Time, Frequency GOES Satellite

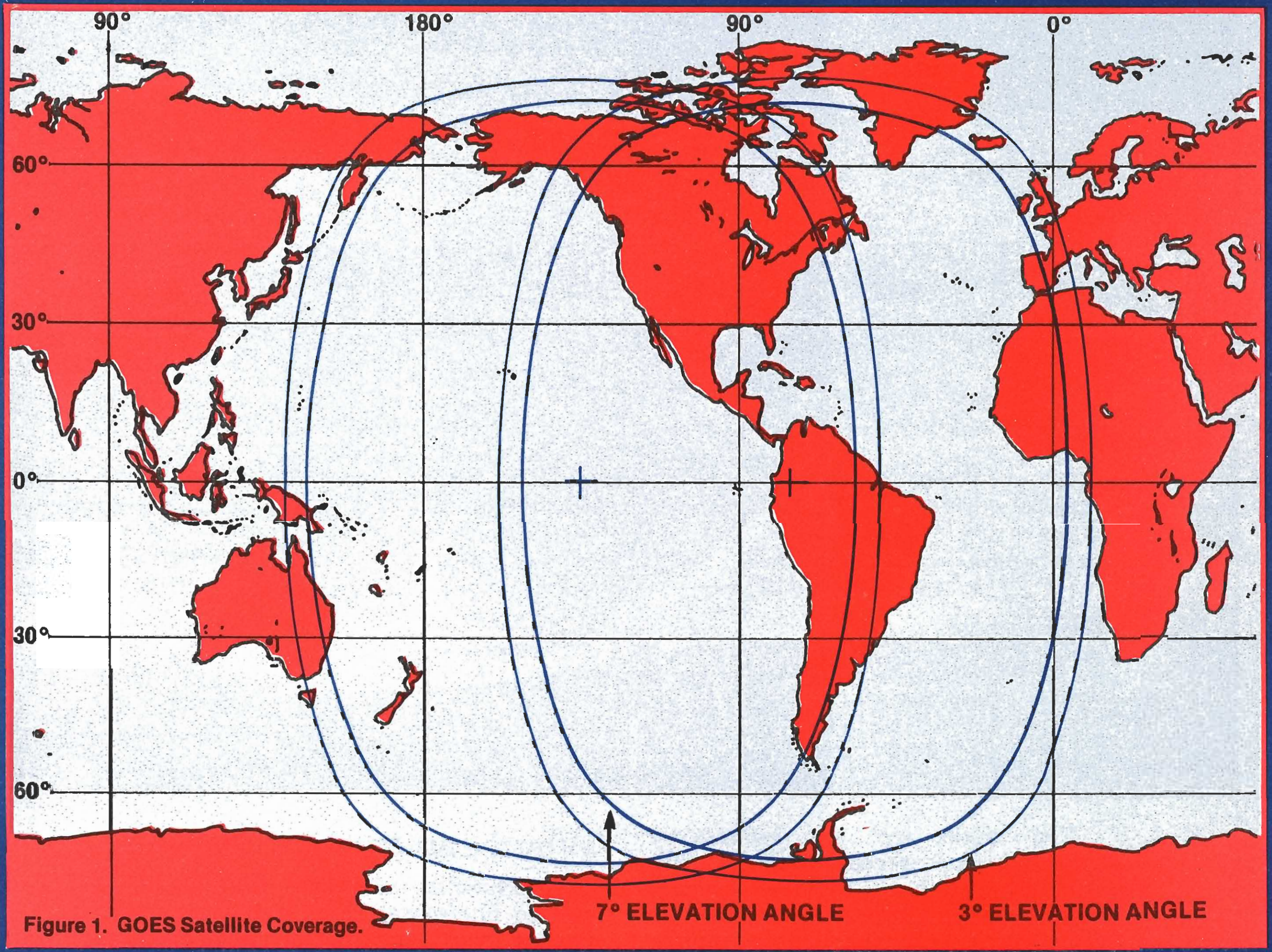

Figure 1. GOES Satellite Coverage.

Using the GOES satellite, atomic oscillators and "smart" clocks, the National Bureau of Standards transmits the official frequency and time standards for the United States.

Since 1923, the National Bureau of Standards (NBS) has been providing time and frequency services for many applications. The most notable of these are the high-frequency radio broadcasts of WWV and WWVH on 2.5, 5, 10, and 15 MHz and the low-frequency broadcasts of WWVB on 60 kHz. Now, in addition to these services, a time code is available on the GOES satellites (Geostationary Operational Environmental Satellites) of the National Oceanic and Atmospheric Administration (NOAA). Although the time code was designed to provide a means of dating environmental data collected by GOES, it is also being used as a general-purpose time and frequency reference for many other applications. The code is referenced to the NBS atomic clock in Boulder, Colorado, which serves as the official frequency and time interval standard for the United States. It gives Coordinated Universal Time (UTC), including day of year, hours, minutes, and seconds. The difference between UTC and astronomical time, UT1, is also contained in the code.

In addition to the time code, the satellite's longitude, latitude, and range from the earth's center are given for free-space propaga-

By Sandra L. Howe
Time and Frequency Division
National Bureau of Standards

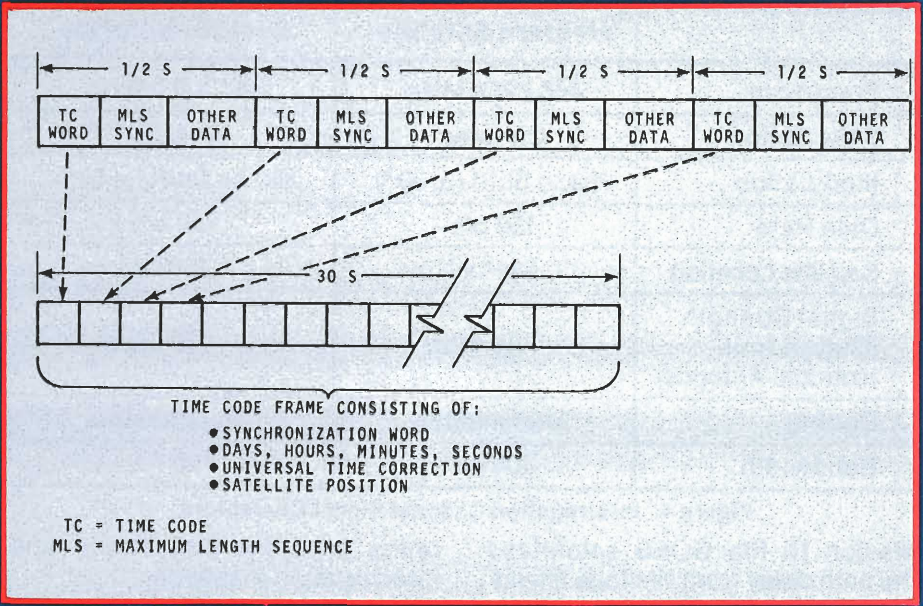

Figure 2. Interrogation Channel Format.

tion time corrections. Preliminary results indicate a timing resolution of 10 microseconds. Frequency calibrations are also possible.

GOES System Description

The GOES satellites are in orbit 36,000 kilometers above the equator and remain continuously above the same spot on earth. Since they always have the same regions of earth in view, they can provide a nearly continuous timing service.

The first GOES satellite was launched in 1974. Three satellites are now in orbit, two in operational status with a third serving as an in-orbit spare. The earth coverages of the two operational satellites are shown in Figure 1. The heavy oval lines overlap the points on earth where each satellite would be seen at 7° above the horizon. The lighter lines represent a 3° elevation angle.

The GOES satellites perform several functions, including the collection of environmental data from remote sensors. Some of these remote sensors are equipped with both a receiver and transmitter. Upon command from one of the satellites, the sensors are activated to transmit the stored data to the satellite. The satellite then relays this information to the NOAA Command and Data Acquisition station at Wallops Island, Virginia, for processing and dissemination to users. The communications channel used to activate this response is called the interrogation channel, which continuously relays messages through the satellites. Its format is shown in Figure 2.

The timing information is contained within the satellite interrogation message, which is exactly one-half second in length or 50 bits. The data rate is 100 b/s. The time-code frame begins on the one-half minute and takes 30 seconds to complete (see Figure 3). Sixty interrogation messages are required to send the 60 BCD time-code words constituting a time-code frame.

The time-code frame contains a synchronization word, a time-of-year word (UTC), the UT1 correction, and the satellite's position in terms of its latitude, longitude, and radius. The position information is presently updated on the half hour.

As shown in Figure 2, an interrogation message contains more than timing information. A complete message consists of four bits representing a BCD time-code word followed by a maximum length sequence (MLS) 15 bits in length for message synchronization, and ends with 31 bits as an address for a particular remote weather data sensor.

The interrogation message phase modulates the carrier ±60°; the signals are right-hand circularly polarized. Characteristics of the interrogation channel are shown in Figure 4.

Time-Code System

The time-code is generated by atomic oscillators and integrated into the interrogation message at the Wallops Island facility for trans-

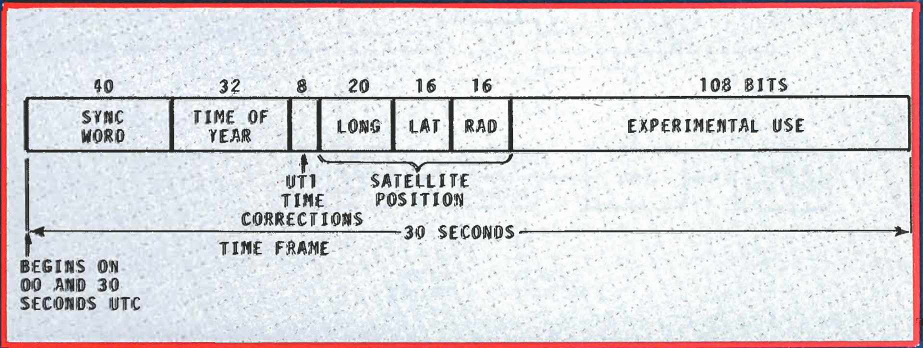

Figure 3. Time Code Format.

	Western Satellite	Eastern Satellite
Frequency	468.8250 MHz	468.8375 MHz
Polarization	Circular	Circular
Modulation	Phase Shift ($\pm 60°$)	Phase Shift ($\pm 60°$)
Data Rate	100 b/s	100 b/s
Satellite Location	135° W	75° W
Signal Strength (Output from Isotropic Antenna)	– 139 dBm	– 139 dBm
Coding	Manchester	Manchester
Bandwidth	400 Hz	400 Hz

Figure 4. Interrogation Channel Signal Characters.

mission to the GOES satellites. The path delay from Wallops Island to the earth via the satellite is approximately 260,000 microseconds. The time signals are advanced in time by this value before transmission from Wallops Island so they arrive at the earth's surface on time to within 16 milliseconds.

The time-code generation system, shown in Figure 5, 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 Wallops Island and stored in memory for eventual incorporation with the time code and interrogation message.

Housekeeping data for the time-code generation equipment are also retrieved from Wallops Island via the telephone line to Boulder. This information includes the frequency of the atomic oscillators and the time of the clocks with respect to UTC as maintained at NBS. All of this information is stored for retrieval in a data logger[1]. 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 Wallops Island.

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.

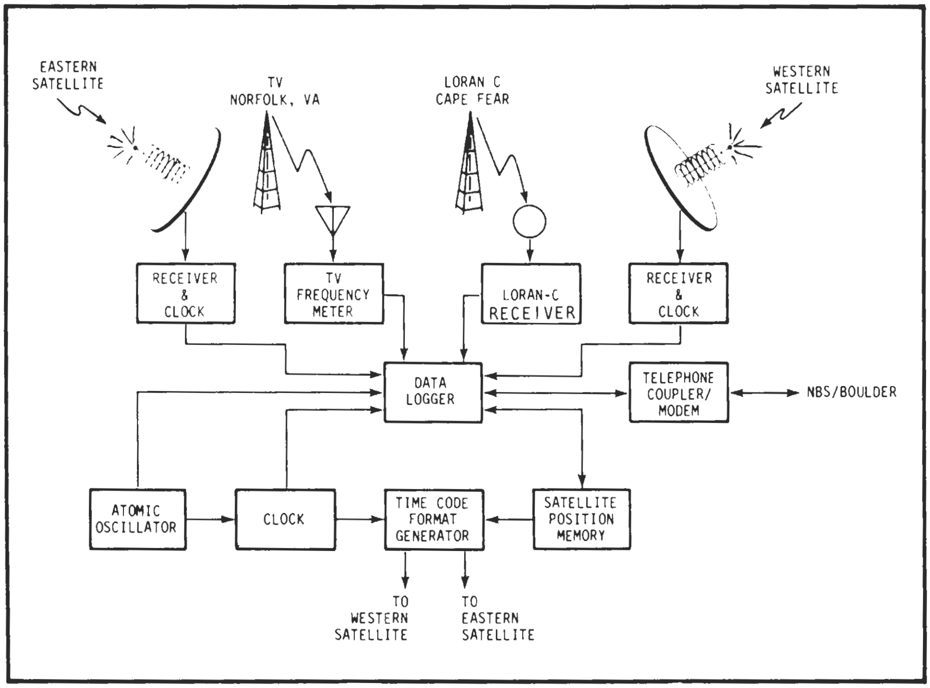

Figure 5. Time Code Generation Equipment at Wallops Island.

The satellite position information contained in the time-code 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 from 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 Wallops Island and sites in Washington and Hawaii. The eastern satellite is observed from Wallops Island, Santiago, Chile, and Ascension Island in the South Atlantic.

Receiving Equipment

The antennas necessary to receive the time-code can be quite small and include simple low-gain helixes or yagis. One antenna used by NBS is shown in Figure 6. Pointing the antenna is relatively easy. Because of the large beamwidths of low-gain antennas (<10 dB), pointing into the general direction of the satellite is usually sufficient. However, the antenna must be located so it has an unobstructed path to the satellite.

There are several receivers on the market that decode and display the satellite time-code. Some units simply display the time as received from GOES. Others contain "smart" clocks that automatically correct for path and equipment delays and synchronize the recovered time to UTC as generated by NBS. One such receiver is shown in Figure 7. NBS has also developed a microprocessor-controlled "smart" clock for receiving the time-code[2,3].

Applications

Although the National Bureau of Standards offers other time and frequency services, such as those provided by WWV, WWVH, and WWVB, they are not adequate for many of today's timing needs. WWVB's coverage is limited to the continental U.S., and WWV and WWVH cannot provide the high accuracy and dependability required for many applications. The GOES time-code was designed to meet these increasing demands for accurate time. In addition, since satellites provide line-of-sight signals, they are not subject to the fading or propagation anomalies characteristic of high frequency radio transmissions.

Present users of the satellite time-code generally fall into four categories: the electric power industry, the Department of Defense, geophysicists, and the communications industry.

Some electric power companies, both in the U.S. and Canada, use the satellite time-code to solve several problems. It is being used to improve overall system timing. In addition, timing near the microsecond level is used to identify, record, and successfully analyze faults. Without a common time reference, correlation of recordings from various sites is almost meaningless or, at best, very difficult to interpret. To do serious fault location analysis, the various, widely-separate sites need to be synchronized to better than one millisecond.

Some power companies also see a future application for 1 to 40 microsecond timing throughout widespread systems to monitor phase angles at many points as an indicator of system stability.

A major application for the time-code in geophysics is for date tagging environmental data. As previously mentioned, the GOES

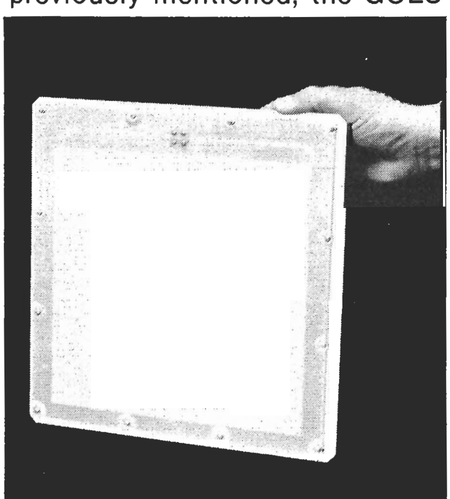

Figure 6. NBS Antenna used to Receive Time Code.

Figure 7. Commercially available "Smart" Clock.

satellites collect this type of information — on floods, rain, snow, tidal waves, earthquakes, and air and water pollution. The NBS code makes the collected data much more useful by adding time and a date to the information as it is sent to the satellites.

The time-code is being used as a time reference in the transmission of data from a joint U.S.-Canadian IMS (International Magnetospheric Study) magnetometer network. The four-year project will provide a better understanding of the coupling between earth and its space environment. Arrays of digital magnetometers will transmit data in real time using the GOES satellites to NOAA's Space Environment Laboratory where the information will be reduced in real time and made available to users.

The Department of Defense is using the satellite code for time synchronization. For instance, it is used to synchronize clocks on submarines, ships, aircraft, and land vehicles. It is also used to synchronize secure communications between command posts and outposts.

Oher applications are found in the communications industry. Broadcasters in Canada are planning to use the GOES time-code to synchronize computers and switching equipment in radio and TV networks. A communications company in the U.S. sees GOES as a possible time and frequency reference for local communications networks. Application involves the use of 3 to 5 synchronized transmitters within a metropolitan area to conduct mobile telephone and paging services. By transmitting exactly the same audio signal simultaneously from all sites, the probability of reception anywhere within the local area is greatly increased. The proposed solution to the problem is locking all transmitters to a common source such as the GOES time-code.

Other users are finding an increasing number of applications where time codes can satisfy their synchronization or timing reference needs. WWV, WWVH, and WWVB have transmitted time codes for many years. Now, the GOES time-code is another source of accurate time that offers several advantages over these other services. These include coverage of large geographical areas, ease of use, and relatively low cost.

References

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2. Cateora, J.V., Hanson, D.W., and Davis, D.D., "Automatic path delay corrections to GOES satellite time broadcasts," Nat. Bur. Stds., Technical Note 1003, February 1978.

3. Cateora, J.V., Davis, D.D., and Hanson, D.W., "A satellite-controlled digital clock," Nat. Bur. Stds., Technical Note 681, June 1976.