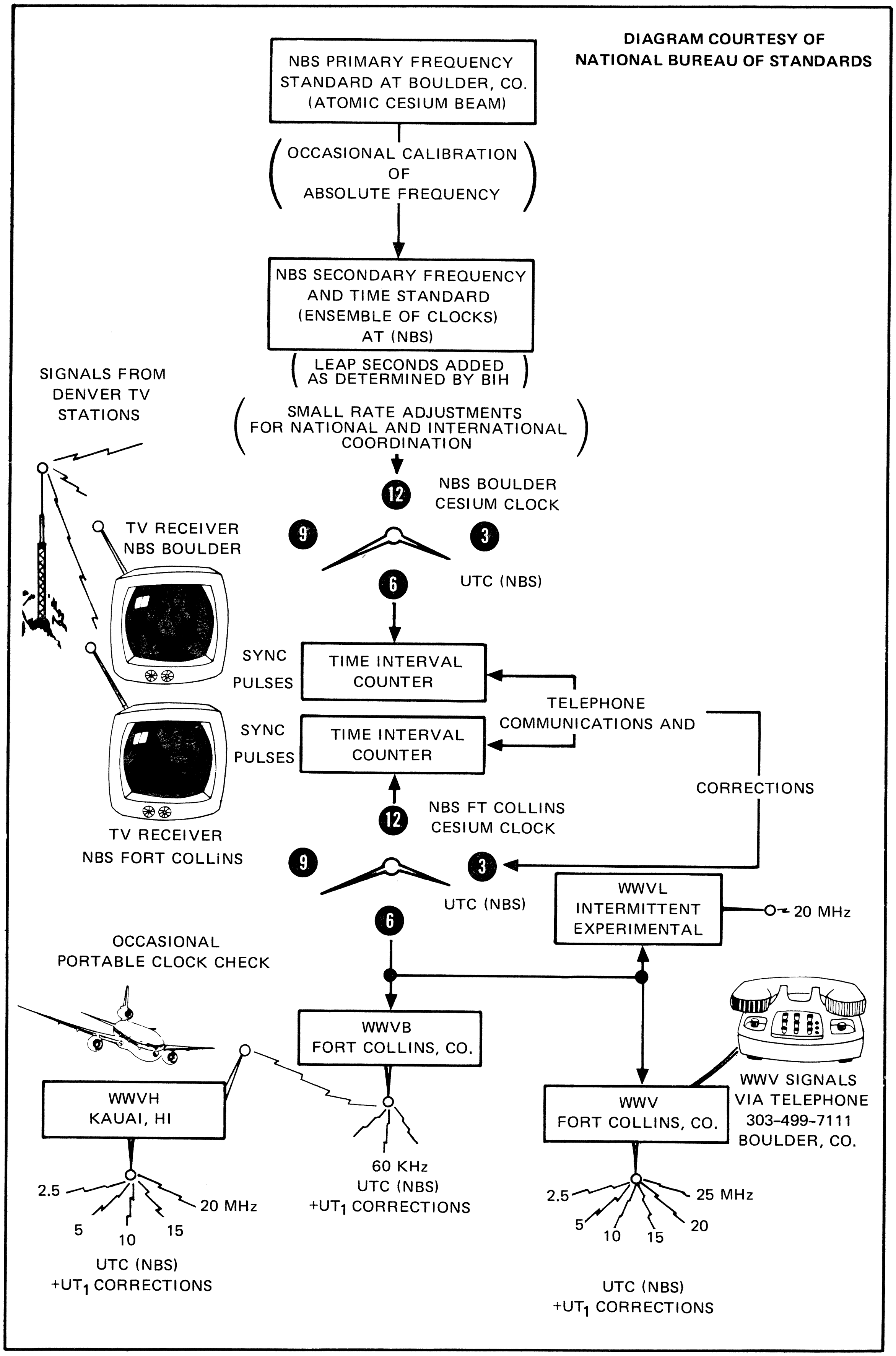


DIAGRAM COURTESY OF NATIONAL BUREAU OF STANDARDS

Figure AII-1. National Bureau of Standards Frequency and Time Facilities

Table AII-2. Authorities Responsible for the Time Signal Emissions

Signal	Authority
BPV, XSG	ZI-KA-WEI Section Shanghai Observatory Academia Sinica Shanghai, Peoples Republic of China
BSF	Telecommunication Laboratories Ministry of Communications Chung-Li P. O. Box 71 Taiwan, Republic of China
CHU	National Research Council, Time and Frequency Section Physics Division (M-36) Ottawa K1A OS1, Ontario, Canada, Attn: Dr. C.C. Costain
DAM, DAN, DAO	Deutsches Hydrographisches Institut 2 Hamburg 4, Federal Republic of Germany
DCF77	Physikalisch-Technische Bundesanstalt, Laboratorium 1.22 33 Braunschweig Bundesallee 100, Federal Republic of Germany
DGI	Amt fuer Standardisierung, Messwesen and Warenpruefung Fachabteilung Elektrizitaet Arbeitsgebiet Zeit und Frequenznormale DDR-102 Berlin Wallstrasse 16
DIZ	Central Earth Physics Institute Time Service DDR 15 Potsdam Telgraphenberg A 17
FFH	Centre National d'Etudes des Telecommunications Groupement Etudes spatiales et Transmissions Departement Dispositifs et Ensembles fonctionnels 38, rue du General Leclerc 92130 Issy-les-Moulineaux, France
FTA91, FTH42 FTK77, FTN87	Observatoire de Paris, Service de l'Heure, 61, avenue de l'Observatoire, 75014 Paris, France
GBR MSF	National Physical Laboratory, Electrical Science Division Teddington, Middlesex, United Kingdom
HBG	Service horaire HBG Observatoire Cantonal, CH - 2000 Neuchatel, Suisse
IAM	Istituto Superiore Poste e Telecomunicazioni Viale di Trastevere, 189 00100 - Roma, Italy
IBF	Istituto Elettrotecnico Nazionale Galileo Ferraris Corso Massimo d'Azeglio, 42 10125 - Torino, Italy

Table AII-2. Authorities Responsible for the Time Signal Emissions (Continued)

Signal	Authority
JJY, JG2AE	Frequency Standard Division The Radio Research Laboratories Ministry of Posts and Telecommunications Midori-cho, Koganei, Tokyo 184, Japan
LOL	Director Observatorio Naval Av. Costanera Sur, 2099 Buenos Aires, Republica Argentina
LQB9, LQC20	Servicio internacional de la Hora Gral. Savio 865 Villa Maipu San Martin, Pcia. de Buenos Aires Republica Argentina
NBA, NDT, NPG, NPM, NPN, NSS, NWC	Superintendant U.S. Naval Observatory Washington, D.C. 20390 U.S.A.
OLB5, OMA	1° - Time information: Astronomicky Ustav CSAV, Budecska 6, 120 23 Praha 2, Vinohrady, Czechoslovakia 2° - Standard frequency information: Ustav radiotechniky a elektroniky CSAV, Lumumbova 1, 180 88 Praha 8, Kobylisy, Czechoslovakia
PPE, PPR	Servico da Hora Observatorio Nacional Rua General Bruce, 586 2000 Rio de Janeiro, GB.ZC. -08, Brasil
RAT, RCH, RES RID, RIM, RKM RWM	Comite d'Etat des Normes Conseil des Ministres de l'URSS Moscou, USSR, Leninski prosp., 9
VNG	Time and Frequency Standards Section A.P.O. Research Laboratories 59 Little Collins Street Melbourne, VIC. 3000, Australia
WWV, WWVH WWVB	Frequency-Time Broadcast Services Section Time and Frequency Division National Bureau of Standards Boulder, Colorado 80302, U.S.A.
YVTO	Direccion de Hidrografia y Navegacion Observatorio Cagigal Apartado Postal N° 6745 Caracas, Venezuela
ZUO	National Physical Research Laboratory P.O. Box 395 Pretoria, South Africa

Table AII-3. *Accuracy of Standard Frequency Broadcasts*

Station	Accuracy of the carrier frequency in 10^{-10}
CHU	0.2
DCF77	0.02
FFH	0.2
GBR	0.2
HBG	0.02
IAM	0.5
IBF	0.1
JJY, JG2AE, JG2AS	0.5
LOL1	0.2
MSF (60 kHz)	0.2
MSF (h.f.)	1.0
NBA (V.L.F.), NDT	0.1
NSS (V.L.F.), NWC	0.1
OMA (all frequencies)	0.5
VNG	1.0
WWV	0.1
WWVB	0.1
WWVH	0.1
ZUO	0.5

Table AII-4. Time - Signals Emitted in the UTC System

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
BSF	Taiwan Rep. of China	5000	Between min 00-05, 10-15, 20-25, 30-35, 40-45, 50-55 from 0100-0900	Second pulses of 5 ms duration, Minute marker is pulse of 300 ms duration. During 29th and 59th min., Morse code and Chinese voice announcement of time. Second markers for DUT1 are pulses of 100 ms.
CHU	Ottawa Canada +45°18′ +75°45′	3330 7335 14670	continuous	Second pulses of 300 cycles of a 1 kHz modulation. Minute pulses are 0.5 s long. A bilingual (Fr.-Eng.) announcement of time is made each minute. DUT1: CCIR code by split pulses
DAM	Elmshorn Germany, F.R. +53°46′ - 9°40′	8638.5 16980.4 4625 8638.5 6475.5 12763.5	11 h 55 m to 12 h 6m 23 h 55 m to 24 h 6 m from 21 Sept. to 20 March 23 h 55 m to 24 h 6 m from 21 March to 20 Sept.	New international system, then Second pulses from minutes 0.5 to 6.0 (Minute pulses prolonged). A1 type. DUT1: CCIR code by doubling after Minute pulses 1 to 5
DAN	Osterloog Germany, F.R. +53°38′ - 7°12′	2614	11 h 55 m to 12 h 6 m 23 h 55 m to 24 h 6 m	As DAM (see above)
DAO	Kiel Germany, F.R. +54°26′ -10° 8′	2775	11 h 55 m to 12 h 6 m 23 h 55 m to 24 h 6 m	As DAM (see above)
DCF77	Mainflingen German, F.R. +50° 1′ - 9° 0′	77.5	continuous, except second Tuesday of every month from 4 h to 8 h	The Second marks are reduction to 1/4 of the carrier's amplitude of 0.1 s duration; the reference point is the beginning of the pulse modulation. The second 59 marker is omitted. DUT1: CCIR code by lengthening to 0.2 s
DGI	Oranienburg Germ. Dem. Rep. +52°48′ -13°24′	185	5 h 59 m 30 s to 6 h 00 m 11 h 59 m 30 s to 12 h 00 m 17 h 59 m 30 s to 18 h 00 m	A2 type Second pulses of 0.1 s duration for seconds 30-40, 45-50, 55-60. The last pulse is prolonged.
DIZ	Nauen Germ. Dem. Rep. +52°39′ -12°55′	4525	continuous except from 8 h 15 m to 9 h 45 m for maintenance if necessary	A1 type Second pulses of 0.1 s duration. Minute pulses prolonged to 0.5 s. Hour pulses marked by prolonged pulses for seconds 58, 59, 60. DUT1: CCIR code by double pulse.
FFH	Chevannes France +48°32′ - 2°27′	2500	continuous from 8 h to 16 h 25 except Saturday and Sunday	Second pulses of 5 cycles of 1 kHz modulation. Minute pulses prolonged to 0.5 s. DUT1: CCIR code by lengthening to 0.1 s.
FTA91	Saint-Andre-de-Corcy France +45°55′ - 4°55′	91.15	at 8 h, 9 h, 9 h 30 m, 13 h, 20 h, 21 h, 22 h 30 m.	A1 type Second pulses during the 5 minutes preceding the indicated times. Minute pulses are prolonged. DUT1: in Morse code.
FTH42 FTK77 FTN87	Pontoise France +40° 4′ - 2° 7′	7428 10775 13873	at 9 h and 21 h at 8 h and 20 h at 9 h 30 m, 13 h, 22 h, 30 m.	A1 type Second pulses during the 5 minutes preceding the indicated times. Minute pulses are prolonged. DUT1: in Morse code.

Table AII-4. Time - Signals Emitted in the UTC System (Continued)

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
GBR	Rugby United Kingdom +52°22′ + 1°11′	16	at 3 h, 9 h, 15 h, 21 h	A1 type Second pulses during the 5 minutes preceding the indicated times. DUT1: CCIR code by double pulse
HBG	Prangins Switzerland +46°24′ - 6°15′	75	Continuous	Interruption of the carrier at the beginning of each second, during 100 ms. The minutes are identified by a double pulse, the hours by a triple pulse. No transmission of DUT1.
IAM	Rome Italy +41°52′ -12°27′	5000	10 m every 15 m from 7 h 30 m to 8 h 30 m and from 13 h to 14 h except Saturday afternoon and Sunday Advanced by 1-hour in summer.	Second pulses of 5 cycles of 1 kHz modulation. Minute pulses of 20 cycles (Announcements and 1 kHz modulation, 5 m before the emission of time signals).
IBF	Torino Italy +45° 2′ - 7°42′	5000	During 15 m preceding 7 h, 9 h, 10 h, 11 h, 12 h, 13 h, 14h, 15 h, 16 h, 17 h, 18 h. Advanced by 1-hour in summer.	Second pules of 5 cycles of 1 kHz modulation. These pulses are repeated 7 times at the minute. Voice announcement at the beginning and end of each emission. DUT1: CCIR code by double pulse.
JG2AE	Koganei Japan +35°42′ -139°31′	8000	from 20 h 59 m to 10 h 59 m.	Second pulses of 1600 Hz modulation. Minute pulses are preceded by a 600 Hz modulation. DUT1: CCIR code by lengthening
JG2AS	Chiba Japan + 35°38′ -140° 4′	40	from 23 h 30 m to 8 h (exc. sunday) and from 8 h to 23 h 30 on Monday. Interruptions during communications.	A1 type Second pulses of 0.5 sec. duration. Second 59 is omitted. No DUT1 code.
JJY	Koganei Japan + 35°42′ -139°31′	2500 5000 10000 15000	continuous, except interruptions between minutes 25 and 34.	Second pulses of 8 cycles of 1600 Hz modulation. Minute pulses are preceded by a 600 Hz modulation. DUT1: CCIR code by lengthening
LOL1	Buenos-Aires Argentina -34°37′ +58°21′	5000 10000 10000	11 h to 12 h, 14 h to 15 h, 17 h to 18 h, 20 h to 21 h 23 h to 24 h	Second pulses of 5 cycles of 1000 Hz modulation. Second 59 is omitted. Announcement of hours and minutes every 5 minutes, followed by 3 m of 1000 Hz and 440 Hz modulation. DUT1: CCIR code by lengthening
LOL2 LOL3	Buenos-Aires Argentina -34°37′ +58°21′	8030 17180	1 h, 13 h, 21 h	A1 Second pulses during the 5 minutes preceding the indicated times. Minute pulses are prolonged. DUT1: CCIR code by lengthening
LQB9 LQC20	Planta Gral Pacheco Argentina -34°26′ +58°37′	8167.5 17551.5	22 h 5 m, 23 h 50 m 10 h 5 m, 11 h 50 m	A1 Second pulses during the 5 minutes preceding the indicated times. Second 59 is omitted, second 60 is prolonged. After the emission, OK is transmitted if the emission is correct, NV if not correct. DUT1: CCIR code by omission of second markers.

Table AII-4. Time - Signals Emitted in the UTC System (Continued)

Station	**Location Latitude Longitude**	**Frequency (kHz)**	**Schedule (UT)**	**Form of the Time Signals**
MSF	Rugby United Kingdom +52°22′ + 1°11′	60	continuous except for an interruption for maintenance from 10 h 0 m to 14 h 0 m on the first Tuesday in each month.	Interruptions of the carrier of 100 ms for the Second pulses, of 500 ms for the minute pulses. The signal is given by the beginning of the interruption. DUT1: CCIR code by double pulse
MSF	Rugby United Kingdom +52°22′ + 1°11′	2500 5000 10000	between minutes 0 and 5, 10 and 15, 20 and 25, 30 and 35, 40 and 45, 50 and 55	Second pulses of 5 cycles of 1 kHz modulation. Minute pulses are prolonged. DUT1: CCIR code by double pulse
NBA	Balboa USA + 9° 3′ +79°39′	24	Every even hour except 24 h and during Monday maintenance (12 h to 18 h)	Experimental FSK Second pulses on 24 kHz.
		147.85 5448.5 11080 17697.5	5 h, 11 h, 17 h, 23 h	CW Second pulses during the 5 minutes preceding the indicated times on the American Code time format. DUT1: by Morse Code, each minute between seconds 56 and 59.
NDT	Yosami Japan + 34°58′ -137° 1′	17.4	to be determined	To be determined.
NPG	San Francisco USA + 38° 6′ +122°16′	3268 6428.5 9277.5 12966	6 h, 12 h, 18 h, 24 h	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format DUT1: by Morse Code, each minute between seconds 56 and 59.
NPM	Honolulu USA + 21°25′ +158° 9′	4525 9050 13655 16457.5 22593	6 h, 12 h, 18 h, 24 h	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format DUT1: by Morse Code, each minute between seconds 56 and 59.
NPN	Guam USA + 13°27′ -144°43′	4955 8150 13380 15925 21760	6 h, 12 h, 18 h, 24 h	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format DUT1: by Morse Code, each minute between seconds 56 and 59.
NSS	Annapolis USA +38°59′ +76°27′	21.4		Experimental FSK Second pulses on 21.4 kHz when transmissions resume.
		88 5870 8090 12135 16180	5 h, 11 h, 17 h, 23 h (on Tuesday 17 h the frequency 185 kHz replaces 88 kHz)	CW Second pulses during 5 minutes preceding the indicated times on the American Code time format.
		20225 25590	17 h, 23 h	DUT1: by Morse Code, each minute between seconds 56 and 59.
NWC	Exmouth Australia - 21°49′ -114° 9′	22.3	Keyed from 28 to 30 minutes after every other even hour beginning 0 h UT	Experimental FSK Second pulses during the indicated times on the American Code time format. DUT1: by Morese Code, between seconds 56 and 58.

Table AII-4. Time - Signals Emitted in the UTC System (Continued)

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
OLB5	Podebrady Czechoslovakia +50° 9′ -15° 8′	3170	continuous except from 5 h to 11 h on the first Wednesday of every month	A1 type, Second pulses No transmission of DUT1
OMA	Liblice Czechoslovakia +50° 4′ -14°53′	50	continuous except from 5 h to 11 h on the first Wednesday of every month	Interruption of the carrier of 100 ms at the beginning of every second, of 500 ms at the beginning of every minute. The precise time is given by the beginning of the interruption.
		2500	between minutes 5 and 15 25 and 30, 35 and 40, 50 and 60 of every hour except from 5 h to 11 h on the first Wednesday of every month	Pulses of 5 cycles of 1 kHz modulation (prolonged for the minutes). The first pulse of the 5th minute is prolonged to 500 cycles. No transmission of DUT1.
PPE	Rio de Janeiro Brazil -22°54′ +43°13′	8721	0 h 30 m 11 h 30 m, 13 h 30 m, 19 h 30 m, 20 h 30 m, 23 h 30 m	Second ticks, of A1 type, during the 5 minutes preceding the indicated hours. The minute ticks are longer. DUT1: CCIR Code by double pulse
PPR	Rio de Janeiro Brazil -22°59′ +43°11′	435 8634 13105 17194.4	01 h 30 m, 14 h 30 m, 21 h 30 m	Second ticks, A1 type, during the 5 minutes preceding the indicated hours. The minute ticks are longer
RAT	Moscow USSR +55°19′ -38°41′	2500	between minutes 30 and 35, 41 and 45, 50 and 60 from 17 h 50 m to 24 h	Second pulses* at the beginning of the minute are prolonged to 0.5 s.
		5000	between minutes 30 and 35, 41 and 45, 50 and 60 from 1 h 30 m to 17 h	DUT1 + dUT1 by Morse Code each hour between minutes 11 and 12.
RBU	Moscow USSR +55°19′ -38°41′	66-2/3	between minutes 0 and 5 from 0 h to 22 h 5 m	A1 type. Second pulses*. The pulses at beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 6 and 7.
RCH	Tashkent USSR +41°19′ -69°15′	2500	between minutes 15 and 20; 25 and 30, 35 and 40, 45 and 50 from 0 h to 3 h 50 m from 5 h 35 m to 9 h 30 m from 10 h 15 m to 13 h 30 m from 14 h 15 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour betweeen minutes 51 and 52.
RID	Irkutsk USSR + 52°46′ -103°39′	5004	between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 0 h to 1 h 10 m from 13 h 51 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 31 and 32.
		10004	between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 1 h 51 m to 13 h 10 m	

*The information about the value and the sign of the DUT1 + dUT1 difference is transmitted after each minute signal by the marking of the corresponding second signals by additional impulses. In addition, it is transmitted in Morse Code as indicated.

Table AII-4. Time-Signals Emitted in the UTC System (Continued)

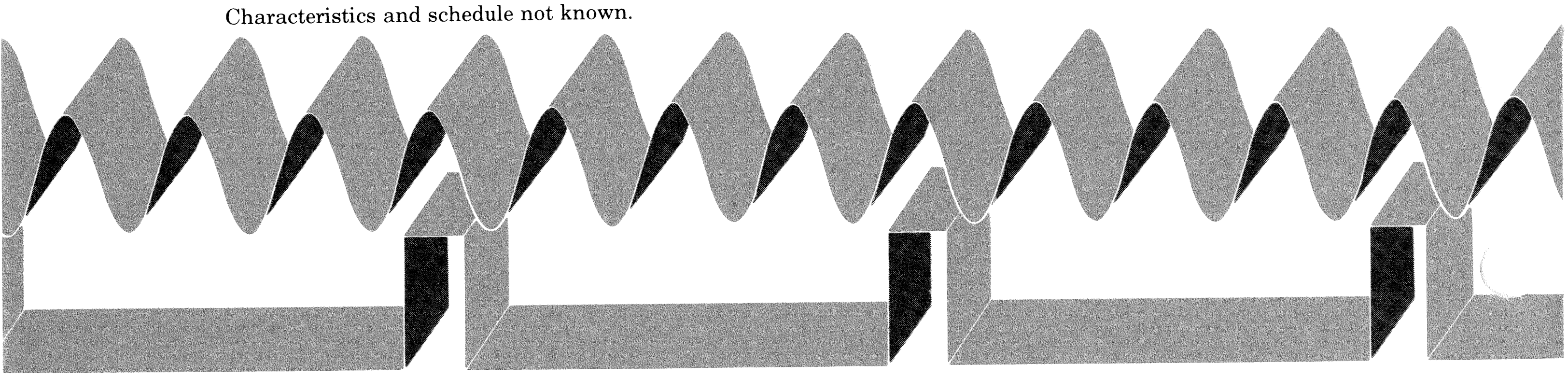
Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UT)	Form of the Time Signals
RIM	Tashkent USSR +41°19′ -69°15′	5000	between minutes 15 and 20, 25 and 30, 35 and 40, 45 and 50 from 0 h to 1 h 30 m from 2 h 15 m to 3 h 50 m from 18 h 15 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 51 and 52.
		10000	between minutes 15 and 20, 25 and 30, 35 and 40, 45 and 50 from 5 h 35 m to 9 h 30 m from 10 h 15 m to 13 h 30 m from 14 h 15 m to 17 h 30 m	
RKM	Irkutsk USSR + 52°46′ -103°39′	10004	between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 0 h to 1 h 10 m, from 13 h 51 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1: by Morse Code each hour between minutes 31 and 32.
		15004	between minutes 5 and 10, 15 and 20, 25 and 30, 51 and 60 from 1 h 51 m to 13 h 10 m	
RTA	Novossibirsk USSR +55°04′ -82°58′	4996	between minutes 5 and 10, 15 and 20, 25 and 29, 35 and 39 from 0 h to 1 h 29 m from 18 h 5 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged. DUT1 + dUT1: by Morse Code each hour between minutes 45 and 46.
		9996	between minutes 5 and 10, 15 and 20, 25 and 29, 35 and 39 from 3 h 5 m to 4 h 39 m from 14 h 5 m to 17 h 29 m	
		14996	between minutes 5 and 10, 15 and 20, 25 and 29, 35 and 39 from 5 h 35 m to 9 h 29 m f4om 10 h 5 m to 13 h 29 m	
RWM	Moscow USSR +55°19′ -38°41′	10000	between minutes 30 and 35, 41 and 45, 50 and 60 from 1 h 30 m to 3 h from 17 h 50 m to 24 h	Second pulses*. The pulses at the beginning of the minute are prolonged to 0.5 s. DUT1 + dUT1 by Morse Code each hour between minutes 11 and 12.
		15000	between minutes 30 and 35, 41 and 45, 50 and 60 from 3 h 50 m to 17 h	
RTZ	Irkutsk USSR + 52°18′ -104°18′	50	between minutes 0 and 5 from 0 h to 22 h 5 m	A1 type second pulses*. The pulses at the beginning of the minute are prolonged. DUT1 + dUT1: by Morse Code each hour between minutes 6 and 7.

*The information about the value and the sign of the DUT1 + dUT1 difference is transmitted after each Minute signal by marking the corresponding Second signals with additional impulses. In addition, it is transmitted in Morse Code as indicated.

Table AII-4. Time - Signals Emitted in the UTC System (Continued)

Station	**Location Latitude Longitude**	**Frequency (kHz)**	**Schedule (UT)**	**Form of the Time Signals**
VNG	Lyndhurst Australia - 38° 3′ -145°16′	4500 7500 12000	9 h 45 m to 21 h 30 m continuous except 22 h 30 m to 22 h 45 m 21 h 45 m to 9 h 30 m	Seconds markers of 50 cycles of 1 kHz modulation; 5 cycles only for Seconds markers 55 to 58; Seconds marker 59 is omitted; 500 cycles for Minute markers. During the 5th, 10th, 15th, etc...minutes, 5 cycles for Seconds markers 50 to 58. Identification by voice announcement during 15th, 30th 45th, and 60th minutes. DUT1: CCIR code by 45 cycles of 900 Hz modulation immediately following the normal Seconds markers.
WWV	Fort-Collins USA + 40°41′ +105° 2′	2500 5000 10000 15000 20000 25000	continuous	Pulses of 5 cycles of 1 kHz modulation. 59th and 29th second pulse omitted. Hour is identified by 0.8 second long, 1500 Hz tone. Beginning of each minute identified by 0.8 second long, 1000 Hz tone. DUT1: CCIR code by double pulse. Additional information on corrections.
WWVB	Fort-Collins USA + 40°40′ +105° 3′	60	continuous	Second pulses given by reduction of the amplitude of the carrier. Coded announcement of the date and time and of the correction to obtain UT1. No CCIR code.
WWVH	Kauai USA + 21°59′ +159°46′	2500 5000 10000 15000 20000	continuous	Pulses of 6 cycles of 1200 Hz modulation. 59th and 29th seconds pulse omitted. Hour identified by 0.8 second long 1500 Hz tone. Beginning of each minute identified by 0.8 second long, 1200 Hz tone. DUT1: CCIR code by double pulse. Additional information on UT1 corrections.
YVTO	Caracas Venezuela +10°30′ +66°56′	6100	12 h to 20 h 0 h 30 m to 1 h 30 m	Second pulses of 1 kHz modulation with 0.1 s duration. The minute is identified by a 800 Hz tone and a 0.5 s duration Between seconds 52 and 57 of each minute, voice announcement of hour, minute, and second.
ZUO	Olifantsfontein South Africa -25°58′ -28°14′	2500 5000 100000	18 h to 4 h continuous continuous	Pulses of 5 cycles of 1 kHz modulation. Second 0 is prolonged. DUT1: CCIR code by lengthening

OTHER TIME SIGNALS: BPV, XSG, Shanghai, China, P.R., Latitude: +31° 12′, Longitude: -121° 26′. Characteristics and schedule not known.



APPENDIX III

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APPENDIX IV

GLOSSARY

GLOSSARY OF TERMS

ACCURACY: The degree to which an oscillator frequency corresponds to that of an accepted definition. The currently accepted definition is that of the 13th General Conference of Weights and Measures. In practice, this involves comparison with some generally accepted physical embodiment of this definition such as the NBS Frequency Standard. The specified accuracy of the 5061A Cesium Beam Frequency Standard is intrinsic to it and is achieved without calibration.

EPOCH (TIME): A selected instant in time, used as a reference point.

LONG-TERM STABILITY: Long-term frequency stability is defined as the absolute value (magnitude) of the fractional frequency change with time. An observation time sufficiently long to reduce the effects of random noise to an insignificant value is implied. Frequency changes due to environmental effects must be considered separately.

REPRODUCIBILITY: The degree to which an oscillator will produce the same frequency from one occasion to another after proper alignment. This does not include calibration.

SHORT-TERM STABILITY: Short-term stability is defined as the standard deviation of fractional frequency fluctuations due to random noise in an oscillator. This specification must include the number of samples, the averaging time, the repetition time, and the system bandwidth.

SETTABILITY: The degree to which the frequency of an oscillator may be adjusted to correspond with a reference. This is also termed calibration.

STANDARDS:

House Standard: The most stable and accurate frequency source available as a reference within the user's facility. Usually kept referenced to national frequency standards.

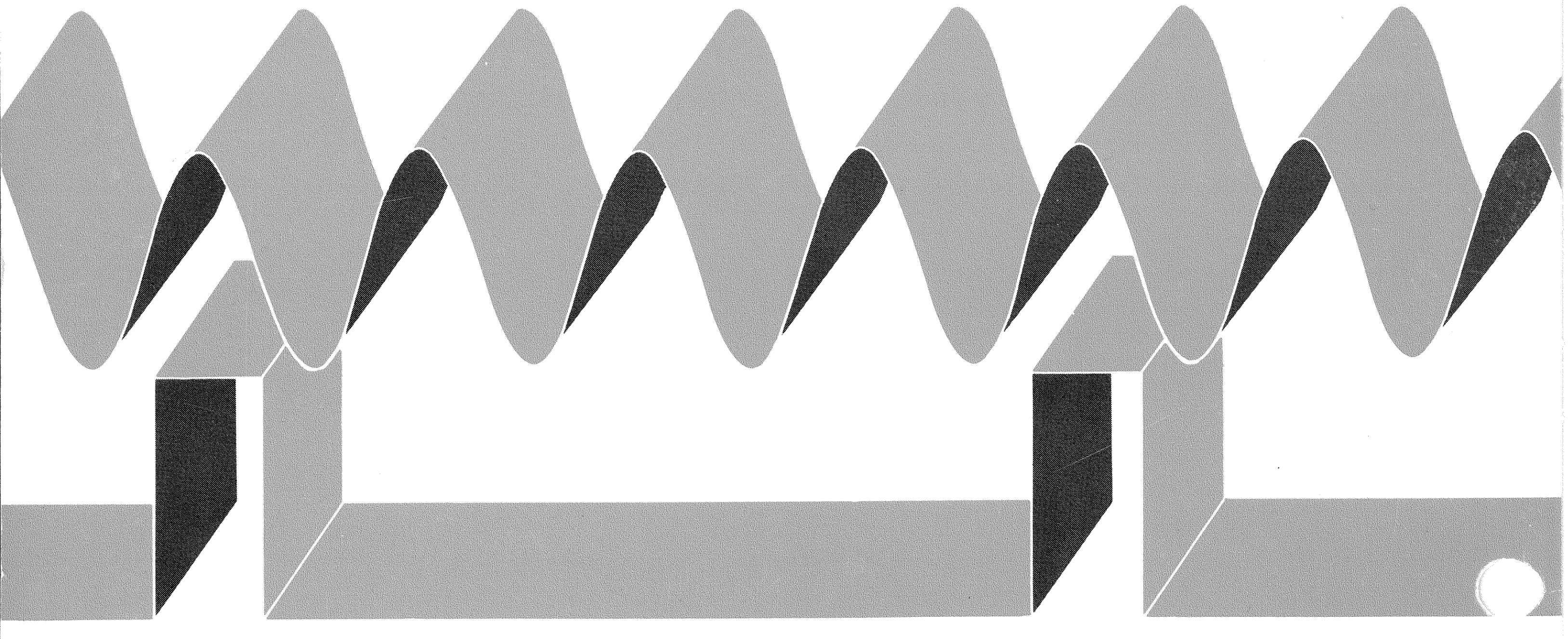
Reference/Transfer Standard: The reference standard used to transfer frequency or time from the "house" standard to "working" standards.

Working Standard: The standard against which instruments are compared for test or repair purposes.

TIME INTERVAL: Time between events, which is independent of a starting point.

UTC: Universal Coordinated Time. An internationally agreed-upon time scale having the same rate as Atomic Time. UTC is corrected in one-second step adjustments, as needed, to remain within 0.7 seconds of Astronomical Time (UT_1).

UT_1: A nonuniform time scale based on the earth's rotation and corrected for the effects of polar motion.



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