Recent Trends in NBS Time and Frequency Distribution Services

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Invited Paper

Since 1967 the National Bureau of Standards has improved its traditional radio broadcast services from radio stations WWV, WWVH, and WWVB and introduced several new services to meet changing needs. The new services are described briefly, including the GOES satellite time code, the Frequency Measurement Service using Loran-C and WWVB, and the Global Time Service based on the GPS satellite common-view technique.

INTRODUCTION

At the time of the June 1967, PROCEEDINGS OF THE IEEE Special Issue on Radio Measurements and Standards, the National Bureau of Standards (NBS) relied primarily on high-frequency (HF), low-frequency (LF), and very-low-frequency (VLF) radio broadcasts to distribute time and frequency (T/F) signals referenced to its primary standards [1]. The respective radio broadcast stations were: WWV (2.5, 5, 10, 15, 20, and 25 MHz); WWVH (2.5, 5, 10, 15, and 20 MHz); WWVB (60 kHz); and WWVL (20 kHz). While that combination of services provided T/F users with nearly worldwide coverage and accuracies extending to about 1 μs for time and better than 1×10^{-12} for frequency, propagation conditions sometimes limited the reliability of reception, particularly in some geographical areas. It became increasingly apparent after the mid-1960s that improvements in the dissemination services were needed in order to respond to the widening use of atomic frequency standards in particular, and more sophisticated T/F technology in general.

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NBS has attempted to respond to these changing needs and opportunities since 1967 by improving its existing services wherever possible and by introducing new services with improved capabilities. Although the WWVL 20-kHz service was discontinued in 1972 due to the availability of the worldwide system of 8 Omega Navigation System VLF broadcasts in the same general frequency range, the remaining NBS services were upgraded by providing more useful broadcast formats, new station facilities, with more reliable equipment, and broadcast schedules that do not require periodic shutdowns for maintenance operations. Today these NBS broadcast services continue to serve an extremely large number of T/F users who need only moderate accuracies and want to invest only modest amounts of money and time. Details about these current NBS broadcast services may be found in [2].

The newer NBS services have been designed to fulfill user needs for higher accuracy, easier and more reliable availability, and, in some cases, on-site NBS-supported turnkey systems furnished on a reimbursable basis. These services are briefly described in the remainder of this paper. More complete information may be obtained from the Time and Frequency Division, National Bureau of Standards, 325 Broadway, Boulder, CO 80303.

GOES SATELLITE TIME CODE

Since the mid-1970s, NBS has disseminated a time code providing complete time-of-year information on a continuous basis to most of the western hemisphere using two geostationary GOES (Geostationary Operational Environmental Satellite) satellites owned by the National Oceanic and Atmospheric Administration (NOAA). The time codes are uplinked to the GOES/EAST and GOES/WEST satellites located at 75° West and 135° West longitude, respectively, from an NBS system of atomic frequency standards and related equipment at Wallops Island, VA. Users may receive these signals from the satellites on two frequencies near 468.8 MHz using readily available commercial time code receivers.

The time code contains both time-of-day information and satellite-position information, thus providing users with options to use the time code at two different accuracy levels. In the simpler mode, the time information can simply be decoded and used without taking into account variations in the satellite position and, thus, also in the signal path delay. Since the time code is advanced by 260 ms as transmitted, corresponding approximately to the mean path delay, and since the user can apply a fixed correction to the received data to account for his particular geographical location, the usable accuracy in this mode can be as good as 1 or 2 ms. Daily variations in the received time code due to changes in the satellite position are generally less than 1 ms as evidenced by years of GOES time code monitoring [3].

For applications requiring higher accuracy, commercial time code receivers are also available that process the satellite position information in the code, in conjunction with the known location of the receiver and time code origination point, to generate path delay corrections that are updated every minute. The resulting timing reference from such receivers can provide long-term accuracies with respect to UTC(NBS) of better than 100 μs [3].

NBS Frequency Measurement Service

Many organizations with a need for frequency calibrations with NBS traceability would apparently prefer not to dedicate the necessary personnel and time resources to developing and maintaining an appropriate measurement system. In recognition of this, NBS recently introduced a new Frequency Measurement Service designed to satisfy such needs [4]. For a one-time initial startup fee and an annual charge thereafter, NBS can provide a complete, turnkey, traceable frequency calibration system at the user's site, including initial installation, operator training, consultation, regular verifications that the system is functioning properly, and all necessary equipment maintenance and replacement support. The customer is responsible only for providing the signals to be calibrated and a telephone line for a modem connection to NBS.

The system includes either Loran-C or WWVB receivers, a microcomputer system controller, disk drives for data storage, time interval counter, printer, monitor, modem, and all necessary software for the system to operate in an automatic mode. Frequency measurements at the user's location can be compared with corresponding measurements made regularly at NBS using the dial-up link to insure traceability to the primary NBS standards. Results of the measurements can be easily plotted at any time by the customer. Though intended primarily for frquency measurements, the system is also capable of timing measurements using the received Loran-C to generate a stable 1-Hz reference pulse.

The inherent stability of the received LF signals permits frequency calibrations with accuracies of 1×10^{-12} in one day and approaching 1×10^{-13} after several weeks. Time comparisons to better than 1 μs are also practical.

Time Dstribution Via GPS Satllites in Common View

The GPS (Global Positioning System) satellite system operated by the Department of Defense offers many advantages for precise time transfer due to the use of atomic frequency standards in orbit, precise satellite orbit determination, redundancy through multiple satellites (at least 18 when the system becames fully operational about 1988), and worldwide coverage. The L-band signals from the satellites contain precise time and satellite ephemeris information in several forms, some of which are available for general civilian use. NBS has developed techniques and equipment for making extremely precise time transfers on a nearly global scale through the simultaneous and common-view observation of a GPS satellite by two or more participating laboratories. The common-view technique is particularly useful, because many of the potential measurement uncertainties, such as clock or ephemeris errors, are significantly reduced from the common-mode cancellation. Almost any two locations can take advantage of the common-view approach at some time because the 12-h, inclined orbits used by the GPS satellites provide many suitable opportunities at reasonable elevation angles.

The high-accuracy potential for time comparisons of 10–50 ns over intercontinental distances offers a superior means for routinely comparing primary frequency standards and time scales maintained by various international laboratories [5]. Using this technique, the primary national frequency standards of the U.S., Canada, Federal Republic of Germany, and Japan are routinely being compared with precisions of better than 1×10^{-14} with averages over about one week. This is more than a factor of 10 better than can be achieved using Loran-C, which was the basis for these comparisons during the 1969–1983 period. The GPS capabilities are being used to provide improved input data into the formation of the International Atomic Time Scale, TAI. Within the U.S., the GPS comparisons are used to regularly monitor differences between the UTC time scales of NBS and the U. S. Naval Observatory with a precision of a few nanoseconds.

In recognition of the outstanding T/F-transfer capabilities offered by GPS, the NBS recently initiated a Global Time Service designed to function similarly to the Frequency Measurement Service described above, but at higher accuracy levels in the 10–50-ns range. NBS provides, for an annual fee, all necessary GPS receiving equipment and required equipment calibration, maintenance, and replacement. The system operates in total automatic mode and internally logs more than one week of data on multiple satellites. The time comparisons of the local clock and the various GPS satellites can be set to automatically occur at times when common view exists between the customer's location and NBS or any other site. NBS monitoring data are accessible to the customer at any time via dial-up telephone link.

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