TIME AND FREQUENCY SERVICES OFFERED BY THE NATIONAL INSTITUTE OF STANDARDS & TECHNOLOGY (NIST)

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Abstract

NIST time and frequency services are described, including WWV, WWVH, WWVB, the GOES satellite time code, and the Automated Computer Time Service. Performance capabilities are discussed, with major emphasis on those services that are most useful for the electric power industry. The paper concludes with some projections concerning trends in time and frequency services during the next ten-year period.

Introduction

The National Institute of Standards and Technology (NIST) is responsible for developing, maintaining, and distributing measurement standards in the United States. This responsibility extends into the area of time and frequency standards. Beginning in 1923, NIST began broadcasting frequency information from radio station WWV. Standard time intervals were added in 1935, and time-of-day information was added in 1945. Since then, NIST has expanded its time and frequency services to meet the needs of a growing number of users. NIST time and frequency services are convenient, accurate, and easy to use. They are widely used by the nation's space and defense programs, by manufacturers, by the transportation and communications industries, and by the general public.

All NIST services distribute UTC(NIST), which is always kept within ±1 ì s of Coordinated Universal Time (UTC). UTC was established in 1972 and is coordinated by the International Bureau of Weights and Measures (BIPM) in Paris, France. Coordination with the international UTC time scale keeps NIST time signals in close agreement with signals from other time and frequency stations throughout the world. UTC is a 24-hour clock system. The hours are numbered beginning with 00 hours at midnight through 12 hours at noon to 23 hours and 59 minutes just before the next midnight. UTC differs from local time by a specific number of hours. The number of hours depends on the number of time zones between your location and the location of the zero meridian (which passes through Greenwich, England). When local time changes from Daylight Saving to Standard Time, or vice versa, UTC does not change. However, the difference between UTC and local time changes by 1 hour.

Broadcast services include radio signals from NIST radio stations WWV, WWVH, WWVB, and the GOES satellites. NIST also offers the Automated Computer Time Service (ACTS), which lets users set their computer clocks to NIST time, and higher accuracy services based on LORAN-C and Global Positioning Satellite (GPS) signals. This paper discusses the strengths and weaknesses of each service with respect to such factors as accuracy, coverage, percent of time available, ease of use, and cost. In general, the stated accuracy of each service is based on what can be achieved under "typical" conditions.

Shortwave Radio Stations WWV and WWVH

NIST's best known source of timing information is its shortwave radio station WWV, which broadcasts from Fort Collins, Colorado. WWV has a sister station called WWVH that broadcasts from Kauai, Hawaii. Both stations can be received with a standard shortwave radio on 2.5, 5, 10, and 15 MHz. WWV also broadcasts on 20 MHz.

Each station radiates 10,000 watts on 5, 10, and 15 MHz. Less power is used on the other frequencies: WWV radiates 2500 watts on 2.5 and 20 MHz, while WWVH radiates 5000 watts on 2.5 MHz and does not transmit at all on 20 MHz.

The same information is transmitted on all frequencies. Multiple frequencies are necessary because propagation conditions in the shortwave bands vary greatly. Using multiple frequencies insures that at least one frequency will work well at all times. Some commercially available receivers scan several frequencies and use the one that currently provides the best reception.

The vagaries of high frequency radio propagation limit the accuracy of WWV and WWVH. Both stations are referenced to the primary NIST frequency standard in Boulder, Colorado, and the frequency as transmitted is accurate to about 1 part in 100 billion (1×10^{-11}) for frequency and about 10 ì s for timing. However, the *received* accuracy is far less due to various propagation effects. The usable received accuracy is about 1 part in 10 million (1×10^{-7}) for frequency and about 1 to 20 ms for timing.

The major advantages of WWV and WWVH include excellent geographical coverage (nearly worldwide), inexpensive receiving equipment, and ease-of-use (especially for timing at the 1 second level). The major disadvantage is that the usable accuracy of the signals is strongly tied to the current propagation conditions. Propagation conditions are highly variable, depending on such factors as the path length, time of year, time of day, and ionospheric conditions. In summary, WWV and WWVH are most useful in situations where modest accuracy is sufficient, cost is an important consideration, and continuous availability of the reference is not necessary.

WWV and WWVH Voice Announcements

The most common usage of WWV and WWVH consists of listening to the voice announcements. Since both stations can be heard in some areas (like California), a man's voice is used on WWV, and a woman's voice is used on WWVH to reduce confusion. The WWVH announcement occurs first, at about 15 seconds before the minute. The WWV announcement follows at about 7.5 seconds before the minute. Though the announcements occur at different times, the tone markers are transmitted at the same time from both stations. However, they may be *received* at different times due to differences in the propagation delays from the two station sites.

WWV and WWVH transmit many different types of information in the interval between the voice announcements (see reference 1 for details). The most frequent sounds heard are the seconds pulses. These pulses are heard every second except on the 29th and 59th seconds of each minute. The first pulse of each hour is an 800-ms pulse of 1500 Hz. The first pulse of each minute is an 800-ms pulse of 1000 Hz at WWV and 1200 Hz at WWVH. The remaining seconds pulses are short audio bursts (5-ms pulses of 1000 Hz at WWV and 1200 Hz at WWVH) that sound like the ticking of a clock.

The audio portions of the WWV and WWVH broadcasts can also be heard by telephone. To listen, dial (303) 499-7111 for WWV, and (808) 335-4363 for WWVH. Callers are disconnected after 3 minutes. These are not toll-free numbers and callers outside the local calling area are charged regular long-distance rates.

The accuracy of the telephone time signals is normally 30 ms or better in the continental United States. In rare instances when the telephone connection is made by satellite, there is an additional delay of about 250 to 500 ms.

WWV and WWVH Time Code

In addition to the voice announcements, WWV and WWVH continuously broadcast a binary-coded-decimal (BCD) time code on a 100-Hz subcarrier. Receivers that receive and decode this information are available commercially. These receivers usually provide a digital time display and often include an interface (RS-232, for example) so that the time can be read by a computer system.

The time code presents serial UTC information at a rate of 1 pulse per second. The information carried by the time code includes the current minute, hour, day of year, and year. See reference 1 for the complete details of the WWV and WWVH time codes.

Low Frequency Radio Station WWVB

Radio station WWVB is located on the WWV site near Ft. Collins, Colorado. WWVB continuously broadcasts time and frequency signals at 60 kHz. It does not broadcast voice announcements, but transmits a BCD time code that provides standard time information, including the year; time intervals; Daylight Saving Time; and leap second and leap-year indicators. In addition, the 60-kHz carrier frequency provides an accurate frequency standard which is referenced to the NIST Frequency Standard.

WWVB transmits 13,000 watts, and its signal can be received nearly anywhere in the continental United States. It identifies itself by advancing its carrier phase 45° at 10 minutes after the hour and returning to normal phase at 15 minutes after the hour. WWVB is also identified by its unique time code.

A number of commercial products that receive WWVB are available, including clocks that decode and display the time. Some of these have computer interfaces and can be used to provide time to computer systems. Other products allow you to calibrate frequency standards by comparing their phase to the WWVB carrier.

Accuracy and Stability

The 60-kHz carrier frequency used by WWVB offers more stable propagation than the shortwave services. As a result, the usable accuracy at the reception site can be as good as 1×10^{-12} for frequency (averaged over 1 day) and 0.1 ms for time (using the time code). More modest accuracies of 1×10^{-10} or 1×10^{-11} for frequency comparisons are easy to obtain with commercially available receivers. Automatic phase-tracking receivers offer convenience of operation at a cost in the $2,000-$4,000 range.

One disadvantage of WWVB, in the case of the electric power industry, is that reception may be difficult in power-system environments due to the harmonic relationship between the 60-kHz broadcast frequency and the 60-Hz power-system frequency.

WWVB Time Code

The WWVB time code is synchronized with the 60-kHz carrier and is broadcast continuously at a rate of 1 pulse per second using pulse-width modulation. Each pulse is generated by reducing the carrier power 10 dB at the start of the second, so that the leading edge of every negative-going pulse is on time. Full power is restored 0.2, 0.5, or 0.8 seconds later to convey a binary “0”, “1”, or a position marker, respectively.

The WWVB code contains information on the current year, day of year, hour, minute, second, status of Daylight Saving Time, leap year, and a leap-second indicator.
Complete details of the WWVB time code are published in Reference 1.

Table 1 summarizes information about WWV, WWVH, and WWVB.

Characteristics & Services:	**WWV**		**WWVH**		**WWVB**
Date Service Began	March 1923		November 1948		July 1956
Geographical Coordinates	40° 40' 49.0” N 105° 02' 27.0” W		21° 59' 26.0” N 159° 46' 00.0” W		40° 40' 28.3“ N 105° 02' 39.5” W
Standard Carrier Frequencies	2.5 & 20 MHz	5, 10, & 15 MHz	2.5 MHz	5, 10, & 15 MHz	60 kHz
Power	2500 W	10,000 W	5000 W	10,000 W	13,000 W
Standard Audio Frequencies	440 (A above middle C), 500, & 600 Hz				
Time Intervals	1 pulse/s; minute mark; hour mark				s; min.
Time Signals: Voice	Once per minute				
Time Signals: Code	BCD code on 100-Hz subcarrier, 1 pulse/s				BCD code
UT1 Corrections	UT1 corrections are broadcast with an accuracy of ±0.1 s				
Special Announcements	Omega Reports, Geoalerts, Marine Storm Warnings, Global Positioning System Status Reports				

GOES Satellite Time Service

NIST has broadcast a time code from the GOES (**G**eostationary **O**perational **E**nvironmental **S**atellite) satellites of the National Oceanic and Atmospheric Administration (NOAA) since 1974. This cooperative arrangement between NIST and NOAA was formalized by a renewable agreement, the latest version of which extends until 1997. The time code is referenced to UTC(NIST) and is broadcast continuously to the entire Western Hemisphere from two satellites (GOES/East and GOES/West).

GOES time-code receivers are commercially available at prices in the $4,000 range. They provide fully automatic acquisition and operation once the initial setup is completed. Most receivers can use the fully corrected time code (discussed later on) and provide UTC(NIST) time accurate to within 100 ì s over periods from minutes to years. Although the GOES service is most often used for timing applications, it can also provide some useful frequency-comparison capabilities.

Receiving GOES requires only a small antenna, and it is relatively simple to point an antenna to either satellite. If the path to the satellite is clear, pointing in the general direction of the satellite is usually sufficient.

GOES Satellites

The GOES satellites are in geostationary orbit about 36,000 km (22,300 miles) above the equator. Geostationary means that the satellites stay above the same spot on the Earth's surface. Because they are geostationary, the path delay for the time code varies by only a few milliseconds over the course of one day.

In the normal GOES satellite configuration there are always at least three GOES satellites in orbit. Two are operational, and one is a spare. GOES/West is normally located at 135° West longitude and transmits at 468.825 MHz. GOES/East is normally located at 75° West longitude and transmits at 468.8375 MHz. The spare is located at approximately 105° West longitude. The satellites do not have clocks on board but instead relay the signals which originate on the ground from NOAA's satellite control facility at Wallops Island, Virginia.

This normal system configuration provides coverage of much of the Atlantic Ocean area extending into western Europe, significant portions of the Pacific area extending into Australia, and overlapping coverage of most of North and South America. The signals are available to users continuously with very high reliability. Under normal conditions the satellites are controlled so that the received time code signal does not vary by more than about 1 ms per day. The main disadvantage of the normal GOES service is that the land-mobile service in the U.S. also uses the 468 MHz frequency band and has primary allocation status. This means that in large urban areas with substantial land-mobile activity there is often interference with the received GOES time code signals. Generally, GOES timing receivers can flywheel through these periods of interference with minimal impact, but in some locations the problem may be particularly severe. GOES/East is normally less affected by interference due to the specific frequencies involved.

For the past several years, however, the GOES satellite configuration has not been operating normally due to the sponsoring agency's (NOAA) inability to replace the older satellites in a timely manner. As a result, the current system differs from the normal one in the following respects: (1) the GOES/East satellite is positioned at 112^{o} West longitude instead of 75^{o} West longitude; and (2) the GOES/West satellite, although positioned correctly at 135^{o} West longitude, is a very old (GOES-2) satellite with reduced performance capability.

The GOES/West satellite (GOES-2) currently has an orbit inclination of more than $10^{o.}$ This large orbit inclination cannot be corrected because the satellite no longer has enough fuel to be relocated. The large orbit inclination causes two problems. First, as GOES-2 swings north and south of the equator each day during its orbit, the signal path delay changes by more than 10 ms. Therefore, receivers that do not correct for path delay changes will show timing errors that are about 10 times larger than normal. Second, the large inclination prevents NIST from transmitting the proper latitude correction for GOES-2 as part of the time code format. This is because the satellite time code format was originally designed 20 years ago to only accommodate latitude corrections of less than 10^{o}. As a result, when the satellite latitude is beyond 10^{o} twice each day, the encoded correction is only approximately correct and automatic receivers will compute a slightly erroneous path delay correction. In the extreme cases for the current satellite orbit, this error can amount to several hundred microseconds. This error will increase slowly until new replacement satellites are available in mid-1994.

GOES-2 is also unable to function during eclipse periods when solar power is not available. This causes a GOES/West time-code outage for up to 4 hours per day (including necessary equipment warm-up time) during the Spring and Fall eclipse periods (approximately 45-60 days each season). This eclipse problem does not exist for GOES/East, and should not be a problem for any of the newer replacement satellites scheduled for launch during the next 1-2 years.

To summarize the time code performance capabilities, GOES/East can be used at the normal accuracy of less than 100 ì s. At present, however, the GOES/West satellite signal may be unavailable for several hours per day and at other times its accuracy may be limited to several hundred microseconds. Normal performance from both satellites should again be available after mid-1994. With respect to coverage area GOES/West provides normal coverage while the current GOES/East is not usable in the eastern Atlantic or western Europe due to its temporary orbit position.

GOES Time Code

The GOES time code includes the current year, complete time-of-year information (day-of-year number, hour, and minute), the UT1 correction (the approximate difference between the astronomical UT1 time scale and UTC), satellite position information, accuracy indicators, Daylight Saving Time and leap second indicators, and system status information.

The satellite position data are included in the time code to provide users with an option for correcting the received time signal for motion of the satellites in their orbits. These relatively small motions cause variations in the signal path delay, which, in turn, produce variations (usually less than 5 ms) in the received time signal. The position data in the time code are predictions, updated each minute, of each satellite position. They are computed from satellite tracking measurements at NIST/Boulder, and then transferred electronically to the time-code equipment at Wallops Island. GOES time-code receivers can be equipped to decode the satellite position information, compute a path delay correction each minute, and automatically correct the output reference signal to remain within 100 ì s of UTC(NIST).

The time code is interlaced with interrogation messages that do not contain time and frequency information. The interrogation messages are used by NOAA to communicate with systems gathering weather data. Once every half-second, a 4-bit time-code word is transmitted at a data rate of 100 bits/s. A complete time-code message is transmitted every 30 s, beginning on each minute and half-minute.

The time code is generated from atomic clocks maintained by NIST at NOAA's facility at Wallops Island, Virginia. These clocks provide a stable and accurate reference for the time code. The transmitted accuracy from Wallops Island is kept within ±10 ì s of UTC(NIST).

Performance Levels

The GOES time code can be used in uncorrected or corrected mode. A discussion of each performance level is given below. The performance information stated below refers to the GOES system operating under normal conditions. The current performance levels may be reduced due to the conditions described previously.

Uncorrected: The path delay from Wallops Island, Virginia (where the time code originates), to the satellite and then back to Earth is about 260 ms. To compensate for this delay, the GOES signals are advanced by 260 ms before being transmitted. This compensates for most of the delay and means that all GOES users should get time accurate within 1 to 16 ms, depending upon the receiver's location. Over a 24 hour period, there may also be 1-10 ms changes in the time code that are caused by satellite motion, especially if a satellite with a large orbit inclination is used.

Corrected: The GOES satellites transmit their position data along with the time code. Obtaining a fully corrected time signal requires reading the position data, and computing the actual path delay between Wallops Island, Virginia, and your location on earth. Once the actual delay is known, it can be used to apply a correction to the time code. Many GOES receivers do all of this automatically and make it very easy to use a corrected time signal. A fully corrected time signal is usually accurate to within ±100 ì s. The ultimate accuracy depends on equipment delays and noise levels in addition to the path delay.

Whether you use GOES in the uncorrected or corrected mode, you may need to know about periodic changes in the GOES time code. Information about the current status of the GOES time code can be obtained from the U.S. Naval Observatory's Automated Data Service database in Washington, DC, and from the monthly *NIST Time and Frequency Bulletin*. These sources inform users about outages, departures from normal performance, announcements of upcoming stationkeeping maneuvers, and other events. To find out more about these sources, contact the NIST Time and Frequency Division.

Automated Computer Time Service (ACTS)

Since 1988, it has been quite easy to set a computer clock to precise time from NIST. That year marked the beginning of NIST's Automated Computer Time Service (ACTS). Using ACTS requires only a modem and some simple software. When a computer connects to ACTS by telephone, it receives an ASCII time code. The information in this time code is then used to set the computer clock to the correct time.

The phone number for ACTS is (303) 494-4774. Nine telephone lines are currently available on a rotary system. ACTS is usable at either 300 or 1200 baud, with 8 data bits, 1 stop bit, and no parity. The 1200 baud time code is transmitted every second and contains more information than the 300 baud time code, which is transmitted once every 2 seconds. A description of the 1200 baud time code is given in Table 2.

A call to ACTS takes just seconds. Since the time setting process is so quick, ACTS limits your time on-line to 56 seconds, or just 28 seconds if all lines are busy.

JJJJJ YRMODA HH:MM:SS TT L DUT1 msADV UTC(NIST) OTM

JJJJJ is the Modified Julian Date (MJD). The MJD is the last five digits of the Julian Date, which is simply a count of the number of days since January 1, 4713 B.C. To get the actual Julian Date, add 2.4 million to the MJD.

YR-MO-DA is the date. It shows the last two digits of the year, the month, and the current day of month.

HH:MM:SS is the time in hours, minutes, and seconds. The time is always sent as Coordinated Universal Time (UTC). An offset needs to be applied to UTC to obtain local time in the United States. For example, Mountain Time in the United States is 7 hours behind UTC during Standard Time, and 6 hours behind UTC during Daylight Saving Time.

TT is a two-digit code (00 to 99) that indicates whether the United States is on Standard Time (ST) or Daylight Saving Time (DST). It also indicates when ST or DST is approaching. This code is set to 00 when ST is in effect, or to 50 when DST is in effect. About 48 days prior to a time change, the code starts counting the days until the change. When ST is in effect, the code counts down from 99 to 51. When DST is in effect, the code counts down from 49 to 01.

L is a one-digit code that indicates whether a leap second will be added or subtracted at midnight on the last day of the current month. If the code is 0, no leap second will occur this month. If the code is 1, a positive leap second will be added at the end of the month. This means that the last minute of the month will contain 61 seconds instead of 60. If the code is 2, a second will be deleted on the last day of the month. Leap seconds occur at a rate of about one per year. They are used to correct for irregularity in the earth's rotation.
UT1 is a correction factor for converting UTC to an older form of universal time that is still used in navigation. It is always a number ranging from -0.8 to +0.8 seconds. This number is added to UTC to obtain UT1.

msADV is a five-digit code that displays the number of milliseconds that NIST advances the time code. It is originally set to 45.0 ms. If you return the on-time marker (OTM) four consecutive times, it will change to reflect the actual one way line delay.

The label UTC(NIST) is contained in every time code. It indicates that you are receiving Coordinated Universal Time (UTC) from the National Institute of Standards and Technology (NIST).

The on-time marker (OTM) is a single character sent at the end of each time code. The OTM is originally an asterisk (*) and changes to a pound sign (#) if ACTS has successfully measured the round trip line delay.

When you connect to ACTS, the last character in the time code is an asterisk (*). The asterisk is called the on-time marker (OTM). The time values sent by the time code refer to the arrival time of the OTM. In other words, if the time code says it is 12:45:45, this means it is 12:45:45 when the OTM arrives.

There is some delay between the time the OTM leaves NIST and the time it arrives at your computer. Part of this delay is the actual data transmission time and part of it is the time it takes your modem to process the incoming data and feed it to your computer. For phone calls within the continental United States, the data transmission delay is usually smaller than the modem processing delay. If the phone call goes through a satellite link, however, the data transmission time will account for most of the delay.

Since ACTS knows that the OTM will be delayed between the time it leaves NIST and the time it gets to your computer, it sends the OTM out 45 ms early. This 45 ms includes the 8 ms that it takes to send the OTM at 1200 baud, 7 ms transmission time to allow for travel from NIST to the average user in the United States, and 30 ms to compensate for the modem processing delay.

The 45 ms advancement of the OTM usually compensates for most of the delay. For example, if you are calling from Chicago and the actual delay is 50 ms, the OTM will arrive at your computer only 5 ms late with about 90% of the delay already removed. However, if you are making an overseas call or any call that goes through a satellite, the delay can be 300 ms or more.

Fortunately, ACTS lets you measure the actual line delay, so you can remove as much of the delay as possible. To do so, your software has to return the OTM to ACTS after it receives it. Each time the OTM is returned, ACTS measures the actual delay. After 4 consecutive measurements have been made, ACTS will begin advancing the OTM by the actual delay amount. For example, if the actual delay is 50.4 ms, ACTS will send the OTM out 50.4 (instead of 45) ms early. Once ACTS begins using the actual measured delay, the OTM changes from an asterisk to a pound sign (#). At this point, the OTM is arriving at your computer within 1 ms of the correct time.

In very rare instances, ACTS won't be able to properly measure the actual delay. This can happen if the phone call goes by satellite in one direction (long delay) and by land in the other direction (short delay). If this happens, the standard 45 ms advancement will be used, even if your software returns the OTM.

A number of commercially-available software packages let PC-compatible computers call ACTS. You can also order software from NIST (Research Material 8101). The current price of this software is $37. To order RM 8101, contact: NIST Office of Standard Reference Materials, B311 Chemistry Building, NIST, Gaithersburg, MD 20899-0001; telephone (301) 975-6776.

Services for Users Needing Higher Accuracy

Two other NIST services are available for users who demand the most accurate time and frequency signals possible. First, NIST offers a Frequency Measurement Service which provides a NIST-traceable frequency reference at the user's site with an accuracy capability of about 1×10^{-12}. NIST provides, maintains, and regularly checks the equipment by telephone modem in return for an annual fee. The service uses either LORAN-C or Global Positioning Satellite (GPS) signals. Advantages include high accuracy, automatic operation, full NIST support, and minimal involvement by the user.

NIST also offers a similar turnkey service which uses common-view reception of GPS satellite signals. This Global Time Service is capable of transferring time-and-frequency references from NIST to the user's site with accuracy capabilities approaching 10 ns for time and 1×10^{-14} for frequency. Receivers can be provided either by NIST or by the user. Other advantages include high reliability because of the 24-satellite GPS configuration, automatic operation, NIST support and traceability, and minimal user involvement. One disadvantage is that the measurement sites being compared must communicate with each other in order to compute the time difference.

Both services require the user to pay an annual subscription fee to NIST. For more information, please contact: NIST Time and Frequency Division, 325 Broadway, Boulder, CO 80303, Telephone: (303) 497-3294.

Future Trends in NIST Time and Frequency Services

Since NIST has a legislative mandate to provide, maintain, and distribute standards of measurement for the U.S. and to assist U.S. industry, it is committed to providing useful time and frequency services well into the future. NIST continually attempts to provide a mix of useful services by paying attention to what users need, and by developing and using new technology that helps meet those needs.

In order to evaluate the future direction of NIST time-and-frequency services, we need to look at trends that are developing both inside and outside the time-and-frequency community. For example, the use of the Global Positioning Satellites (GPS) is becoming widespread for timing applications. This trend should continue as the cost of GPS equipment continues to fall and as the number of GPS satellites in orbit approaches the planned configuration of 24. GPS is a very accurate source of time. Even with Selective Availability (which limits the accuracy of GPS to civilian users) in place, its timing accuracy is 1 ì s or better. Another development which may have a major impact on future time and frequency services is the emerging synchronized optical-communication network technology. Such systems are being developed worldwide and have the potential for very accurate and convenient time-and-frequency transfer. Still another possibility is the use of available and planned international satellite systems such as INMARSAT for general time-and-frequency distribution that could be more accurate than GPS. Any future impact of such developments on present NIST services would likely be minimal during the next 5-10 years.

In the shorter term (1-10 year) period we foresee no major changes in existing NIST services. During the past several years, significant improvements in the form of new transmitters, time code generators, voice-announcement systems, and other equipment have been made at both the WWV and WWVH broadcast station sites in Colorado and Hawaii. With their clientele of many thousands of users and the continuing need for inexpensive, convenient signals for general civilian timekeeping, these services will be needed for a long time. The WWVB service at 60 kHz has a smaller user base, but user surveys continue to indicate a need for this broadcast. NIST plans to continue the WWVB service until other alternatives can offer the same or better performance with the same mix of convenience, modest cost, and high reliability.

NIST also plans to continue the GOES time code service well into the future, although this clearly depends on NOAA's continued cooperation and its ability to successfully replace the existing satellites. The current 10-year NIST/NOAA Memorandum of Agreement is scheduled for renewal in 1997. According to the latest information from NOAA officials, they are relatively confident that they can meet the planned schedule for launching new GOES satellites in June 1994 and June 1995. The plan, assuming a successful launch in 1994, is to move the current GOES-7 spacecraft westward to become GOES/West at its normal orbit position of 135^{o} West. At the same time the new GOES-8 would then become GOES/East operating at the designed orbit location of 75^{o} West longitude. The GOES-9 spacecraft in June 1995 would then provide additional system reliability. If these changes are successful, the present degraded performance of GOES/West will be corrected as of June 1994.

And finally, the relatively new ACTS service seems to have attracted an appreciative audience and is growing more and more popular. It is cost-effective both for NIST and its users, and is projected to provide a useful service for many years. At this writing, the system is receiving over 4,000 calls per day using 9 telephone lines. ACTS can easily be expanded in terms of additional telephone lines and time code generators in order to meet increased demand.

Summary

As shown in this paper, NIST offers a variety of time and frequency services that cover a broad range of performance levels and that are suitable for a number of timing applications. For assistance in using any of these services, please contact: NIST Time and Frequency Division, 325 Broadway, Boulder, CO 80303, Telephone: (303) 497-3294.

References

[1] Roger E. Beehler and Michael A. Lombardi, NIST Time and Frequency Services, NIST Special Publication 432, U. S. Government Printing Office, June 1991.

[2] George Kamas and Michael A. Lombardi, Time and Frequency Users Manual, NIST Special Publication 559, U. S. Government Printing Office, September 1990.