RECENT CHANGES AND FUTURE TRENDS IN NBS TIME AND FREQUENCY DISSEMINATION SERVICES

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ABSTRACT

During the past two years a number of improvements have been made in the NBS Time and Frequency (T/F) Dissemination Services. These range from making the WWVB 60 kHz broadcasts available on a continuous basis to implementing a new nationwide frequency calibration service using television techniques. NBS now provides regularly published calibrations of both the East Coast and the West Coast commercial TV network subcarrier frequencies for use as a transfer standard. With these data a user anywhere with access to a TV network signal can easily and inexpensively determine his oscillator's frequency. An accuracy of a few parts in 10^{11} relative to the NBS Frequency Standard is obtainable with only 15 minutes measuring time. Several versions of NBS-developed user equipment are described, covering a broad range of required user involvement, cost, and complexity.

During the first half of 1975 the NBS conducted an extensive survey of WWV/WWVH users to obtain their views relating to possible reductions in the present broadcast services. A summary of the results of this survey, based on about 12,000 responses, is included along with a discussion of possible actions to be taken by NBS to reduce operating costs of these services. Future trends in NBS T/F dissemination services are discussed with special emphasis on the objectives and major milestones of the NBS program to disseminate T/F information via satellite. The NBS program to provide an eventual full WWV-type service via satellite on the internationally allocated 400.1 MHz frequency is outlined, including its present status. Current efforts are centered on providing experimental time code transmissions from one of NOAA's GOES geostationary satellites and on developing detailed requirements for the later permanent service.

INTRODUCTION

Since 1923 the National Bureau of Standards (NBS) has distributed highly accurate time and frequency (T/F) reference signals via radio broadcasts. Throughout the years many improvements have been incorporated into these broadcasts to provide greater coverage, easier-to-use information, more reliable reception, more useful formats, and higher accuracy. Some of the major milestones along the way are included in reference [1], which is a general description of the present NBS time and frequency dissemination services.

For many years the high-frequency (HF) time and frequency signals broadcasted from NBS station WWV (and since 1948 from WWVH in the Pacific area) were generally adequate to meet the needs of most users. The inherent reception accuracy limitations of about 1×10^{-7} in frequency and 1 ms in time, imposed mainly by variations in the propagation medium, caused significant problems in relatively few application areas. More recently, however, as the state-of-the-art in T/F technology advanced rapidly and as more and more applications came to depend in important ways on T/F technology, it became apparent that improved T/F dissemination methods were needed. The NBS responded in the 1960's by inaugurating low-frequency (LF) broadcasts from WWVB on 60 kHz and very-low-frequency (VLF) broadcasts from WWVL on 20 kHz. These broadcasts provided widespread T/F reference signals that were much less affected by the propagation medium. Under favorable reception conditions, where measurement averaging times could be extended to many hours or days, the LF and VLF signals permitted frequency comparisons to 1×10^{-11} or even better and time (phase) comparisons at the microsecond levels.

During the same period NBS began to explore other methods for distributing T/F information that might potentially offer better accuracy, reliability, coverage, and convenience than the radio broadcast services. Eventually, three dissemination techniques which seemed to offer the most promise were selected and funded for further development into new NBS T/F dissemination services. In all three cases the basic T/F information was to be "piggybacked" onto existing widespread information-distribution systems, consisting of the nationwide television network facilities, certain satellites of opportunity, and the Omega Navigation System broadcasts.

The following sections of this paper describe the progress to date and the relevant future plans for implementing and improving these new NBS services. In addition, conclusions and potential implications from the recent survey of 12,000 WWV/WWVH users are summarized.

WWV/WWVH SURVEY CONCLUSIONS

During the first half of 1975 NBS conducted an extensive survey, by questionnaire, of WWV and WWVH users. The survey was motivated by a desire on the part of NBS to explore various means for reducing the broadcast services' operating costs with as little adverse effect on the users as possible. While the survey was designed to identify those transmission frequencies or features of the format that might be discontinued with some net cost and/or energy savings, it was also recognized that the responses could provide other valuable information about the broadcast services and those who use them.

A single-page questionnaire was designed, which allowed the user to indicate his use and estimate the importance of each of the WWV/WWVH frequencies and the different forms of information contained within the broadcast format. Information was also requested on the user's geographical location, reception conditions, classification, and particular application. Space was provided for additional miscellaneous comments.

The questionnaires were distributed as widely as possible by a variety of means. About 1,500 copies were sent to those on NBS Time and Frequency Division mailing lists, and another 13,000 went to lists compiled by several yachting/boating organizations and the National Weather Service. The availability of the questionnaire was announced in voice several times per hour on both WWV and WWVH. A number of magazines and other publications, with combined circulation of several hundred thousand, printed editorials or brief publicity items about the survey. Finally, at least 10 periodicals, with a combined circulation of about 250,000, published the questionnaire itself. At the end of the survey period a total of 12,050 completed responses had been received. Twenty-three per cent of these responders purported to "officially" represent more than their own individual use of the services.

Figure 1 shows the geographical distribution of the responses. Every continent is represented in the totals. Figure 2 indicates how the users classified themselves within the 14 possible categories given on the questionnaire. In retrospect, it is now clear that three major categories were overlooked and hence tend to be lumped into the "other" group. These three are private citizen, watchmaker/jeweler, and amateur radio operator. It should be noted that in many cases users checked more than one classification category, resulting in the totals in figure 2 being greater than the number of individual questionnaires returned.

Figure 3 shows the relative use of WWV, WWVH, and the telephone time-of-day service from WWV available via the regular commercial number (303) 499-7111. The 0-3 numerical rating in each case is a weighted average of all responses where the weights 0, 1, 2, and 3 have been assigned to the four choices given on the questionnaire for "Frequency of use"--i.e., "Never," "Rarely," "Sometimes," and "Frequently," respectively. While WWV is obviously the most-used service, it is interesting to note that the least-used service, the telephone time-of-day service, receives more than one million calls per year.

Figure 4 summarizes the data on how often the various WWV/WWVH broadcast frequencies are used, again using the same 0-3 scale discussed above. Clearly, most users depend on the 5, 10, and 15 MHz transmissions. These results are not really surprising, of course, since (1) the radiated power is highest on these frequencies, (2) many commercial receivers are designed to receive 5, 10, and 15 MHz only, and (3) the present phase of the sunspot cycle tends to adversely affect the propagation characteristics of the higher frequencies of 20 and 25 MHz.

Figure 5 displays the rating (on the 0-3 scale) for each of the 14 user categories and for each of the 8 services provided by WWV and WWVH. Also shown on the matrix are the overall ratings and the sizes of each of the user categories. The 0-3 numerical ratings within the matrix represent the concensus response for a given population (i.e., a specific user group) with respect to one of the 8 WWV/WWVH services. The specific number is a weighted average of the individual responses to the question: "To what extent do you use the following information (followed by a list of the 8 services)?", where the numbers 0, 1, 2, and 3 refer to "Never," "Rarely," "Sometimes," and "Frequently," respectively, as before. The overall ratings given in the "Services" column provide a composite score for each service based on the responses of all users, irrespective of their particular user category. The most obvious features of the matrix are that the voice time-of-day announcements are uniformly the most used aspect of the WWV/WWVH broadcasts, and the DUT1 values are uniformly the least used.

The questionnaire also invited the participants to make any miscellaneous comments about the WWV/WWVH services. More than 5,000 of the responders took advantage of this opportunity. A few of the more frequently recurring suggestions include:

a) Do not reduce radiated power--reception is already marginal
b) Add NBS time signals to VHF weather broadcasts
c) Reinstate time signals in Morse Code
d) Add weather information for the continental U. S.
e) Add one or more low-power repeater stations on the U. S. East Coast
f) Provide more detailed weather, geoalert, and radio propagation information and do it more often than once per hour
g) Reduce costs by eliminating some frequencies (2.5, 20, and 25 MHz were mentioned most often)
h) Make the WWV-by-phone number a toll-free service from anywhere in the U. S.

For a representative selection of verbatim comments taken from the returned questionnaires, as well as for more detailed results from the survey in general, see reference [2].

POSSIBLE CHANGES IN NBS BROADCAST SERVICES

As of this date (November, 1975) final decisions have not yet been made on possible reductions in WWV/WWVH services. The survey did reveal, however, that the present services are heavily used and strongly supported--especially, the primary frequencies of 5, 10, and 15 MHz. As a result, it is clear that there will be no reductions in service on at least those frequencies. If any service reductions do become necessary, the data in figure 4 suggest that minimal impact on users would result if reductions are confined to one or more of the 2.5, 20, or 25 MHz transmissions.

One cost-reduction plan under active consideration would couple the elimination of some of the lesser-used transmission frequencies with the implementation of partially automated operation at WWV and WWVH. The transmitters freed by the reductions in service would become dedicated backups for the primary 5, 10, and 15 MHz transmissions, with highly automated switchover systems to provide high reliability with unmanned operation. By thus reducing labor costs, substantial savings may be realizable which could then be used in the continued development of new improved T/F dissemination services, such as a satellite-based operation.

NEW/EXPANDED NBS T/F DISSEMINATION SERVICES USING TELEVISION

Time Comparisons Using Line-10 Method

The time comparison technique known in the U. S. as the line-10 method was first used successfully in Czechoslovakia during the mid-1960's [3]. The technique basically consists of using a particular horizontal synchronization pulse in the normal television picture format (tenth line of the vertical interval, odd field) as a passive transfer standard for comparing two clocks within common view of the television transmission [4]. The method may be used either locally, where the two clocks can be compared with the TV pulse from a single TV station, or over widespread geographical areas, where the same network broadcast can be received simultaneously at both sites. In the local mode clock comparisons to 100 ns or better are possible (if the differential path delay is known sufficiently well), while comparisons to a few microseconds are usually possible using network transmissions to link widely separated clocks.

For several years both NBS and the U. S. Naval Observatory, as a service to users interested in making time comparisons with the NBS and USNO master clocks, have published regularly their calibrations of the three commercial TV networks' line-10 pulses at selected specified times each day [5,6]. A user wishing NBS traceability, for example, need only compare his local measurement of the received line-10 pulse with the similar measurement for that network published by NBS. Even if the appropriate path delay is not known for the local measurement, repeated comparisions--e.g., on a daily basis, can show easily whether the local clock is gaining or losing time relative to the UTC(NBS) time scale, assuming the unknown path delay remains constant. Possible changes in the network path delay can usually be detected by comparing results from measurements on two or three networks, since delay changes are usually uncorrelated.

One limitation in the past on use of the line-10 method has been the lack of NBS traceability for users in the western U. S. (Pacific Time Zone). The problem existed because: (1) the TV network signals available to West Coast users are originated in Los Angeles independently of the New York-originated transmissions; and (2) only the East Coast networks can be received and thus calibrated by NBS in Boulder, Colorado.

Since August 1975, this limitation has been removed through a cooperative measurement program between NBS and the Hewlett-Packard Co. in Santa Clara, California. Daily measurements of the major West Coast networks' line-10 pulses are made at Hewlett-Packard Co. and then referred to the UTC(NBS) time scale by using the known relationship between the local time scale maintained in Santa Clara and UTC(NBS). The uncertainty in the West Coast-NBS link is about 1 μs. The publication [5] of both the West Coast and East Coast line-10 data referred to UTC(NBS) thus makes the technique useful on a nationwide basis. Commercial equipment to use this service is now available from several sources for several hundred dollars.

Frequency Comparisons Using 3.58 MHz Color Subcarrier

Use of the network television subcarriers as frequency transfer standards was first proposed by NBS more than four years ago [7]. Advantages include a high-resolution, stable signal originated from rubidium frequency standards at the three commercial television network operating centers in New York and Los Angeles. The frequency offsets of the network rubidium standards are measured daily and published in the NBS Time and Frequency Services Bulletin. Triple redundancy (3 networks) assures the user of a reliable signal traceable to NBS with uncertainty of less than $\pm 3 \times 10^{-11}$ for 15-minute averaging times. This represents almost four orders of magnitude improvement over HF calibration, using WWV or CHU. WWVB on 60 kHz can usually provide a calibration uncertainty of $\pm 3 \times 10^{-11}$, but only with many hours of averaging time.

The general concept of the new NBS frequency calibration service via television is illustrated in figure 6. The user, located anywhere within the U. S. where he can receive a network-originated program from one of the three commercial networks, simply makes a frequency comparison of his local oscillator with the network color subcarrier frequency available from a slightly modified color TV set. A comparison of this measurement result with the published frequency offset for that same network as calibrated by NBS provides the NBS-traceable calibration of the local oscillator. NBS has also devoted considerable effort to encouraging the commercial development of several forms of user equipment based on this technique.

As in the line-10 case discussed previously, NBS calibration of the TV network signals on a nationwide basis is complicated by the fact that East Coast and West Coast originated network signals, and hence the color subcarrier frequencies involved, are generated independently. The situation is illustrated in figure 7. The East Coast network signals are received in Boulder and calibrated directly. The West Coast-originated signals are measured via an NBS automated measurement system located in Los Angeles. The comparisons are made with respect to the ABC East Coast signal which is transmitted into the Los Angeles area for internal network use, thus providing a link between measurements made in Los Angeles and Boulder. This extension of the frequency calibration service via television to users in the Pacific Time Zone has been operational since April 1975, when NBS began regularly publishing the frequency offsets for the West Coast networks in its Time and Frequency Services Bulletin.

NBS has developed four versions of user equipment for measurement of the frequency offset between the 3.58 MHz network subcarrier and the oscillator to be calibrated. All methods depend on measurement of the period of the "beat note" between the network subcarrier and the oscillator being calibrated. Typically, this beat note period is approximately 9.3 seconds for the nominal -3000×10^{-11} offset of the network subcarriers.

The simplest version, known as the color bar comparator [8], connects easily to the antenna terminals of any color TV set and generates a colored bar on the screen. The colored bar cycles through a changing color sequence at a rate which depends on the frequency offset between the oscillator to be calibrated and the TV network subcarrier frequency. The measurement is made by manually timing with a stopwatch the period of the changing color cycle and performing a simple calculation with the result. Accuracies of 1×10^{-9} to 1×10^{-10} are possible. Commercial versions are available for about $100 plus the cost of the TV receiver.

The second version of NBS-developed user equipment requires a slight modification to the TV receiver but provides a square wave output of the beat note [8]. The period of the beat note may then be measured on any digital counter. A phase cursor output is provided for coarse frequency adjustment. A commercial version of this type is also available which displays the period measurement on an LED display and provides accuracies of about 1×10^{-10}.

A more accurate and easy-to-use beat note calibrator is called the "NBS System 358 Frequency Measurement Computer" [8]. This unit, shown in figure 8, provides a multiple digital readout of the frequency offset between the oscillator being calibrated and the network subcarrier. Operation is completely automatic, with multiple cues for easy user interpretation.

This display is presented on the screen of the 5-inch color televison receiver that also is used to supply the 3.58 MHz signal that is phase-locked to the network color burst.

The network rubidium standards are offset a nominal -3000×10^{-11} with respect to the NBS Frequency Standard. When a phase comparison is made with a locally generated 3.58 MHz signal with zero offset, the result is a full cycle of phase difference, or a "beat note" with a period of about 9.3 seconds. The offset computer measures the period of each beat note cycle and digitally computes the corresponding offset for that beat note period.

The left column of 4-digit numbers displayed is the offset readout for the ten most recent beat note periods, about 93 seconds of data at the nominal -3000×10^{-11} offset. Each of the 4-digit numbers in the right column is the average of ten readings in the left column. An average of the right column would therefore represent about 900 seconds, or 15 minutes of data.

The phase cursor provides an analog indicator of the phase difference between the local oscillator being calibrated and the 3.58 MHz television signals. The phase cursor has a "sawtooth" response that provides advance/retard phase sensing. If the oscillator being calibrated is "on frequency," the phase cursor will move slowly from left to right and rapidly retrace right to left with a period of about 9 seconds. Frequency response of the phase cursor allows the viewing of beat notes greater than 2 kHz. The system can therefore view offsets approaching 1×10^{-3} while allowing the user to calibrate his oscillator with an uncertainty of a few parts in 10^{11}.

Use of the measurement computer requires practically no training. The only operator adjustments required are tuning the companion television receiver to the correct channel and pushing a "reset" button that resets the display to all zeros. With a few minutes of instruction, a technician should be capable of calibrating a stable crystal oscillator to within a few parts in 10^{11} in about 15 minutes. Commercial versions of this type of equipment are available for \$2000-\$3000.

Microprocessor Offset Computer (MOC)

A microprocessor version of the offset computer has recently been developed by NBS. A block diagram of the "MOC" system is shown in figure 9.

The "MOC" system was primarily developed to provide the TV network color subcarrier offset calibration published in the monthly Time and Frequency Services Bulletin. The microprocessor can store, and read out on command, four weeks (28 days) of data for each of the three networks plus a fourth comparison channel.

Figure 10 shows a one-week sample of microprocessor data for each network. In this case the "MOC" system was interrogated early on November 17, at which time only two or three 15-minute averages of each network's frequency offset had been accumulated for that day. The system then provides the daily averages for each network and the number of measurements acquired. A weighted average is also performed and printed out, using all valid 15-minute samples from the preceding seven-day period.

Although we have a very limited amount of experience with the "MOC", it appears that the standard deviation for weekly averages (30 hours of data/week) is less than 2×10^{-12}. This performance would improve in locations where more "live" network programming is available.

The microprocessor receives data from four independent "beat note" time interval counters. For network programming, and with a nominal offset of -3000×10^{-11}, the period measurement will be $\sim$9.3 seconds. (The four-digit counters utilize a 500 Hz time base and the actual BCD four-digit count is nominally 4650. The microprocessor normalizes the offset readings by dividing them into 13968250.)

Since the microprocessor operates 24 hours per day, it receives much more local station 3.58 MHz than live network. A three-step screening process is used to reject this "bad" non-network data. Each of the four data channels has a 16-digit "screening" word that can be entered through the keyboard interface. The format of the screening work is shown below:

300864 040 012 003 0

A B C D E

where group A = expected offset in parts in 10^{13};
group B = single period (1P) window in parts in 10^{11};
group C = 10 period (10P) window in parts in 10^{11};
group D = 100 period (100P) window in parts in 10^{11}; and
group E = 0 for ABC network, 1 for CBS, 2 for NBS, and 3 for the standard.

Each 10-second (1P) measurement is subtracted from the expected offset, and the absolute difference (without regard to sign) is compared to the 1P window. If the difference is less than the window, the 1P data are saved. After accumulating ten 1P values the screening process is repeated. All 10P data that pass are saved to form a 100P (15-minute) average. If the 100P data pass the screen, they are added to the daily total of 100P readings.

The expected offset of the screening word is changed weekly so that it is usually within 3×10^{-12} of the measured weekly average. The 3×10^{-11} 100P window represents at least 4σ for these data. The selection of the 1, 10, and 100P windows is a compromise between rejecting outliers and "skewing" the output data if the expected offset is in error.

The microprocessor, four comparators, four 4-digit counters and TTY interface are on a single 7" x 15" card. In one version, the microprocessor and power supply are in one 3 1/2" rack mount case, and the TV tuners are in a second 3 1/2" rack mount case. A second version will have the complete "MOC" in a single 7 1/2" x 16" rack mount.

FUTURE TRENDS: SATELLITE T/F DISSEMINATION

NBS has been studying the feasibility of introducing a new time and frequency service using geostationary satellites. This service would operate on the frequency of 400.1 MHz, a primary service allocation for space-to-earth broadcasts of time and frequency information.

Studies at NBS have indicated a growing need to improve the quality of our time and frequency broadcasts. They are deficient for many applications in terms of signal reception reliability, accuracy, and their ability to be processed by the user's equipment automatically.

Past experimental efforts by NBS with geostationary satellites--i.e., ATS-1, ATS-3, ATS-6, LES 6, TACSAT, and SMS-2, have verified the obvious superiority of satellite broadcasts to provide orders of magnitude improvement over our HF services via WWV/WWVH [9]. There are positive indications, also, that a satellite T/F service can save on operation expenses while still allowing for user equipment cost comparable to that required for WWV and WWVH.

The 400.1 MHz allocation is international in scope and is a primary service allocation. It confines the T/F emissions to within ± 25 kHz of the center frequency and also provides ± 25 kHz guard bands. Our studies and experiments indicate that this allocation can support a 1 μs time system with voice, ticks, tones, and an effective time code. User equipment can range from a low-cost receiver and antenna (a single quarter wave dipole) to a sophisticated system which automatically corrects itself for propagation delay and eliminates nearly all the interfacing so prevalent to terrestrial systems in existence today.

The service will not come into existence before the early 1980's, but definite plans are underway. Just recently NASA has agreed to begin a systems design and feasibility study, which should be completed by the end of FY 77.

As an interim step on the way to providing the permanent, complete T/F dissemination service on 400.1 MHz, NBS is currently transmitting an experimental time code on 468.825 MHz via NOAA's Synchronous Meterological Satellite/ Geostationary Operational Environmental Satellite (SMS/GOES) series.

The time code is used by NOAA in their data-collection program, where SMS/GOES meterological satellites collect data from remote observing platforms such as buoys, automatic weather stations, ships, aircraft, and balloons. Many of these platforms will use the time code to date the data as they are collected or to time order their data transmissions to the satellites. NBS designed and implemented the time code for these satellites. To ensure a proper interface of the time code with the data-collection platforms (DCP's), which both transmit and receive to and from the satellites, NBS designed digital clocks using random logic and the simplest and lowest cost microprocessor available at the time. The microprocessor approach to the digital clock design was taken because it offered the lowest cost and provided the flexibility to include or delete functions through software changes rather than through hardware redesign.

As of November 1975, only one satellite at 115° West Longitude transmits the time code. Very soon a second satellite will also transmit the time code. Long-range plans for these NOAA satellites call for the positioning of one satellite at approximately 135° West Longitude, another at 75° West Longitude, and a third to be an in-orbit spare. The approximate coverage for the time code from two active satellites is shown in figure 11. The coverage area outlined by the heavier line for each satellite applies for an elevation angle of 7°, while the larger area outlined by the lighter line is valid for 3° elevation angle. As these satellites deteriorate with age, replacement satellites will be launched. This planned configuration of satellites is expected to be in effect by early 1976.

The time information, a digital time code, is multiplexed into the interrogation format relayed by the SMS/GOES satellites. The format consists of a 15-bit, maximum-length sequence (MLS) for message synchronization, immediately followed by 31 bits comprising a (31, 21) binary BCH code. Four additional bits, beginning on each half second, precede each MLS sequence and comprise a BCD word of the time code.

Figure 12 is the interrogation message format: four time code bits followed by 15 bits of the message synchronization word and 31 bits of the address word. The pattern is repeated every 0.5 second at a 100 bits-per-second rate. The first bit of every time code character defines the UTC half-second mark. Figure 12 also shows the time code format; four bits are extracted from the interrogation frame every half second for 30 seconds. The first 40 bits is the time code synchronization message consisting of 10 BCD character A's beginning on the UTC minute mark and 10 BCD 5's beginning at the UTC half-minute mark. Following the code synchronization message are 10 BCD characters of the time code, followed by 13 BCD characters representing the satellite's current position in geocentric longitude and latitude and the departure in its radial distance form a reference orbit.

Time Code Distribution

The interrogation message is sent to the SMS/GOES spacecraft at S-Band and retransmitted to the earth through a global antenna at 468.825 MHz. The message phase modulates the carrier $\pm 60^{\circ}$ after being Manchester encoded. The interrogation message is received by data-collection platform radio sets (DCPRS), which provide the communication interface with rain and river gauges, ships, buoys, seismograph stations, tide gauges, and tsunami detectors. The DCPRS derives a bit rate clock from the received interrogation message which is used to decode the interrogation message.

When a DCPRS is addressed its stored data is transmitted to the satellite for relay to the Wallops Island Command and Data Acquisition Station (CDA). In some cases, such as the monitoring of seismic activities, it is desirable to label the data with the date of occurrence. Attempts to use internal clocks set by infrequent clock carries or by reception of HF or LF radio signals are expensive, labor intensive, and subject to an unacceptable failure rate. The time-of-year code in the interrogation format eliminates these disadvantages and provides the SMS/GOES Data Collection System (DCS) user with a cheap, reliable, and simple system for data labeling or any other time-ordered function required at remote sites or in difficult environments.

Figure 13 illustrates the time-code distribution. Derived from atomic clocks located at the CDA in Wallops Island, Virginia, the time code is combined with the current satellite position, multiplexed with the interrogation address and sync word and transmitted to the satellites at S-Band. The satellites transpond the signals back to earth at 468.825 MHz, where they are received by the DCPRS's.

Time Code Generation

NBS has installed, at the CDA at Wallops Island, Virginia, equipment to generate the time code and maintain Coordinated Universal Time (UTC) to within a few microseconds of the master clock at NBS in Boulder, Colorado. Figure 14 is a block diagram of the equipment. There are two atomic frequency standards, each driving a clock and format generator, making two independent systems. Each system provides the time code and satellite position to two DCS equipment racks for multiplexing into the interrogation channels of two SMS/GOES satellites. All components of each system are backed with rechargeable batteries with sufficient capacity to operate four hours without primary power. Should a failure be experienced in one of the time-reference systems, the other can be switched in while it is repaired. The frequency of the atomic frequency standards can be compared to the NBS Frequency Standard in Boulder, Colorado, using the television frequency comparison technique discussed previously in this paper. This comparison is accomplished by NBS staff at routine intervals. The satellite position is computed at NBS Boulder from orbital elements issued by NASA's Goddard Space Flight Center. A table of positions, with dates, is constructed at NBS and sent to Wallops Island by telephone. An automatic answering system interfaces the telephone line with a memory bank, which stores the table, valid for one week, for the two satellites. The time code format generator addresses the memory with the data (days, hours, and minutes) and fetches the currently valid position for multiplexing into the interrogation message.

The interrogation channels on both satellites are monitored continuously in Boulder. Any failure or drift of the clocks at Wallops Island is automatically noted for appropriate action.

Time Code Reception

The time signals sent from Wallops Island to the SMS/GOES satellites are advanced by the approximate time it takes the signal to travel from Wallops Island to the satellite's subsatellite point on the equator ($\approx$260,000us). The signals thereby arrive on the earth nearly on time.

In the case of the SMS-2, currently at 115° West Longitude, the 260,000μs advance means that the signals arrive at the earth's surface within 8ms of being "on time." The inclination and eccentricity of the satellite's orbit introduce a small "diurnal" component to this "apparent" delay. Figure 15 shows typical "diurnal" peak-to-peak values. An actual chart recording of this diurnal as received at the NBS labs in Boulder, is shown in figure 16.

For a time signal accurate to a few tens of milliseconds, the time code as received requires no delay corrections. Time to a few milliseconds requires the correction to compensate for the earth's spherical shape. Time to better than a few milliseconds requires the consideration of the "diurnal effect," which can be compensated for with the "tools" developed at NBS. Using the current satellite position provided in the interrogation channel format i.e., the satellite's longitude, latitude, and radius, the slide rule shown in figure 17 will calculate the delay to a 10μs precision. NBS also has programmed the delay calculation in the BASIC computer language and for programmable pocket calculators. This calculation will also be handled in an expanded version of an NBS designed microprocessor time-decoder-clock. The accuracy for the time code, using satellite-position data, has consistently been better than 100μs.

Decoder-Clock

NBS has designed a digital clock for direct connection to the DCPRS's. The digital clock is a device which achieves bit synchronization, interrogation frame synchronization, and time code frame synchronization to correctly reconstruct the received data bits into the time-of-year message and satellite position. The digital clock also contains an internal clock which is set by the satellite time code. If the satellite signal is lost for any period of time, the digital clock "flywheels" the internal time with an accuracy consistent with the quality of its internal oscillator. If an incorrect time message is received by the digital clock, (corrupted by noise or interference) the digital lock tends to ignore this incorrect time and accept only the correct time for comparison or resetting its internal clock. The initial design effort on the digital-clock used a random logic design approach and is shown in figure 17. A new design using a four bit microprocessor will soon be completed. The microprocessor design will be smaller, cheaper, and more reliable while providing flexibility to include, at the user's option, many features through simple software additions rather than difficult hardware modifications [10].

These features of the microprocessor digital-clock, as shown in figure 18, can include any or all of the following:

1. LED display of the time-of-year (TOY).
2. LED display of the satellite position.
3. LED display or BCD representation of delay corrections.
4. Standard code outputs such as IRIG-H, NASA 36, etc.
5. Automated delay corrections.
6. Interrogated outputs (TOY on demand).
7. Special rate outputs, 1 pps, 10 pps, 1/10 pps, etc.
8. AC or DC power input.

FUTURE TRENDS: OTHER METHODS

Several years ago NBS developed and evaluated a T/F dissemination technique involving the addition of an active time-of-day code to the vertical blanking interval of normal TV network program transmissions [11]. Modified television receivers could be used to decode and display the time information on the TV set screen. As a result of successful tests of the technique, using both local and nationwide TV network facilities, the Department of Commerce submitted a petition to the FCC, requesting permanent allocation of Line 21 of the vertical interval for use with this NBS TV-Time System. To date this petition has not been acted upon by the FCC. It is therefore unclear at this time whether the technique can ever be implemented on a permanent basis.

NBS also proposed the addition of a slow time-of-day code to one or more broadcasts of the Omega Navigation System [12]. The intent was to gain worldwide coverage with very high reliability at a relatively small incremental cost. In view of recent decisions by Omega personnel to prohibit any modulation of the Omega transmissions, NBS has suspended work on this technique for the foreseeable future.

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[6] "U. S. Naval Observatory Time Service Announcement, Series 4," published weekly.

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[12] HOWE, D. A., "Nationwide precise time and frequency distribution utilizing an active code within network television broadcasts," Proc. 26th Annual Symposium on Frequency Control (U. S. Army Electronics Command, Ft. Monmouth, NJ, June 6-8, 1972), pp. 292-308 (Electronic Industries Association, Washington, DC, 20006).

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LIST OF FIGURES

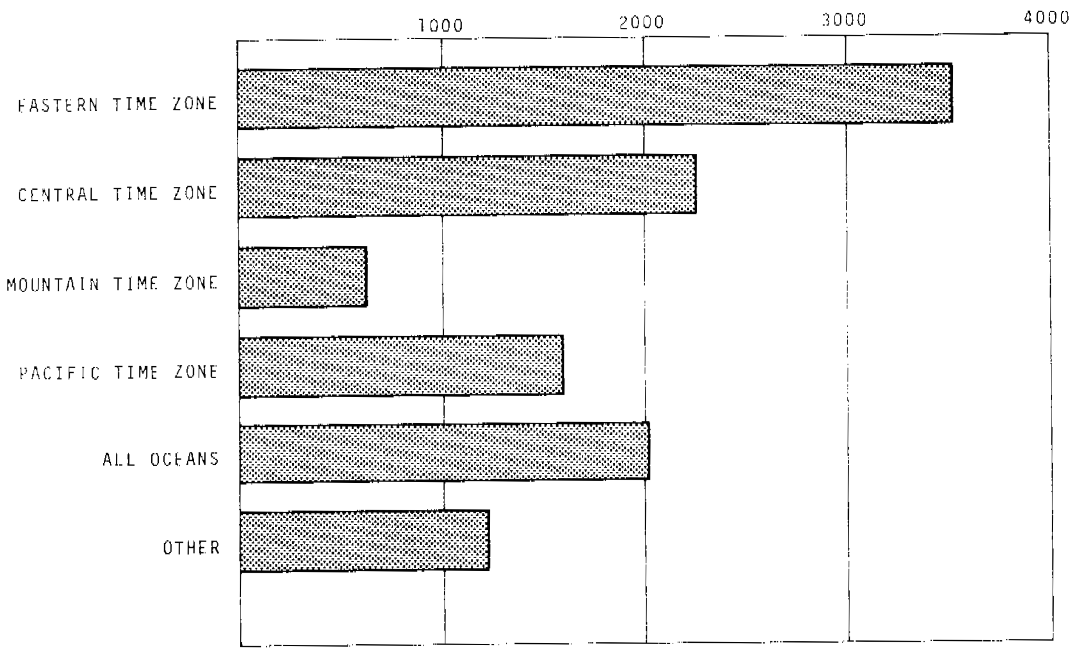

Fig. 1-Geographical distribution of responses

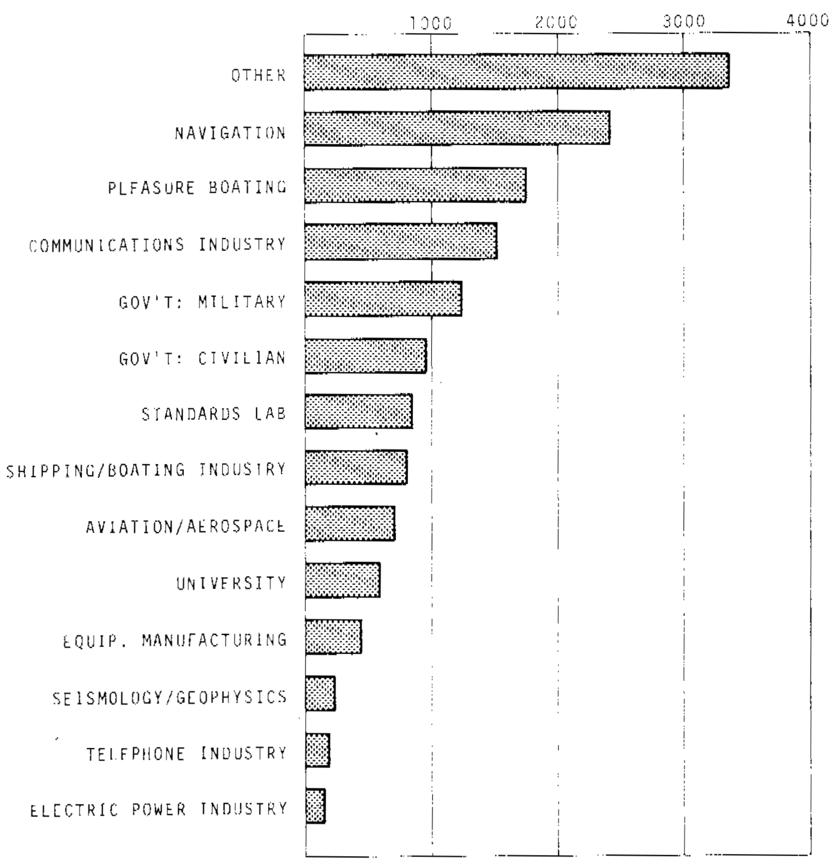

Fig. 2-Number of responses for each user category

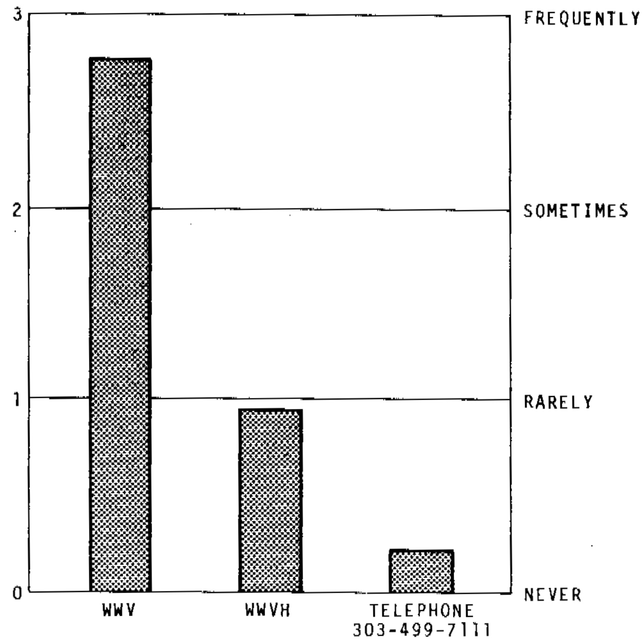

Fig. 3-Use of facilities

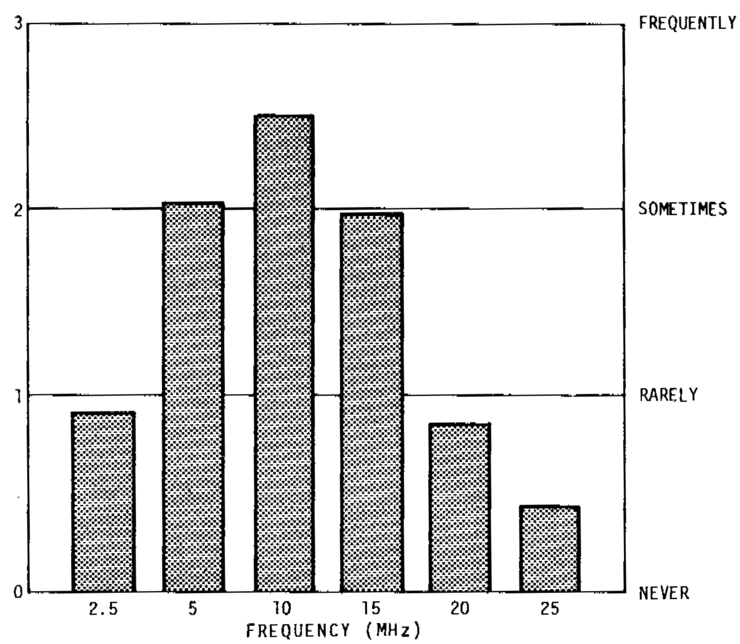

Fig. 4-Use of the broadcast frequencies

SERVICES (OVERALL RATING) \ USER CATEGORY (NUMBER OF RESPONSES)	OTHER (3318)	NAVIGATION (2385)	COMMUNICATIONS INDUSTRY (1492)	PLEASURE BOATING (1714)	GOV'T. CIVILIAN (955)	GOV'T. MILITARY (1227)	STANDARDS LABS (817)	AVIATION/AEROSPACE (693)	UNIVERSITY (577)	SHIPPING/BOATING INDUSTRY (791)	EQUIPMENT MANUFACTURING (424)	SEISMOLOGY/GEOPHYSICS (220)	TELEPHONE INDUSTRY (174)	ELECTRIC POWER INDUSTRY (148)
Time-of-Day: Voice (2.79)	2.84	2.78	2.81	2.72	2.76	2.67	2.60	2.85	2.86	2.81	2.77	2.85	2.68	2.62
One-Second Ticks (1.97)	1.98	2.07	2.13	1.91	2.15	1.83	2.28	2.19	2.32	2.27	2.27	2.45	1.90	2.12
Standard Frequency (1.74)	1.82	1.18	2.48	1.11	1.92	1.32	2.36	1.67	1.93	1.37	2.31	1.68	2.42	2.08
Propagation Forecasts (1.40)	1.52	1.04	1.88	0.99	1.36	1.02	1.44	1.40	1.51	1.19	1.55	1.57	1.64	1.27
Weather (1.35)	1.24	1.82	1.41	1.93	1.15	0.87	1.17	1.53	1.33	1.85	1.32	1.54	1.18	1.22
Geoalerts (0.92)	1.02	0.77	1.20	0.80	0.92	0.64	0.96	0.98	1.23	0.73	1.05	1.68	1.04	0.80
Time-of-Day: BCD (0.67)	0.55	0.83	0.83	0.63	0.82	0.76	0.75	0.88	0.81	1.06	0.75	1.13	0.67	0.77
DUTI Values (0.28)	0.25	0.25	0.41	0.21	0.34	0.29	0.47	0.38	0.47	0.24	0.42	0.45	0.31	0.38

Fig. 5-Use of services for each user category

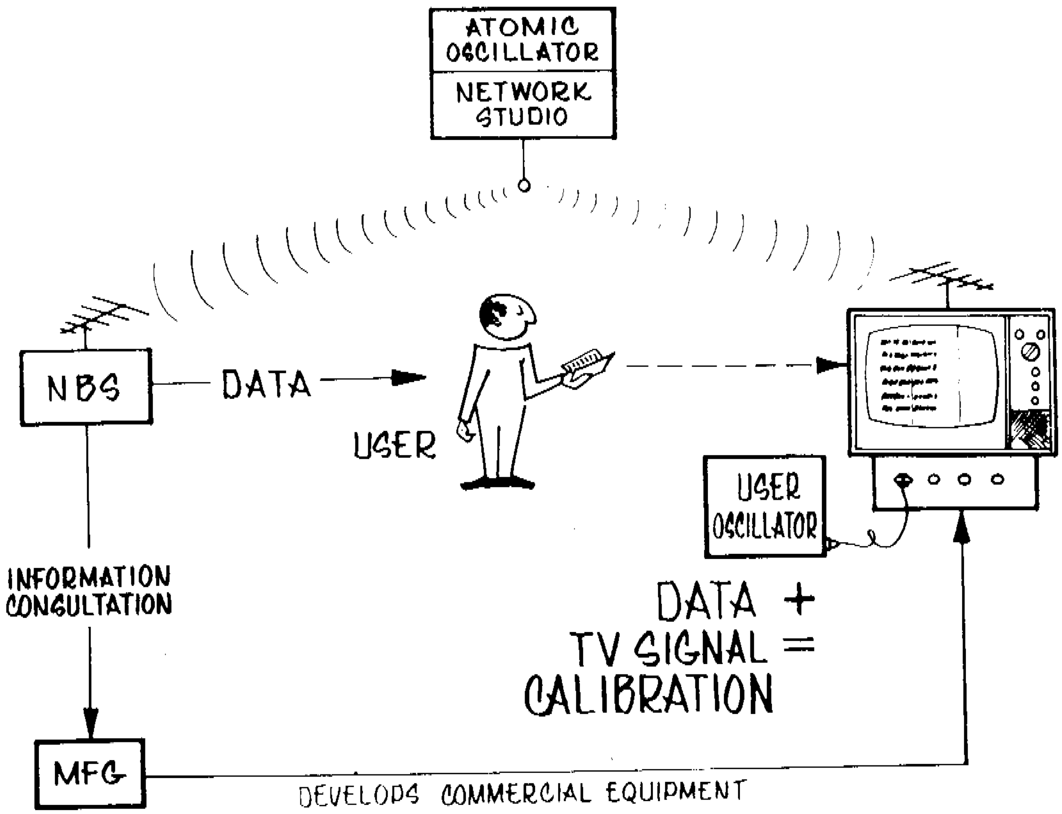

Fig. 6-TV frequency calibration service

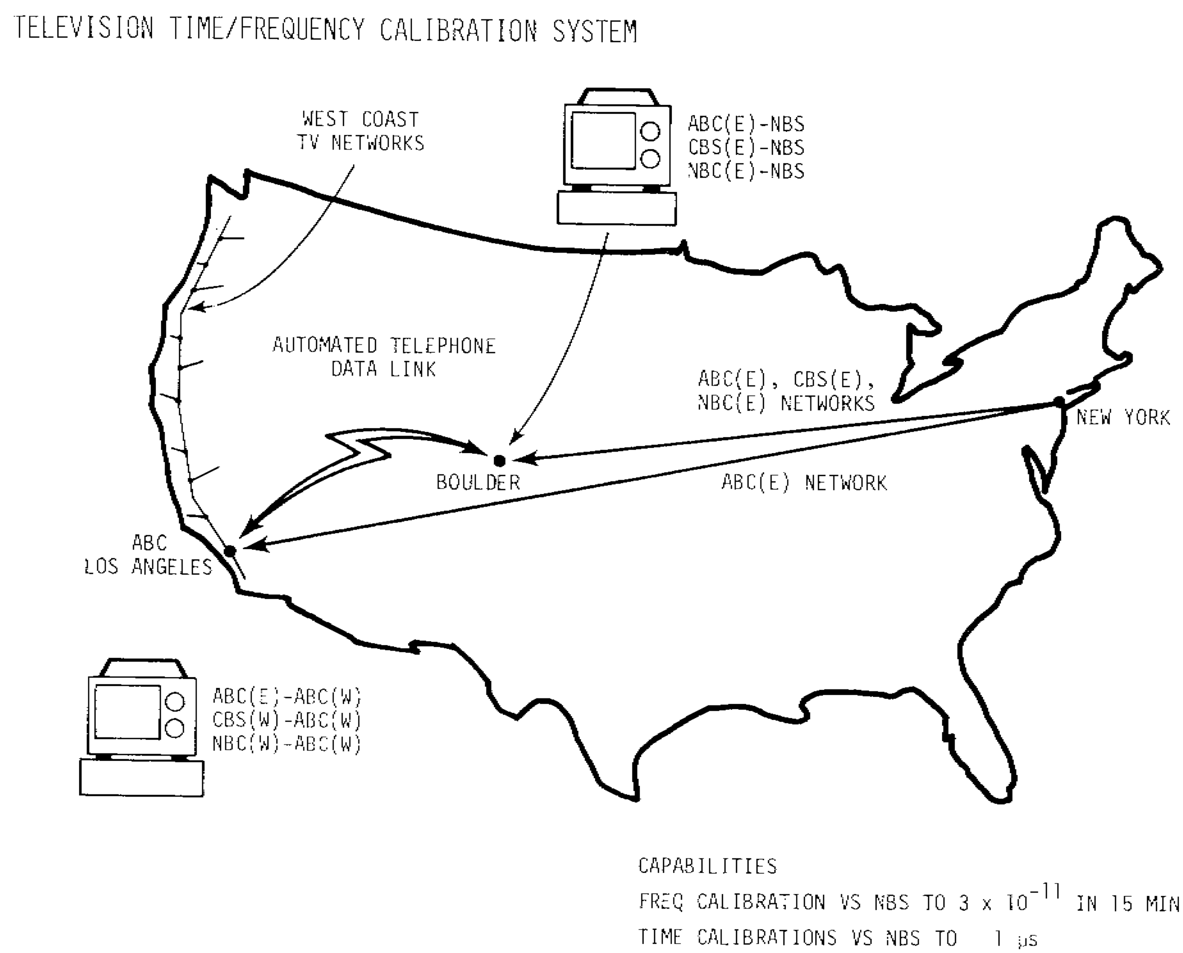

Fig. 7-NBS calibration of network frequency offsets

Fig. 8-NBS frequency measurement computer

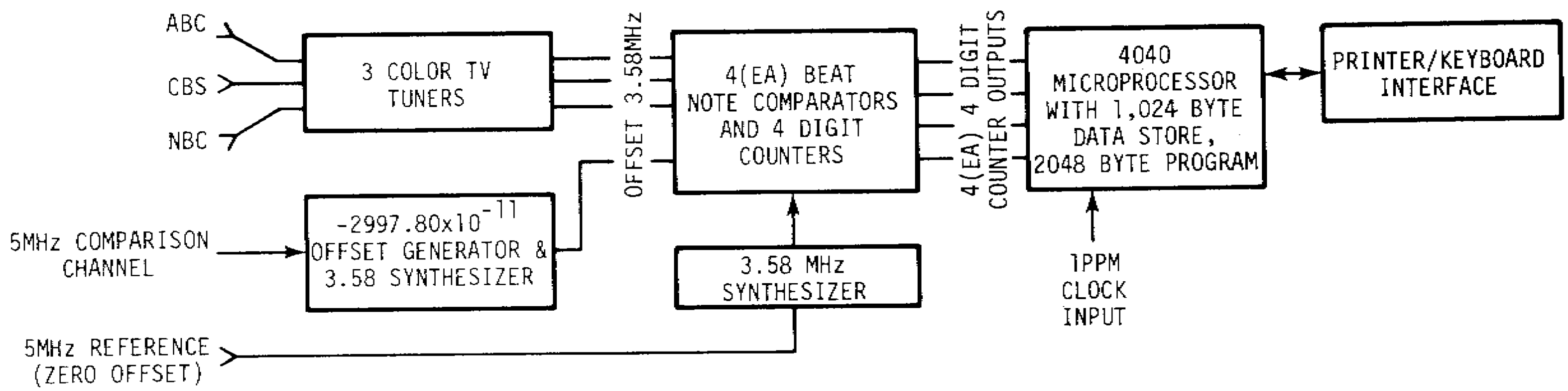

Fig. 9-Block diagram of microprocessor offset computer

NETWORK	DATE	NUMBER OF 15-MINUTE SAMPLES	AVERAGE FREQ. OFFSET PARTS IN 10^{11}
ABC	11/17	02	3012.61
ABC	11/16	03	3011.20
	11/15	31	3010.97
	11/14	17	3010.98
	11/13	18	3010.58
	11/12	16	3011.24
	11/11	14	3010.49
	11/10	20	3010.91
	Weekly Avg.	119	3010.88 (Weighted)
CBS	11/17	03	2962.53
CBS	11/16	07	2964.27
	11/15	20	2962.31
	11/14	07	2962.49
	11/13	04	2962.59
	11/12	04	2963.22
	11/11	05	2962.24
	11/10	04	2962.38
	Weekly Avg.	51	2962.69 (Weighted)
NBC	11/17	02	3018.68
NBC	11/16	00	0000.00
	11/15	16	3017.77
	11/14	14	3017.71
	11/13	15	3018.04
	11/12	15	3018.19
	11/11	13	3018.01
	11/10	14	3017.88
	Weekly Avg.	087	3017.93 (Weighted)

Fig. 10-One-week sample of microprocessor offset computer data

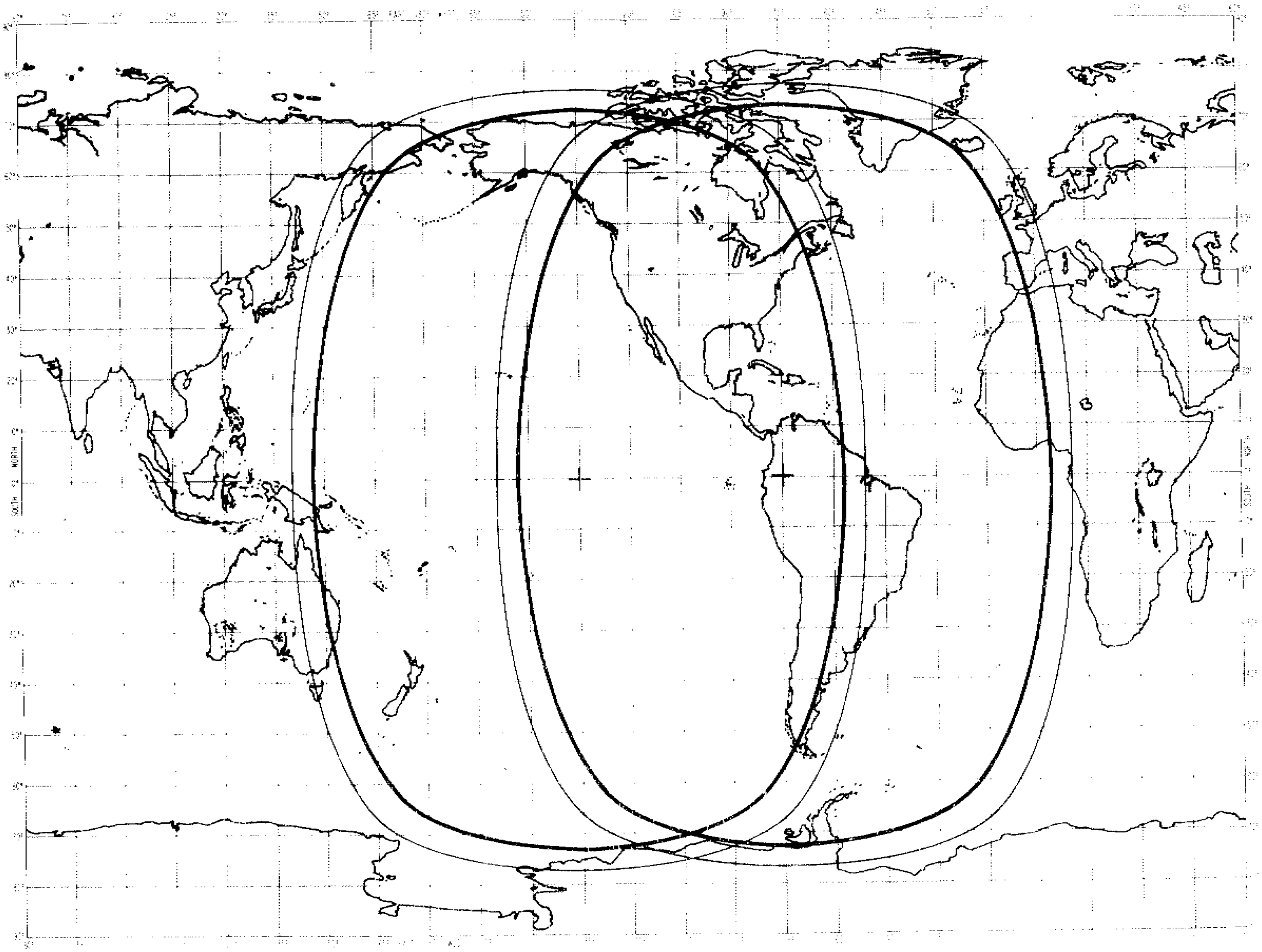

Fig. 11-Approximate time code coverage from two SMS/GOES satellites

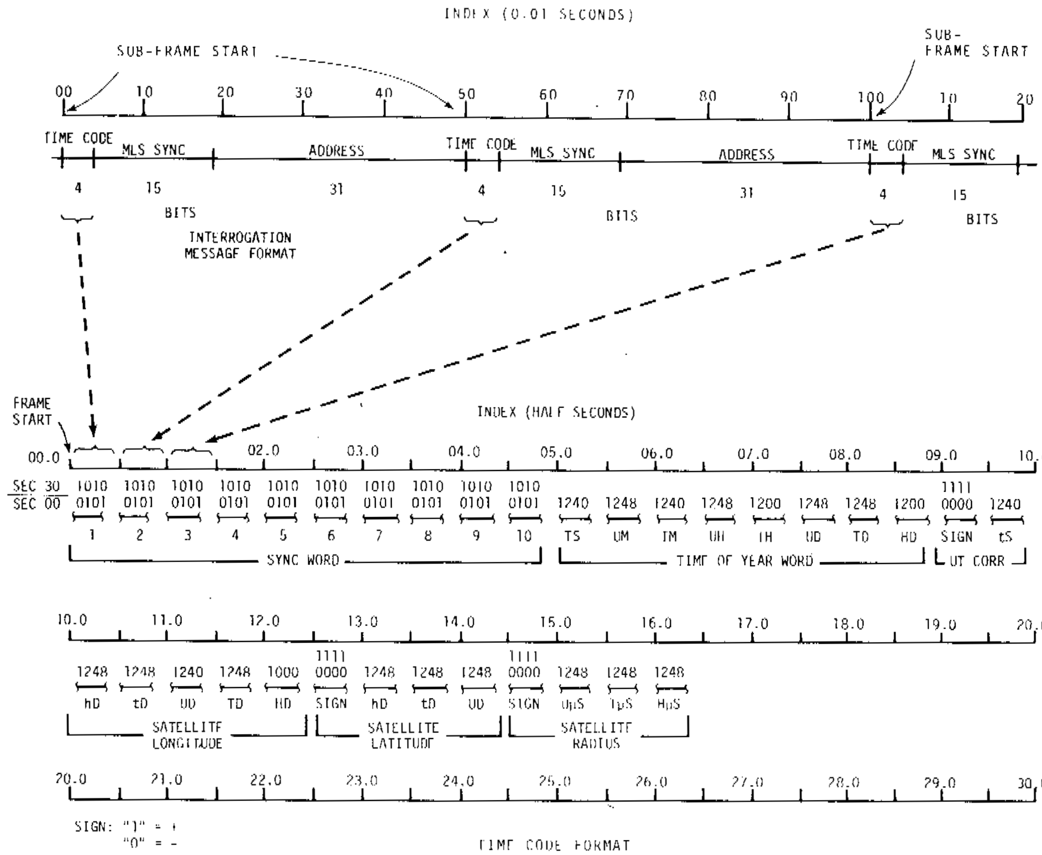

Fig. 12-SMS/GOES interrogation message format

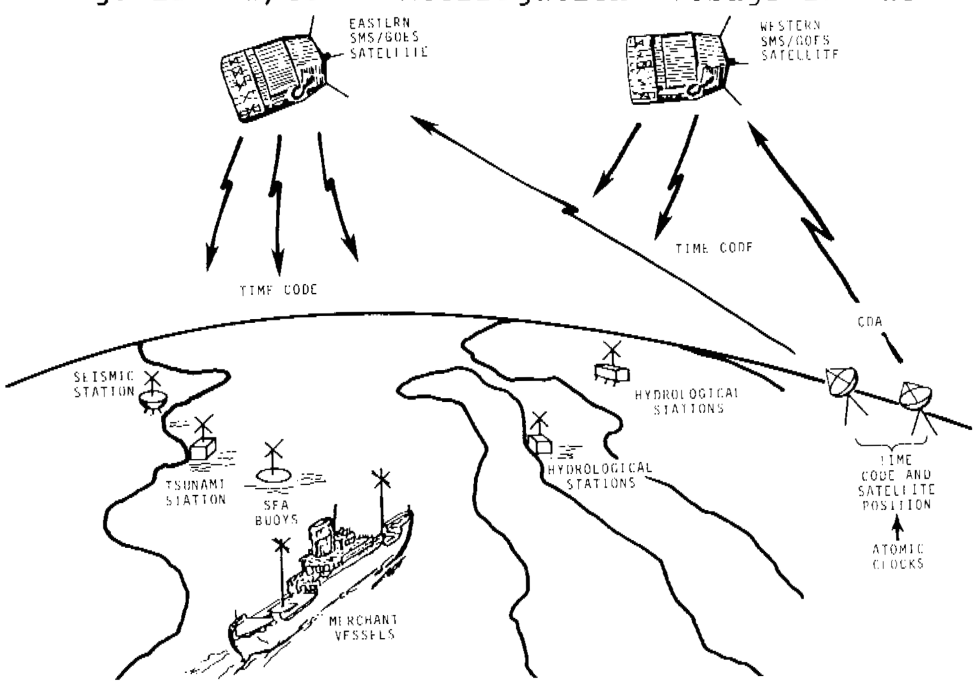

Fig. 13-Illustration of SMS/GOES time code distribution

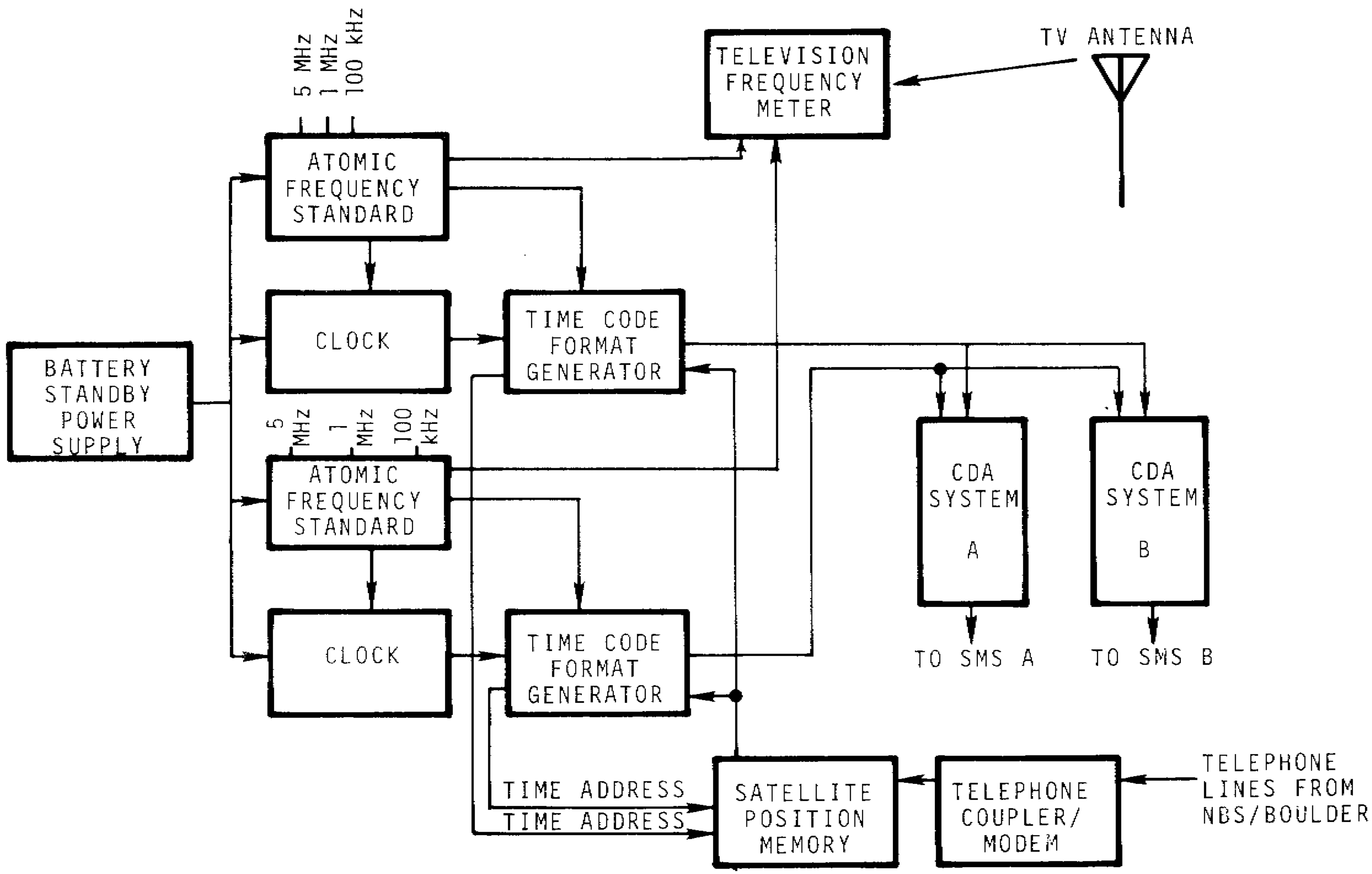

Fig. 14-Block diagram of SMS/GOES time code generation equipment

Fig. 15-Approximate diurnal component (peak-to-peak) of received time code from SMS-2 satellite

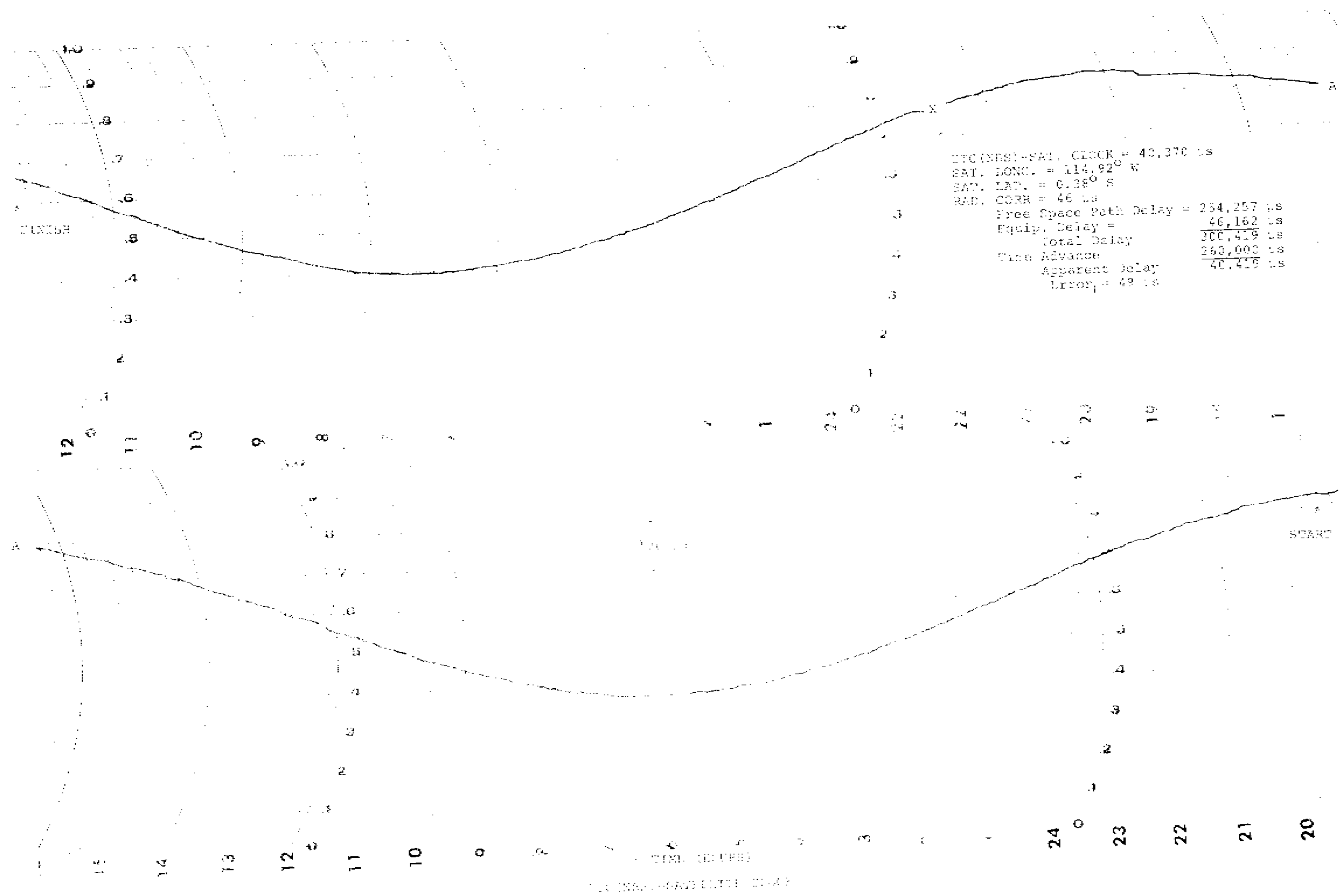

Fig. 16-Features of microprocessor version of satellite decoder-clock

Fig. 17-NBS-developed satellite decoder-clock and path delay slide rule

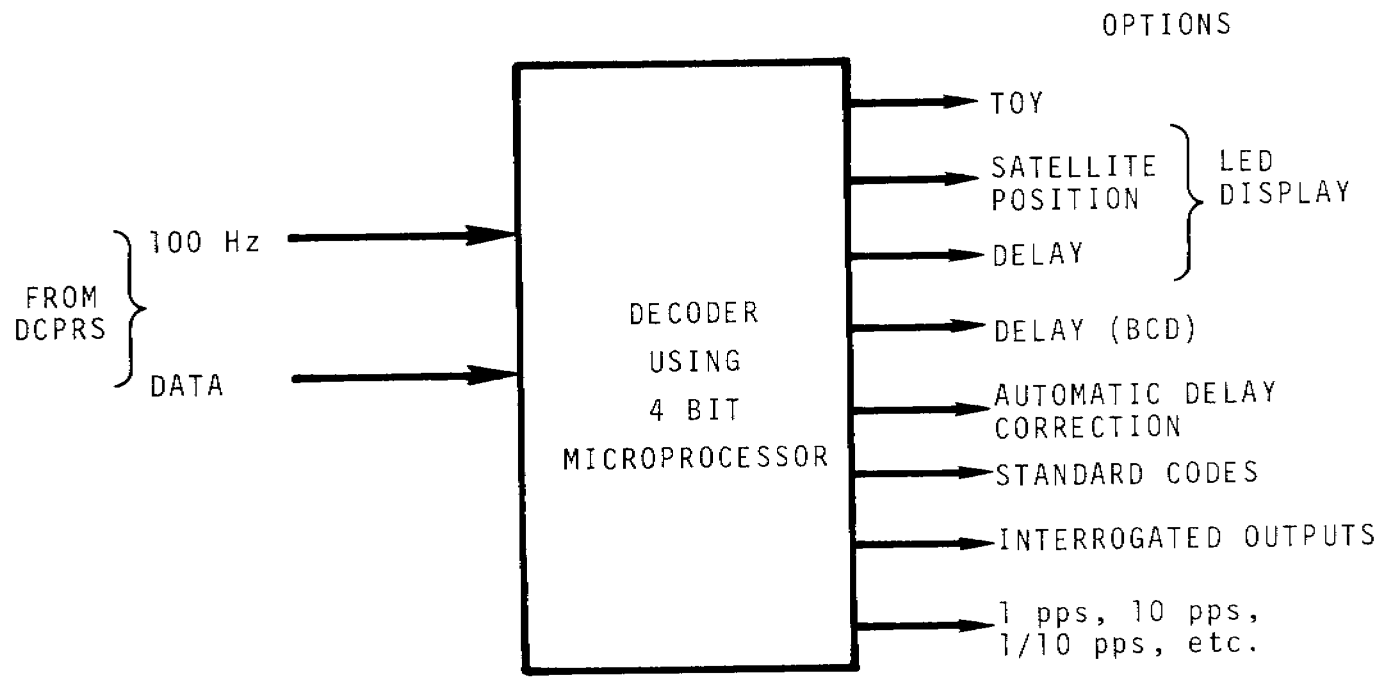

Fig. 18-Features of microprocessor version of satellite decoder-clock

QUESTION AND ANSWER PERIOD

DR. SHEPARD:

Shepard, ILC Industries.

I have several comments. One, I would like to make a suggestion that you may skew your responses if you put an in-watts on that time of day telephone line.

On the television frequency transfer, do you actually measure the frequency of the subcarrier or do you use the time difference measurements?

DR. BEEHLER:

At present, for the West Coast data we are actually using the time transfer, but we are in the process of putting another system out there which will really measure the frequency, using this microprocessor system that I mentioned.

DR. SHEPARD:

How about the East Coast?

DR. BEEHLER:

The East Coast is direct frequency measurement now.

DR. SHEPARD:

All Right. How long has this been in existence?

DR. BEEHLER:

The East Coast measurements have been done for several years. We did infer the East Coast measurements from time. I think it has been about three years. The West Coast measurements, we began publishing the offset, I believe, in the April 1975 issue of the Bulletin.

DR. SHEPARD:

But, the current East Coast data and the East Coast data for the past couple of years has been derived from the frequency rather than the day to day time difference.

DR. BEEHLER:

The East Coast data up until recently was by time difference measurement. Recently, we also switched over to the direct frequency measurement there.

DR. SHEPARD:

Okay. That was my question, because there were irregularities in the published data that would vary from week to week which would seem inconsistent with the rubidium and it was my impression that these would be due to phase changes in the program material depending on what was happening. If the World Series game was on, you get different average data by time measurement than you would by direct phase measurement.

DR. BEEHLER:

Yes, I think that is probably quite correct. In fact, that is the reason we have gone to the direct frequency measurement, it seems to be much more reliable.

DR. SHEPARD:

All right, now what is the situation on line 10, fields 1, 3, pulse edge reference at the present time?

DR. BEEHLER:

The situation?

DR. SHEPARD:

Leading edge versus trailing edge.

DR. BEEHLER:

We are using trailing edge, I believe, at the present time. There is some thought being given to making a switch at some point because the data would, indeed, be better, at least for some users if we did.

DR. SHEPARD:

There is no schedule, or nothing firm on that switchover yet?

DR. BEEHLER:

That is correct.

MR. RUEGER:

Rueger, The Johns Hopkins University

Do you have precedents for being able to phase out a service like the operation of WWV? It seems to me that some of the electronic navigation aids have been years trying to phase out the service and I don't think 20 years advance notice was enough to complete the job.

DR. BEEHLER:

That may very well be. This is kind of a theoretical argument at the moment. I think when we do get down to that stage of actually trying to implement that, we may, indeed, find similar problems. But, I think as better services come along, if they are really capable of giving the user at least as much information and doing it as cheaply or more cheaply with less effort, that it seems like we should be trying to go in that direction.

MR. RUEGER:

The criteria of the past seems to have been based on the wear-out of the users' equipment after you tell him they are going to be shut down and not the lack of the service or a different way of getting it.

DR. BEEHLER:

I am sure that is true.

DR. WINKLER:

I have, also, several questions. Do you provide or do you envision to include the DUT-1 code on the satellite broadcasts?

DR. BEEHLER:

We do not include the DUT-1 code at the moment on GOES because it is just an experimental thing. Certainly when we go to a service arrangement, if we do, the DUT-1 would be included as long as the CCIR recommendation is still effective.

DR. WINKLER:

The second, is the 100 pulse per second time code identical with the 100 pulse per second which you have on WWV sub-carrier?

DR. BEEHLER:

No, it is not.

DR. WINKLER:

Where do you publish these codes?

DR. BEEHLER:

Check with Wayne Hanson.

MR. INOUYE:

Inouye, National Research Laboratory of Metrology in Japan.

I am interested in the Radio serviced area from the satellite. I could not find out if Japan is included or not.

MR. HANSON:

There are two U. S. controlled satellites. They do not cover Japan.

DR. KLEPCZYNSKI:

He said the current satellites do not cover Japan, but there is the possibility in the future, after some negotiation, that a Japanese satellite will cover the area.