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# NBS time to the Western Hemisphere by satellite

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As a complement to the present time and frequency services of WWV, WWVH, and WWVB, the National Bureau of Standards (NBS) is now providing a satellite-disseminated time code using the Geostationary Operational Environmental Satellites (Goes) of the National Oceanic and Atmospheric Administration (NOAA). The time code is referenced to the NBS time scale, giving coordinated universal time (UTC). In addition to the usual information of day of year, hours, minutes, seconds, and the UT1 correction the time code contains the satellite's current position for use in path delay calculations. The time signals are relayed to the entire Western Hemisphere from two geostationary satellites on a full-time basis except during brief periods of solar eclipses occurring during the vernal and autumnal equinoxes. The time code, originally intended for use by environmental monitoring platforms, is easily accessible by anyone using relatively simple, commercially available equipment. Physically small antennas (30 cm × 30 cm × 1cm) are typical. The generation, satellite relay, and recovery of these signals is discussed. Results obtained with commercial receiving equipment are included.

## 1. INTRODUCTION

In May 1974 the NBS began an experiment of time code broadcasts from NOAA's Goes satellites. Based upon subsequent successful performance and useful application for the users of the Goes satellites, the time code is now a permanent feature of these satellites.

There are three satellites in orbit; two are opertional, the other serving as the 'in-orbit' 'hot' spare ready to replace either satellite in case of failure. Other satellites are ready for launch when needed. The present complement of satellites is expected to insure two satellites in continuous operation until the late 1980's. Plans exist to continue the program beyond the year 2000.

Considering the long life of the Goes system, the important mission 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 nongeostationary satellites which can only provide exposure to the user during brief periods of time. Also, the Goes time signals are not subject to the fading and unpredictable path delays that limit terrestrial systems operating in the low- to high-frequency ranges.

## 2. SATELLITE SYSTEM DESCRIPTION

The Goes satellites are primarily for meteorological purposes including the production of images of cloud systems for improving the accuracy of short-term weather forecasts. Additionally, a data collection system on the spacecraft, illustrated in Figure 1, receives and relays environmental data sensed by widely dispersed surface data collection platforms (DCP's) such as rain and river gauges, seismometers, tide gauges, buoys, ships, and automatic weather stations. The DCP's transmit data to the satellite at regular intervals, upon interrogation by the satellite, or in an emergency alarm mode. The time code is sent continuously through the satellite so the DCP's may label the environmental data with date and time as it is collected, thereby enhancing its usefulness.

The interrogation and time code messages comprise a continuous data stream sent through two Goes satellites. These messages originate at Wallops Island, Virginia, where two 18.3-m (60 foot) diameter parabolic antennas maintain the continuous data link with the satellites. The signals are sent to the satellites on a carrier of approximately 1.68 GHz. The 1.68-GHz carrier is changed in frequency at the satellite to nominally 469 MHz and is retrans-



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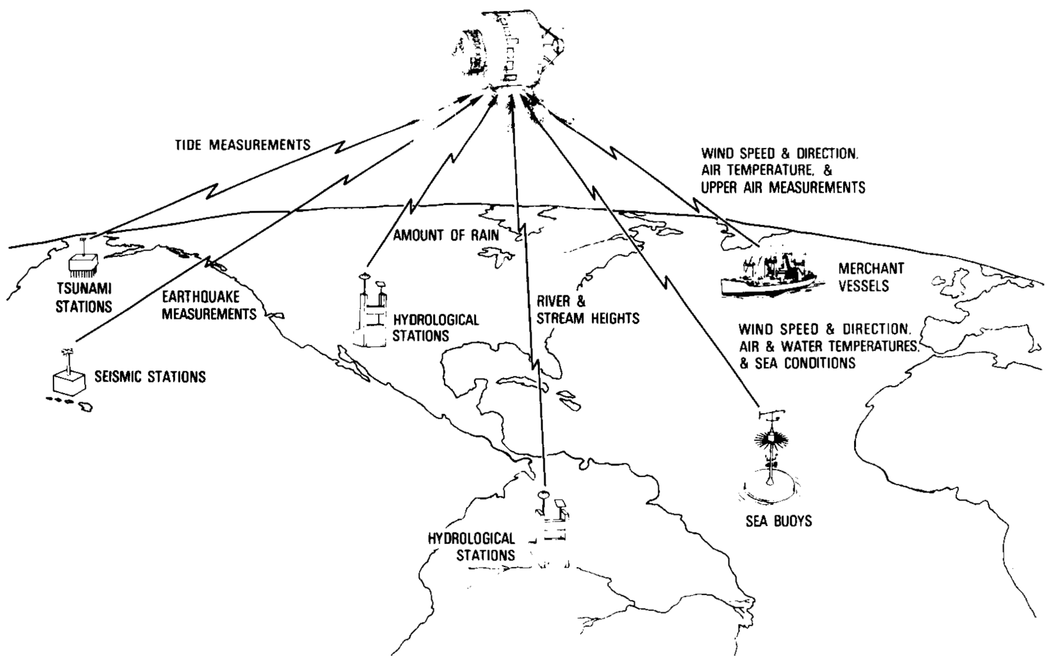


Fig. 1. Collection of environmental data from data collection platforms.

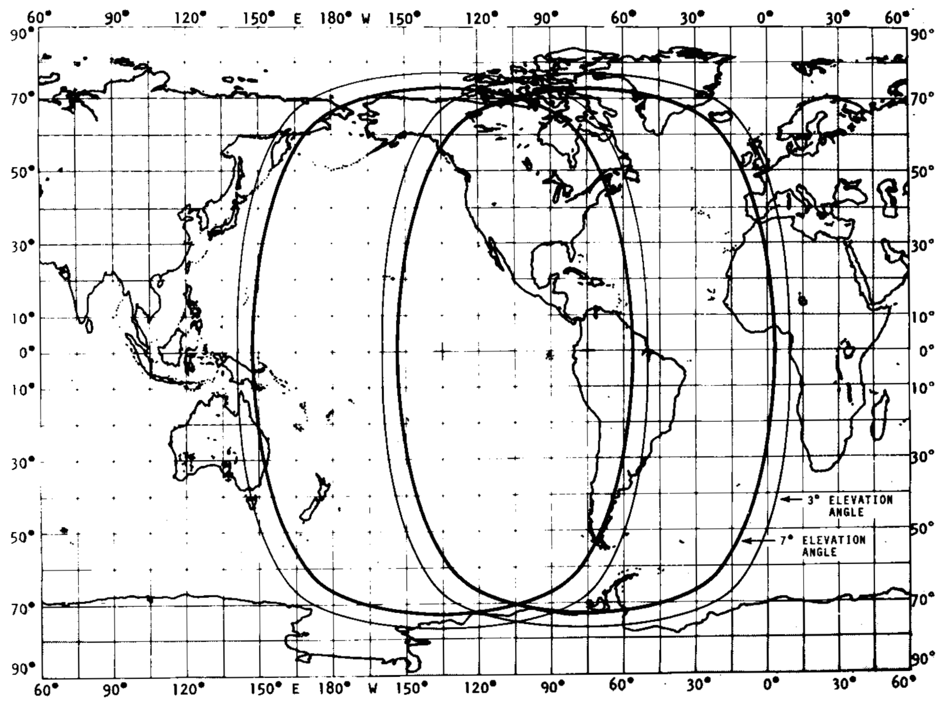


Fig. 2. Coverage of Goes satellites.

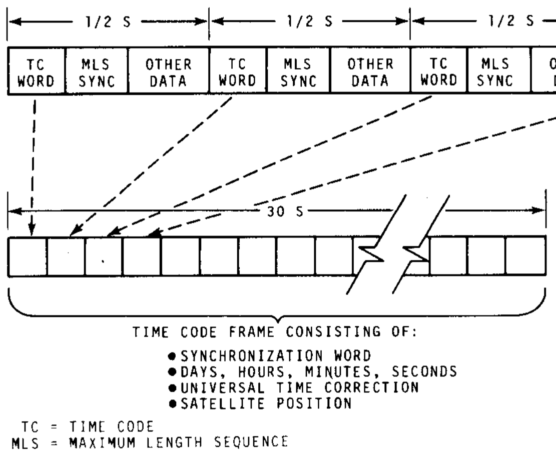


Fig. 3. Interrogation channel format.

mitted to the earth through antennas with global coverage beamwidths.

The Goes satellites represent the U.S. link in a five-satellite project, part of the Global Atmospheric Research Program (GARP). The chain of spacecraft includes a Japanese satellite, a European satellite, and a Soviet vehicle still to be launched. The operational Goes satellites are located over the equator at 135° and 75° West longitude. The approximate coverage of the earth from these two satellites is shown in Figure 2. The periphery of its coverage is denoted by a heavy curve, where the satellite is 7° above the horizon and a lighter curve, where the satellite is 3° above the horizon. The European equivalent of Goes, called Meteosat, is located at 0° East longitude, and the Japanese satellite, GMS, is stationed at 140° East longitude.

### 3. TIME CODE TRANSMISSION

The time code is contained within the interrogation channel of the Goes satellites. The interrogation channel is used to command remote DCP's 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 interrogation messages is shown in Figure 3.

The interrogation message is exactly $\frac{1}{2}$ s in length, or 50 bits. The data rate, controlled by atomic oscillators, is 100 b/s (bits per second). An interrogation message consists of 4 bits representing a binary coded decimal (BCD) word of time code beginning 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 DCP. 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 s (see

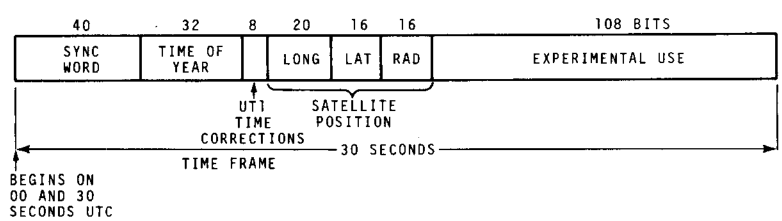


Fig. 4. Time code format.

| | 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. 5. Interrogation channel signal characteristics.

Figure 4). 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 μs. The position information is updated frequently; presently, every 4 min.

## 4. CHANNEL CHARACTERISTICS

The Goes time signals from both satellites are summarized in Figure 5. The signals are right hand circularly polarized (RHCP), coherent phase shift keyed (CPSK), and separated in frequency by 12.5 kHz. The data rate, being 100 b/s, occupies only 400 Hz of bandwidth. The data are Manchester coded and phase modulates the carrier ±60°, thus providing a carrier for conventional phase-locked loop demodulation.

## 5. TIME CODE GENERATION AND CONTROL

NOAA's CDA ground stations are located at Wallops Island, Virginia, where all interrogation signals sent to the satellite are originated. NBS maintains an ensemble of three atomic clocks at that site. These clocks provide the time and frequency reference for the time code. The time code generation system, partly shown in Figure 6, 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.

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

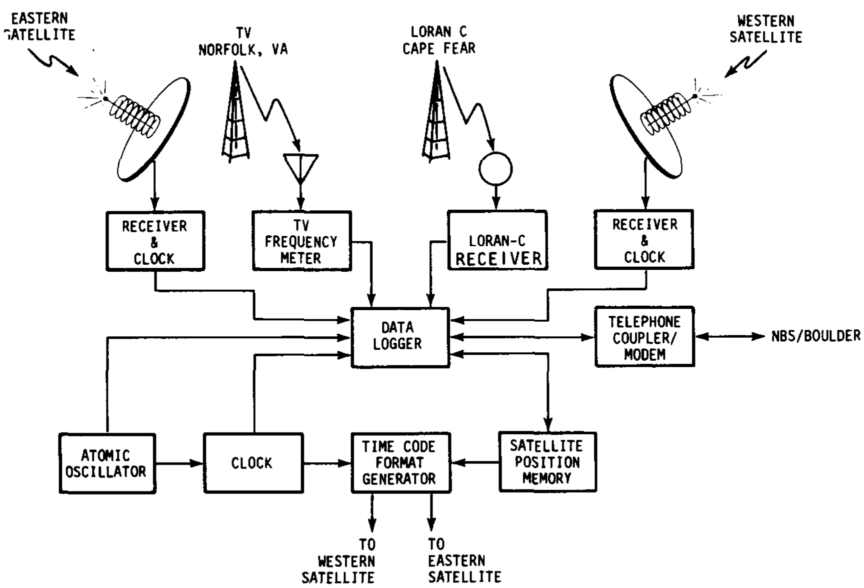


Fig. 6. Time code generation system.

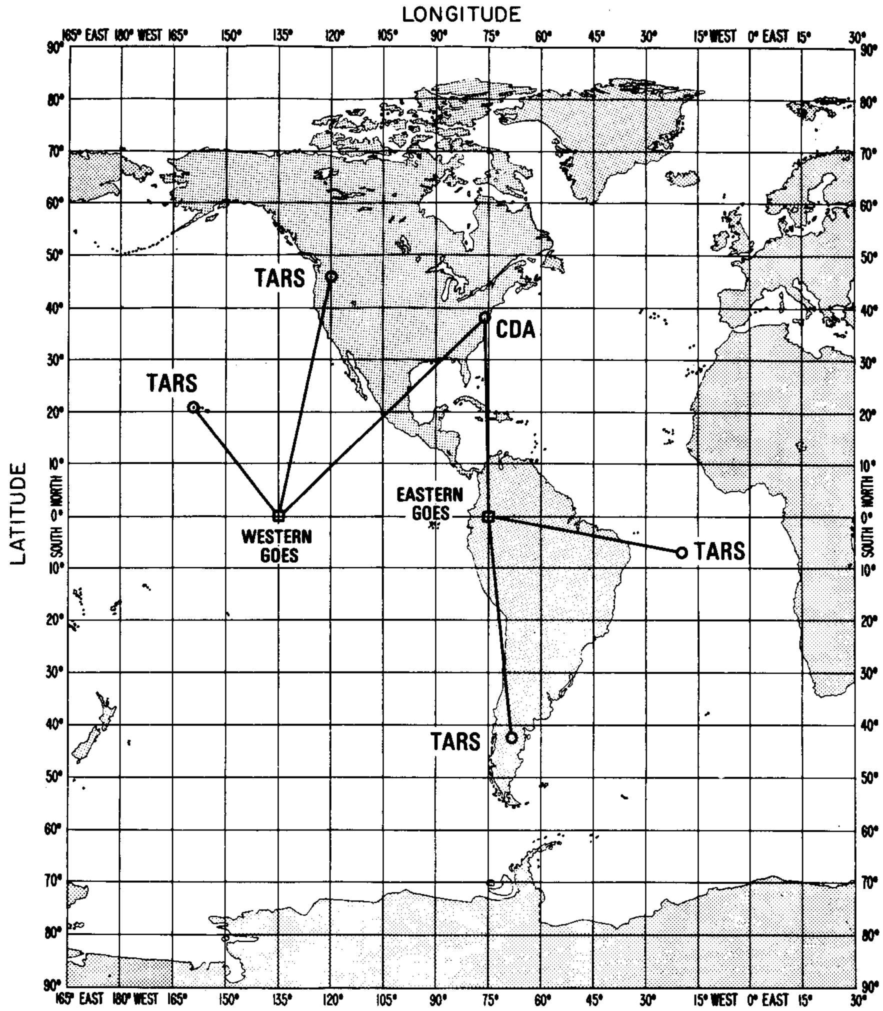


Fig. 7. Tracking network for the Goes satellites.

of the clocks relative to UTC compared with 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 to correct them through the switching of redundant system components.

The satellite position information is generated at Boulder by using a large scientific computer and orbital elements furnished by NOAA's National Environmental Satellite Service (NESS). NESS generates these orbital elements weekly using data obtained from the trilateration range and range rate (RRR) tracking network shown in Figure 7. The tracking data are obtained by measuring the RRR to the western satellite from the CDA and sites known as Turn Around Ranging Stations (TARS) in the states of Washington and Hawaii. The eastern satellite is observed from the CDA and TARS in Santiago, Chile, and Ascension Island in the South Atlantic.

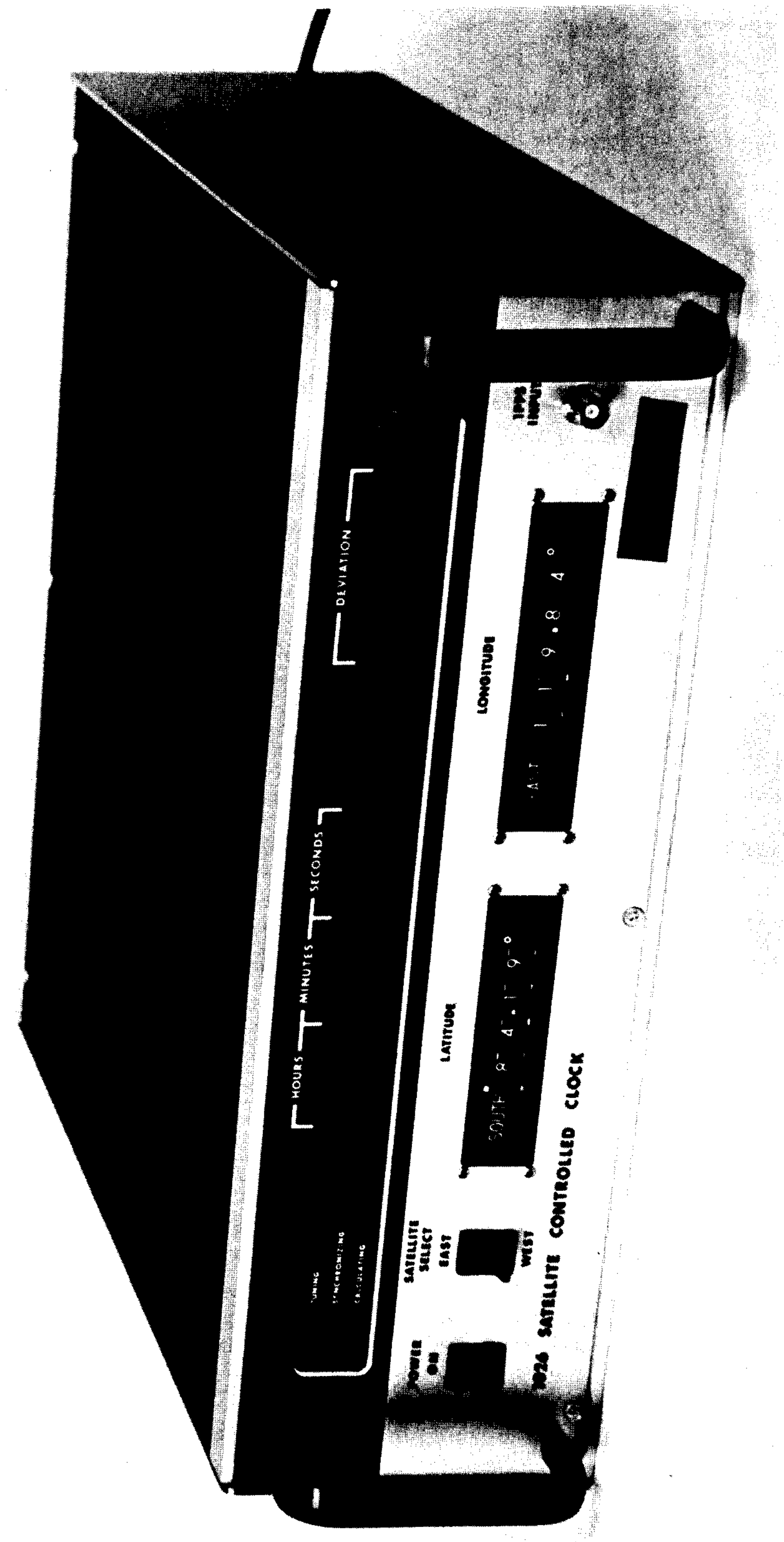


Fig. 8. Commercial Goes time receiver.

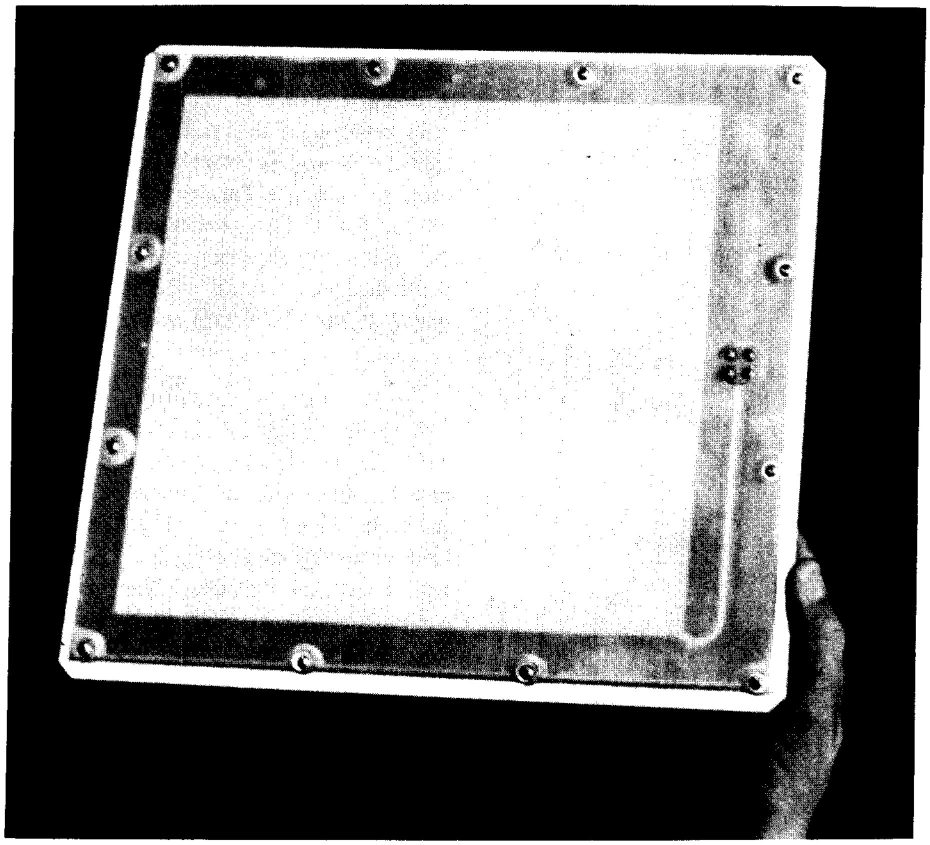

Fig. 9. Goes antenna.

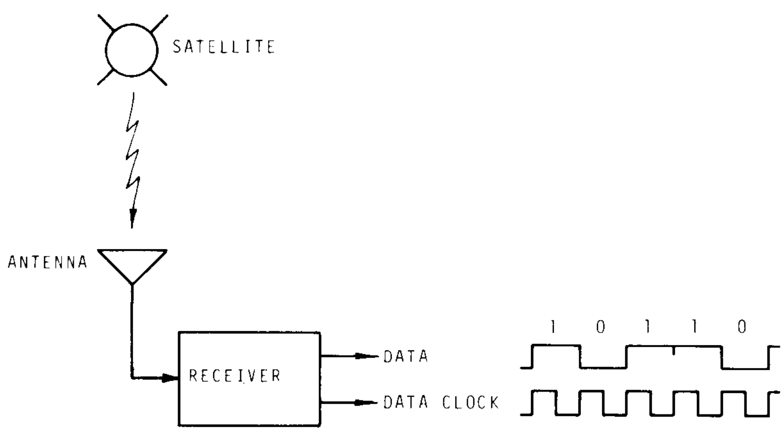


Fig. 10. Receiver outputs.

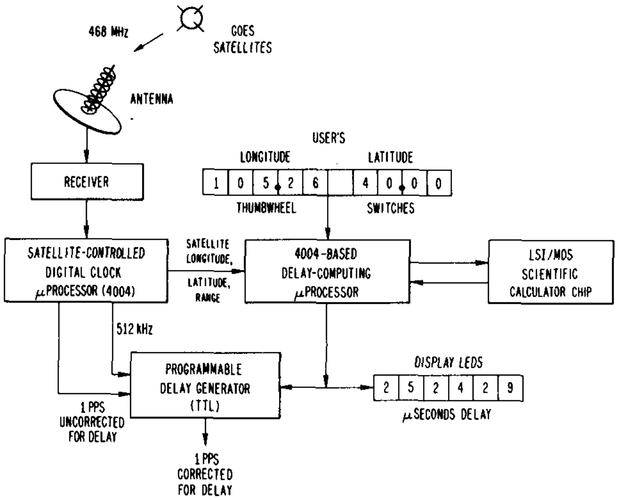


Fig. 11. Satellite-controlled clock.

## 6. RECEIVING EQUIPMENT

Figures 8 and 9 show a commercial system including the antenna and a receiver with a Goes-controlled clock. The antenna is of printed circuit board construction and yields a circular polarized gain of 4–5 dB. The receiver provides double-down conversion, demodulation using a phase lock loop, and bit synchronization with outputs of the data and data clock as illustrated in Figure 10. The NBS-designed Goes-controlled clock is shown in Figure 11. The two outputs of the receiver are the inputs to a microprocessor which demultiplexes the channel, decodes, and stores the time and satellite position data [see *Cateora et al.,* 1976, 1978]. Another processor (this could be the same processor) computes the path delay from the inputs of the user's and satellite's position using a calculator chip to execute functions like sin $x$, cos $x$, $x^{1/2}$, and so forth. The processor controls a delay generator to correct the recovered time for the free space path delays, via the satellite, between the master clock at the CDA and the receiver.

## 7. RESULTS

The accuracy of the Goes time signals is most probably limited by the existing knowledge of exact satellite position and the delay stability of all equipment involved with the generation, transmission, and recovery of the signals. An effort is presently underway to evaluate the accuracy. Long-term measurements at NBS in Boulder, Colorado, have shown the signals to be repeatable to better than 20 μs.

Shown in Figure 12 are the results of measurements of the difference between UTC(NBS) and the recovered time from a Goes satellite. These measurements were made every half hour for 3 consecutive days (dashed curves) and again for 3 consecutive days 2 weeks later (solid curves). The satellite position data used for the two 3-day periods were generated from independent sets of orbital elements supplied by NESS.

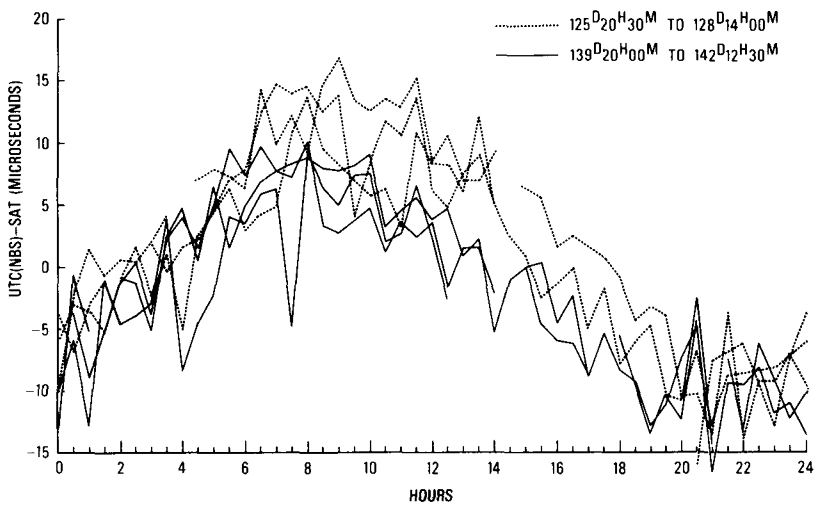


Fig. 12. UTC(NBS) compared with recovered time from Goes.

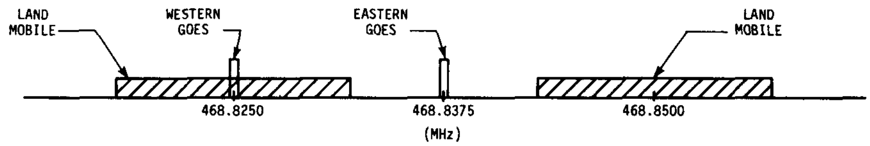


Fig. 13. Frequency usage in the United States.

The well-defined diurnal in Figure 12 indicates that the position data for the satellite were in error for both 3-day periods to approximately the same level. This diurnal has existed ever since NBS began systematically collecting these data more than 2 years ago. The diurnal, we believe, is due to systematic errors in the orbital elements or in their processing. NBS is attempting to identify the source of the errors and to remove them. If successful, the Goes time signals should then be capable of 10-μs synchronization to UTC(NBS).

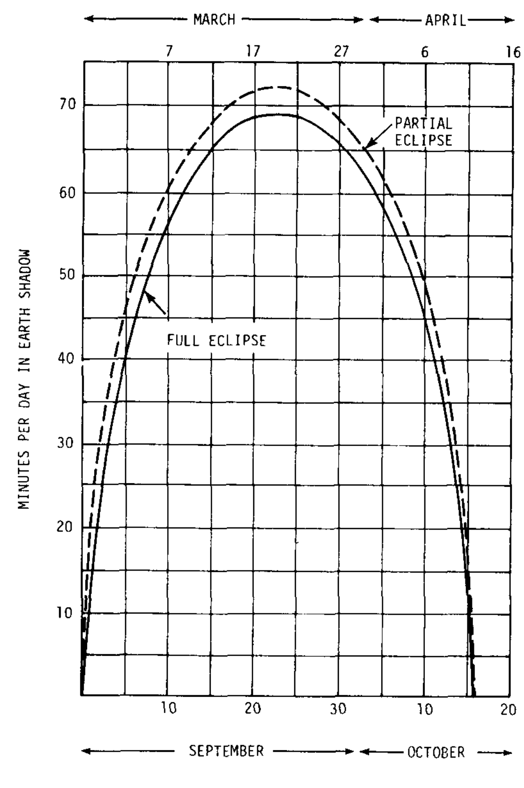


Fig. 14. Solar eclipse of a geostationary satellite.

## 8. PROBLEMS

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. In the United States and possibly elsewhere 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. The spectrum use by satellite and land-mobile services is illustrated in Figure 13.

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 signals. Therefore the eastern satellite should be used by those situated in large urban areas.

The Goes satellites transmit continuously except 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 min 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 (see Figure 14). These outages occur during local midnight for the satellite's mean meridian.

## 9. SUMMARY

An operational satellite-disseminated time system has some clear advantages over the more conventional HF and LF services. With improvements to the quality of the satellite position data the system seems capable of 10-μs synchronization with UTC(NBS). The advent of microprocessors has enabled the automatic recovery of Goes time signals including the compensation for path delays. Commercial equipment is now available for the reception of Goes time from more than two manufacturers.

## REFERENCES

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