TIME FROM NBS BY SATELLITE

D. W. Hanson, D. D. Davis, and J. V. Cateora National Bureau of Standards, Boulder, Colorado

ABSTRACT

As a complement to the present time and frequency services of WWV, WWVH, and WWVB, the National Bureau of Standards (NBS) is now sponsoring a satellite-disseminated time code using the GOES[1] satellites of the National Oceanic and Atmospheric Administration. The time code is referenced to the UTC(NBS) time scale, giving Coordinated Universal Time. It is considered by NOAA to be a permanent feature of the GOES satellites intended to serve the GOES users. It may, however, be used by others requiring a general purpose time reference. The time code is available to the entire Western Hemisphere from two satellites on a near full-time basis.

This paper is basically an update of last year's PTTI paper on the GOES time code. The time-code generation system is being improved to include a continuous update of its ephemeris message in place of the present 30-minute updated message; triple redundancy is being designed into the generation equipment at the Wallops Island, Virginia, ground station; and monthly status reports will be included in the NBS Time and Frequency Services Bulletin; e.g., scheduled outages, solar eclipses, and past performances. This paper includes comments on NBS experience with the reception of the signals, possible sources of interference, and how to obtain best results.

INTRODUCTION

In May 1974, NBS began an experiment of time-code broadcasts from the National Oceanic and Atmospheric Administration's (NOAA's) Geostationary Operational Environmental Satellites (GOES). Based upon subsequent successful performance and useful application for the users of the GOES

---

[1] GOES is the acronym for Geostationary Operational Environmental Satellite.

satellites, NOAA now considers the time code to be a permanent feature. In March 1977, NBS and NOAA formally agreed to continue the time code broadcasts, with NBS operating the code and providing the time and frequency reference.

There are now three satellites in orbit; two are operational and the third is an "in-orbit" "hot" spare ready to replace either satellite in case of failure. There is another satellite ready for launch when needed and three more satellites are under construction. This complement of GOES satellites is expected to insure two satellites in continuous operation until the late 1980's. Plans to continue the program beyond the year 2000 are being made.

Considering the long life, the important mission[2] of the GOES program, and the wide geographical coverage of the satellites, the GOES time signals are finding many applications where reliability, automatic signal recovery, and accuracy are desirable. Being geostationary, GOES is a source of continuous synchronization, offering a significant advantage over non-geostationary satellites which can only provide exposure to the user during brief periods of time at intervals ranging from about one hour to many hours or even days.

TIME CODE SYSTEM

The time code is part of the interrogation channel of the GOES satellites. The interrogation channel is used to command remote sensors to send their collected data to the GOES satellites. The satellites relay these data to the Command and Data Acquisition (CDA) facility at Wallops Island, Virginia, for processing and dissemination to users. Interrogation messages are continuously being sent through the GOES satellites. The format of the messages is shown in figure 1.

The interrogation message is exactly one-half second in length or 50 bits. The data rate, provided by atomic oscillators, is 100 bits per second (b/s). The interrogation message is binary and phase modulates a carrier ± 60 degrees after being Manchester-encoded; i.e., data and data clock are modulo-two added before modulating the carrier. An interrogation message consists of four bits representing a BCD word of time code beginning

---

[2]The GOES satellites provide meteorological observations for:
- -Continuous storm tracking through cloud photography
- -Cloud analysis-density, temperature, height, wind velocity
- -Surface temperature mapping
- -Space environment sun/earth interaction
- -Remote sensing of floods, rain, snow, Tsunamis, earthquakes, air/water pollution, etc.

on the half-second of UTC, followed by a maximum length sequence (MLS) 15 bits in length for message synchronization, and ending with 31 bits as an address for a particular remote sensor. Sixty interrogation messages are required to send the 60 BCD time-code words constituting a time-code frame. The time-code frame begins on the half minute of UTC and repeats every 30 seconds (see figure 2). The time code frame contains a synchronization word, a time message (UTC), the UT1 correction, and the satellite's position in terms of its longitude, latitude, and height above the surface of the earth minus a bias of 119,300 microseconds. The position information is presently updated on the half hour.

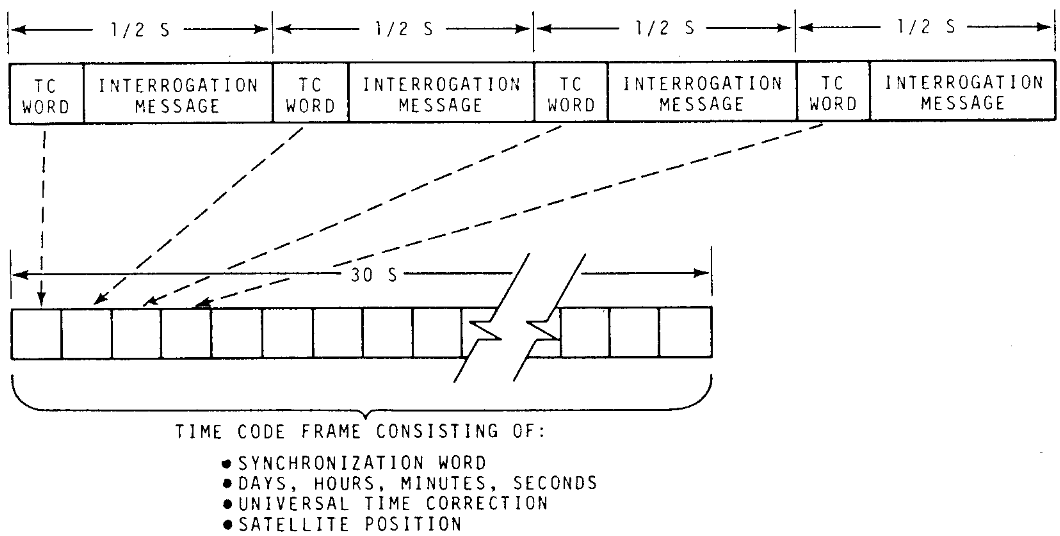

Fig. 1-Interrogation message format

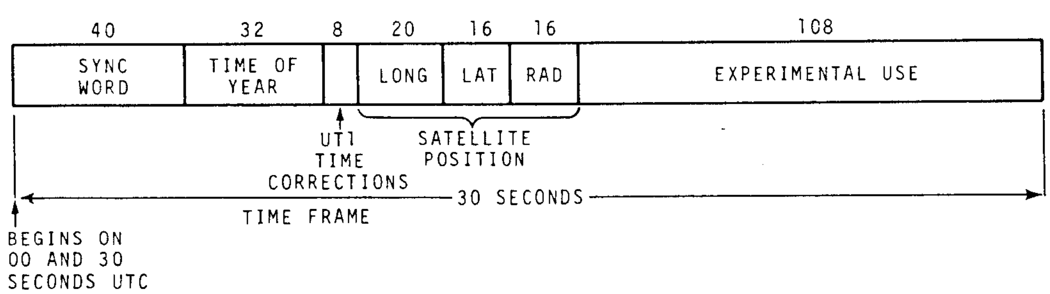

Fig. 2-Time code format

NBS maintains an ensemble of three clocks at NOAA's CDA facility, Wallops Island, Virginia. These clocks provide the time and frequency reference for the time code. The time-code generation system, partly shown in figure 3, is completely redundant and fully supported by an uninterruptable power supply. There is a communication interface between the equipment and NBS/Boulder using a telephone line. Over the telephone line, satellite position information is sent to the CDA and stored in memory for eventual incorporation into the time code and interrogation message.

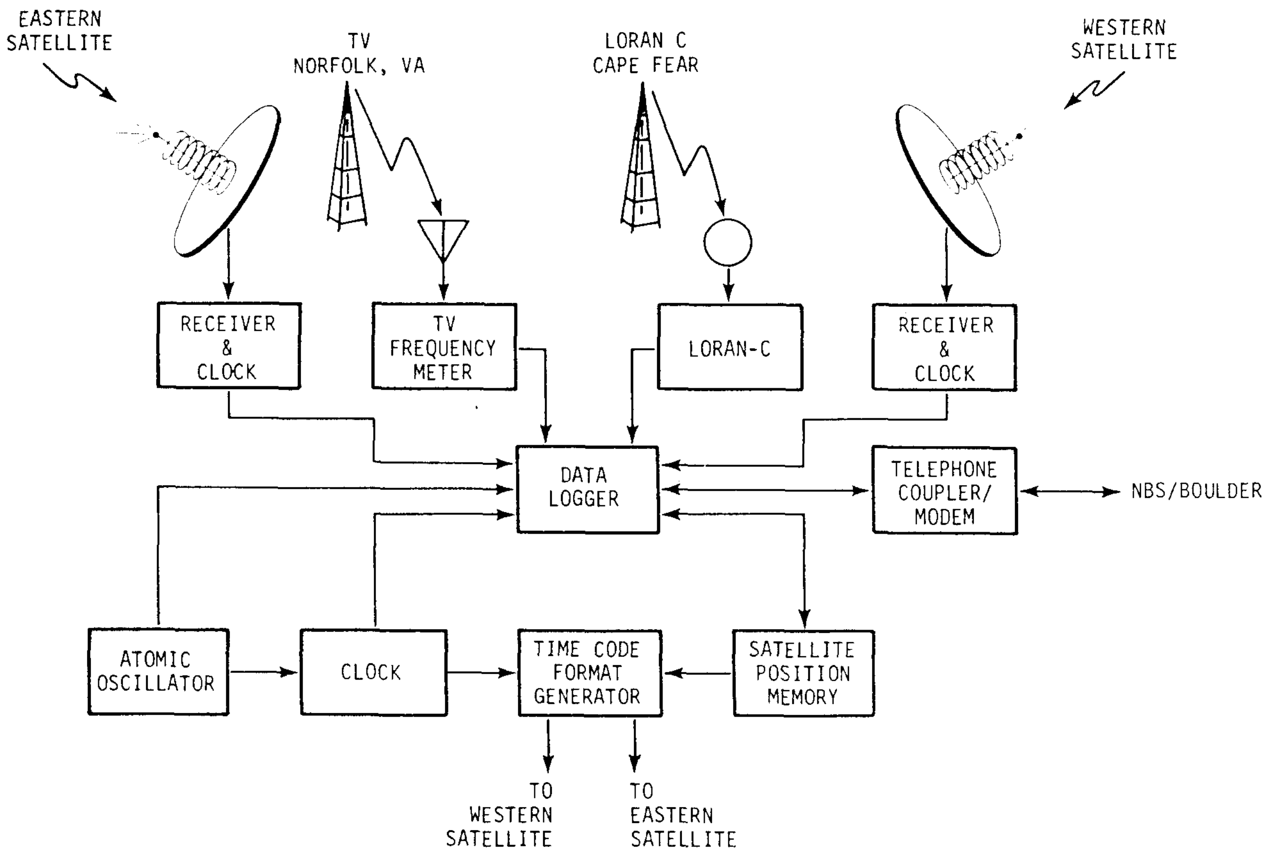

Fig. 3-Time code generation at CDA

Data are also retrieved from the CDA via the telephone line to Boulder. These data include the frequency of the atomic oscillators and the time of the clocks relative to UTC as compared to TV transmissions from Norfolk, Virginia, and to Loran-C transmissions from Cape Fear, North Carolina. The Data Logger also measures and stores the time of arrival of the signals from both the Western and Eastern GOES satellites as received at the CDA. Besides the time and frequency monitoring functions, the Data Logger provides the information necessary for NBS staff at Boulder to remotely determine if and where malfunctions exist and how to correct them by switching in redundant system components.

The satellite position information is generated at Boulder using a CDC 6600 computer and orbital elements furnished by NOAA's National Environmental Satellite Service (NESS). NESS generates these orbital elements weekly using data obtained from their trilateration range and range rate (R&RR) tracking network. The tracking data are obtained by measuring the R&RR to the Western satellite from the CDA, and sites in the states of Washington and Hawaii. The Eastern satellite is observed from the CDA, Santiago, Chile, and Ascension Island in the South Atlantic.

	WESTERN SATELLITE	EASTERN SATELLITE
FREQUENCY	468.8250 MHz	468.8375 MHz
POLARIZATION	RHCP	RHCP
MODULATION	CPSK (± 60°)	CPSK (± 60°)
DATA RATE	100 BPS	100 BPS
SATELLITE LOCATION	135° W	75° W
SIGNAL STRENGTH (OUTPUT FROM ISOTROPIC ANTENNA)	-139 dBm	-139 dBm
CODING	MANCHESTER	MANCHESTER
BANDWIDTH	400 Hz	400 Hz

Fig. 4-Interrogation channel signal characteristics

The GOES time signals for both satellites are summarized in figure 4. The signals are right-hand circularly polarized and separated in frequency by 12.5 kHz. The data rate is 100 b/s requiring 400 Hz of bandwidth. The data are Manchester coded and phase modulate the carrier ± 60 degrees, thus providing a carrier for the application of conventional phase lock demodulation techniques. The geographical coverage of the two satellites is shown in figure 5.

Figure 6 shows equipment designed for automatic time recovery from the GOES satellites. The antenna uses microstrip construction and provides 5 dB of gain right circularly polarized. It has a low noise preamplifier attached to its back plane. The receiver contains a microprocessor to determine and automatically compensate for net propagation delay of the time signals.

RESULTS

Data have been collected at NBS in Boulder, Colorado, using a receiver designed for automatic time recovery. Figure 7 shows the results of measurements taken every half hour for one day. These results have been repeated every day for more than one year. The results have shown the GOES system to provide a time reference to easily within ± 20 microseconds.

An equation relating the time recovered from the satellite to the master clock at Wallops Island is given below. Term 1 is known to better than 1 μs using the data logger which compares the CDA clocks to Loran-C and TV Line-10. This term will be controlled in the next generation system to be installed at Wallops Island early next year at this level or better. Terms 2, 4, 5, and 6 are expected to remain constant at the few microseconds level and can for the most part be calibrated out of a user's system. Term 3 is computed and compensated for by the user or his receiver with microprocessor capabilities.

$$\text{UTC(NBS)} - \text{SATELLITE RECEIVER} = \overset{1}{(\text{UTC} - \text{CDA})} + \overset{2}{(\text{CDA EQUIP DELAY})} + \overset{3}{\left(\begin{array}{c}\text{FREE SPACE}\\ \text{PROPAGATION}\\ \text{DELAY}\end{array}\right)} + \overset{4}{\left(\begin{array}{c}\text{SATELLITE}\\ \text{TRANSPONDER}\\ \text{DELAY}\end{array}\right)} + \overset{5}{\left(\begin{array}{c}\text{IONOSPHERE \&}\\ \text{TROPOSPHERE}\\ \text{DELAY}\end{array}\right)} + \overset{6}{\left(\begin{array}{c}\text{RECEIVER}\\ \text{AND CLOCK}\\ \text{DELAY}\end{array}\right)}$$

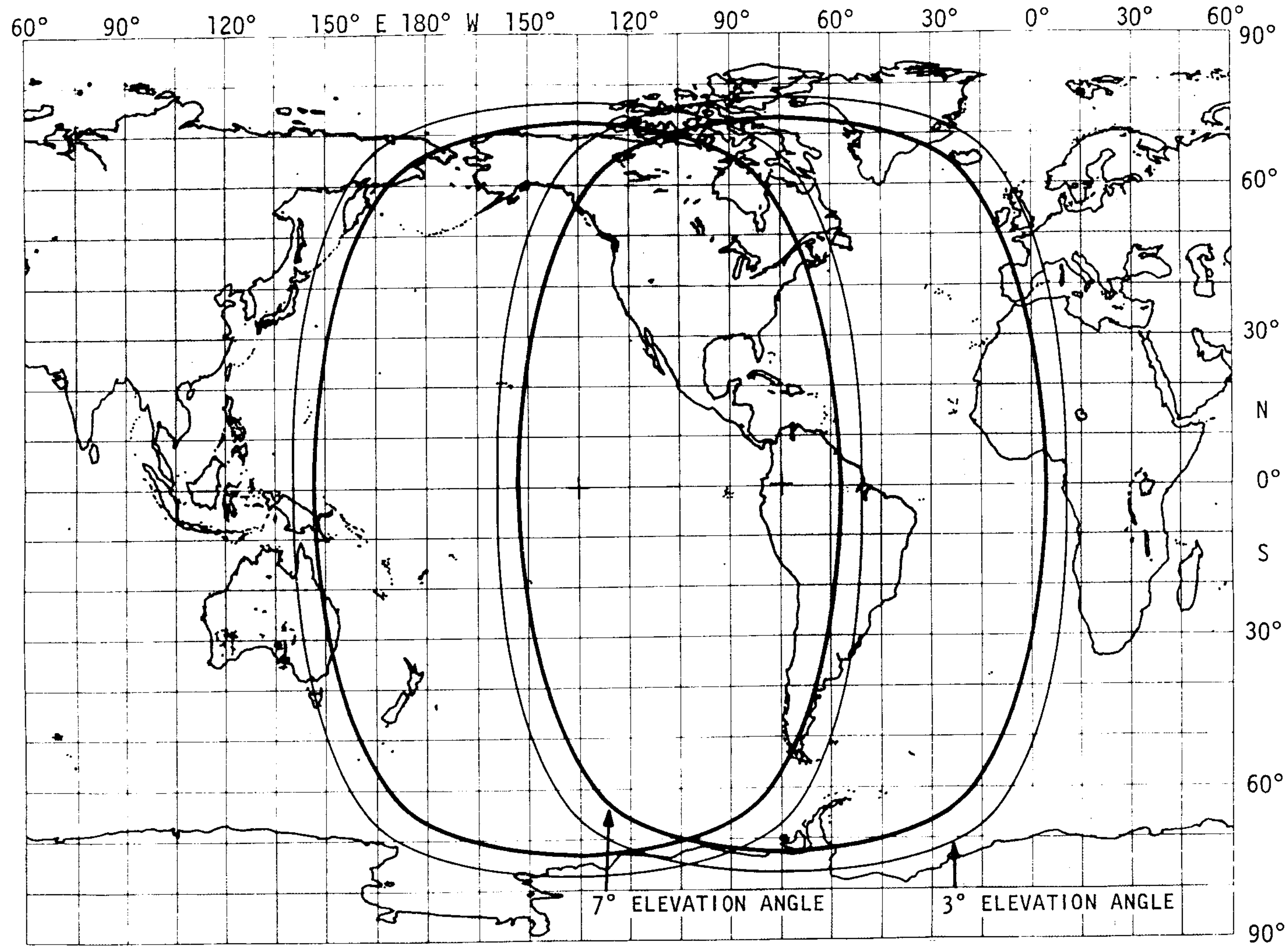

Fig. 5-Coverage of GOES satellites

Fig. 6a-GOES time receiving equipment

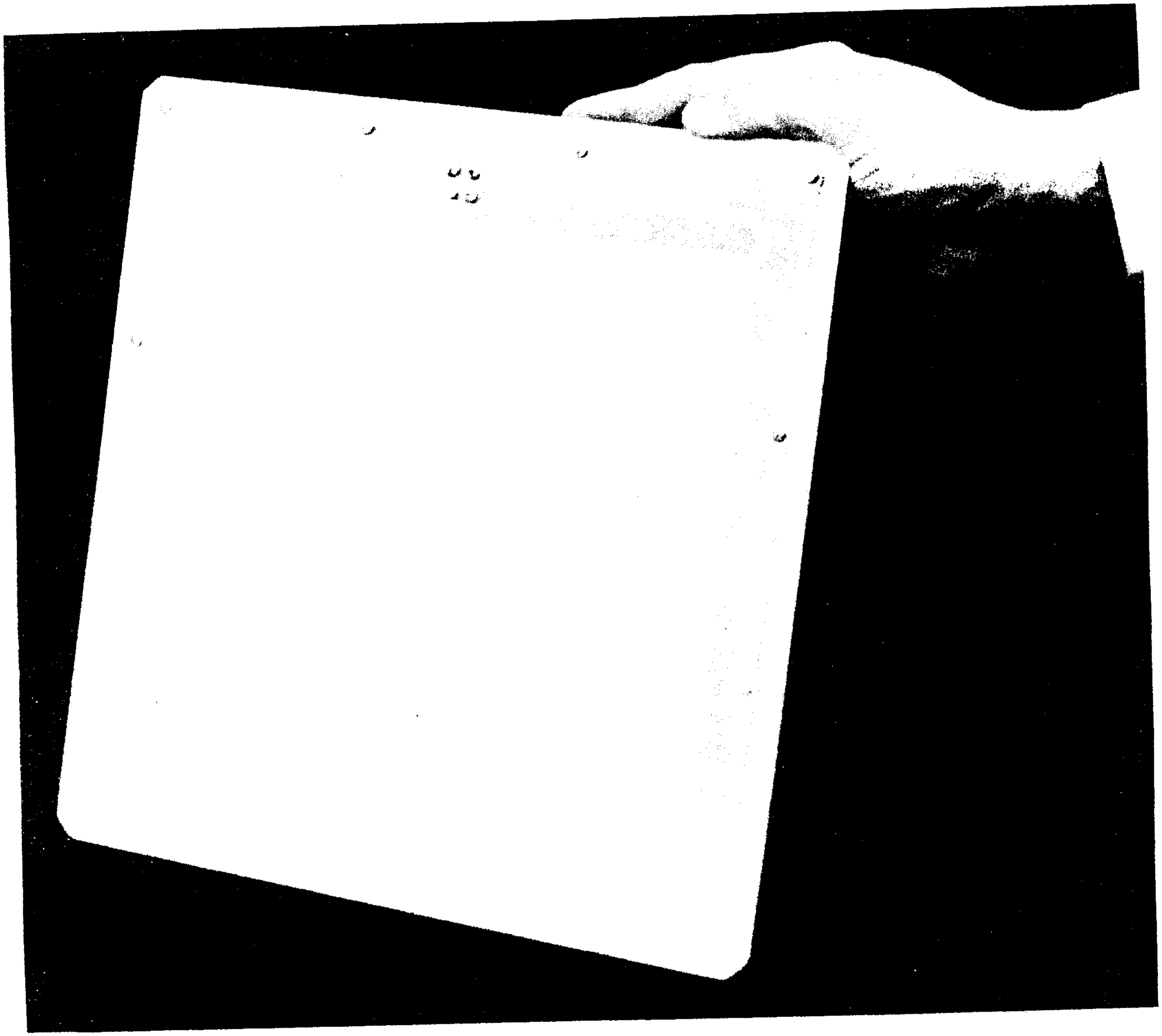

Fig. 6b-GOES time receiving equipment

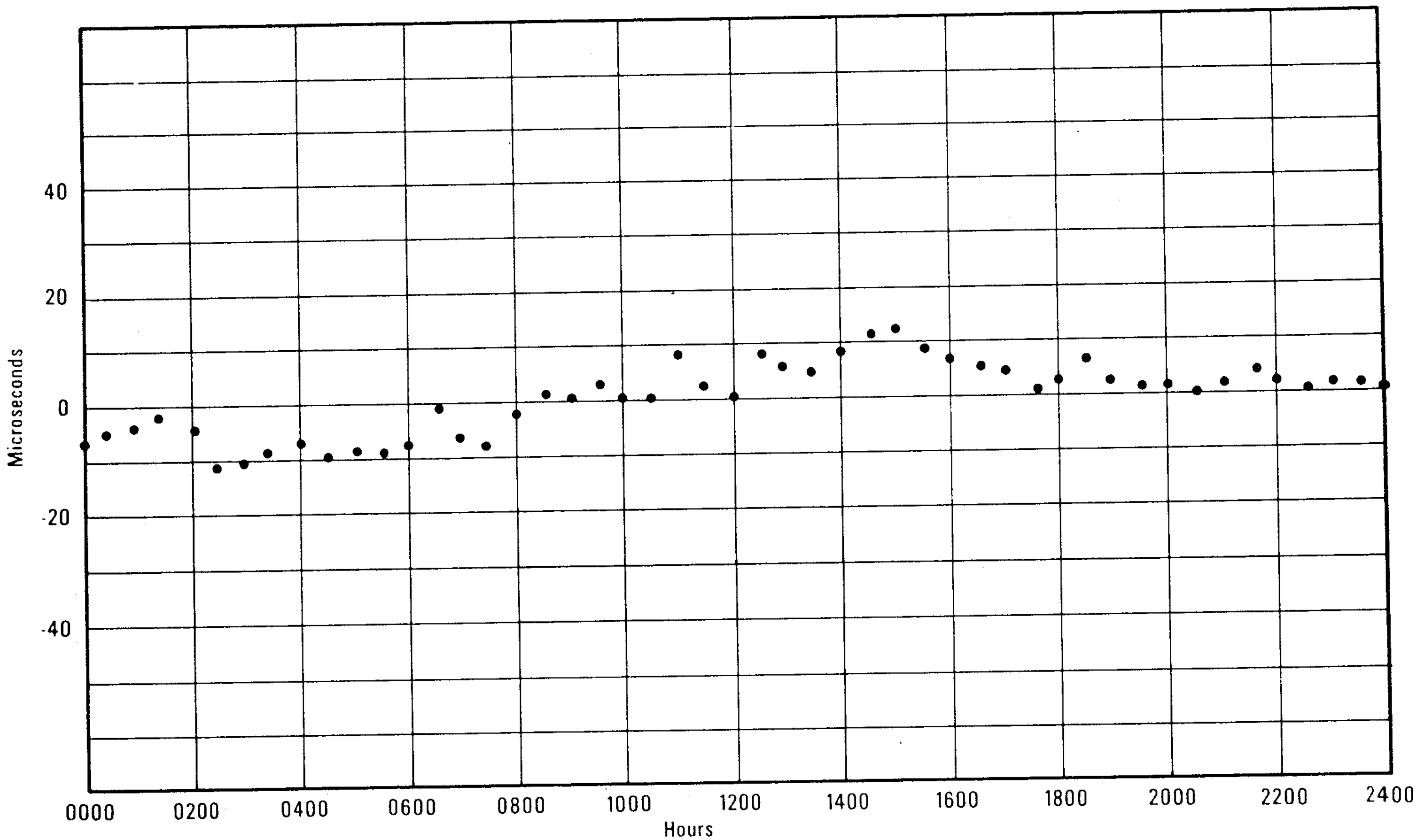

Fig. 7-UTC(NBS)-GOES receiver (NBS manufactured)

Since the GOES time code is transmitted outside the spectrum reserved exclusively for time and frequency broadcasts, it cannot be considered an NBS service in the same sense that WWV, WWVH, and WWVB are services. The "land-mobile" services and the GOES interrogation channels use the same frequency allocations (468.8250 and 468.8375 MHz), which means the time code may suffer interference from land-mobile transmissions. This is particularly true in urban areas where there is a high density of land-mobile activity. The satellite frequency allocations are secondary to the land-mobile services. Therefore, any such interference must be accepted by the time signal users. Complaints to the FCC will not result in any adjustments in favor of such users. The spectrum use by satellite and land-mobile is illustrated in figure 8.

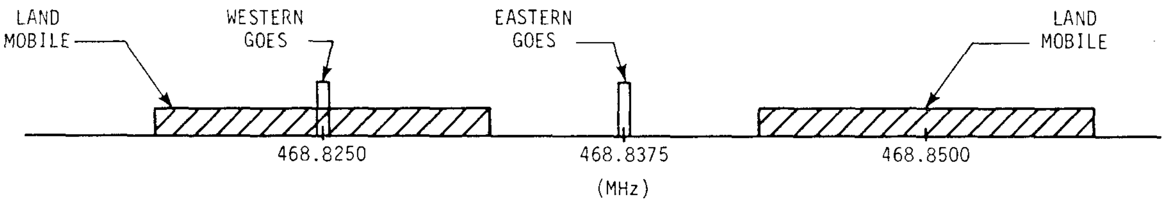

Fig. 8-Frequency use

Because of the spacing of frequency assignments to the land-mobile users, there is far less interference to the eastern satellite signals than to the western satellite. Therefore, the eastern satellite should be used by those users situated in large urban areas.

Although the GOES satellites transmit continuously, there may be interruptions during the periods of solar eclipses. The GOES satellites undergo spring and autumn eclipses during a 46-day interval at the vernal and autumnal equinoxes. The eclipses vary from a few minutes at the beginning and end of eclipse periods to a maximum of approximately 72 minutes at the equinox. The eclipses begin 23 days prior to equinox and end 23 days after equinox; i.e., March 1 to April 15 and September 1 to October 15. The outages occur during local midnight for the satellites' mean meridian (see figure 9).

There will also be shutdowns for periodic maintenance at the Wallops Island ground station. These scheduled outages will be reduced in the future as redundancy is added to the system.

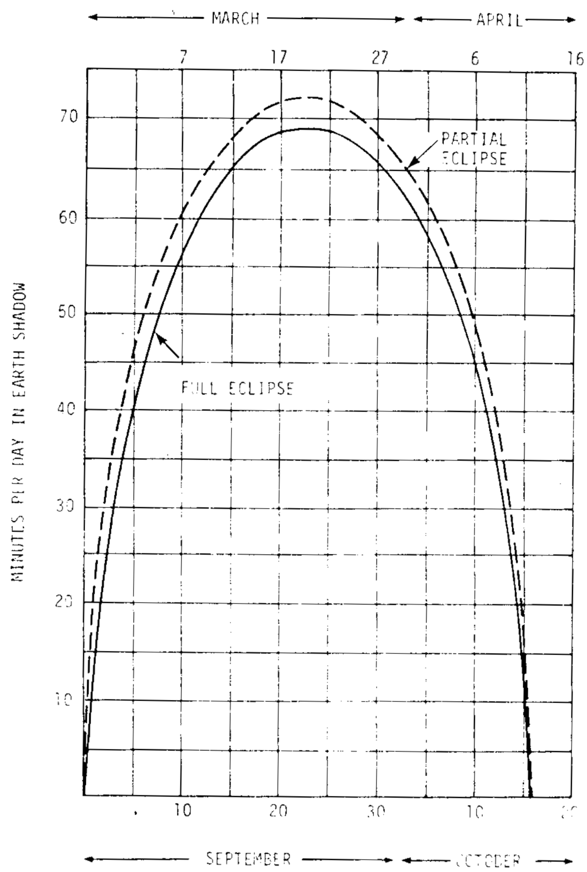

Fig. 9-Solar eclipse time

FUTURE PLANS AND IMPROVEMENTS

The satellites now under construction will have a 3 dB increase in radiated power and an improved antenna system. The time-code generation system at Wallops Island will be replaced with one of an improved design which reduces parts count by a factor of four. The system will be triple redundant. The satellite position data will be compressed using Chebychev polynomials to reduce storage requirements at the CDA and allow more frequent updates in the time-code message. By early 1978, the satellite position data will be updated every five minutes rather than at the present thirty-minute intervals.

Early in 1978, NBS will begin to report on the status of the GOES time system, including expected outages and improvements, in the NBS Time and Frequency Services Bulletin issued monthly.