16 D - ARTIFICIAL SATELLITES AS A MEAN OF TIME DISSEMINATION

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ABSTRACT

Satellite time and frequency dissemination systems offer certain advantages over conventional HF broadcast services. Some of the important deficiencies of HF broadcasts are discussed together with the corresponding advantages of satellite systems. Experimental results obtained at NBS using UHF/VHF satellite transponders are reviewed. Work performed by other experimenters at higher frequencies is described.

The relationship of disseminated time and frequency to the design and operation of navigation and communication systems is described. There are significant advantages to relating the time and frequency information disseminated incidental to navigation and communication system operation to external standards.

L'Espace et la Communication, Vol. 1,
pp. 426-433, (40, rue de Seine, Paris 6e:
Editions Chiron, 29 March-2 April 1971)

INTRODUCTION

Communication satellite timing systems offer advantages over existing time and frequency dissemination services. This paper will describe some satellite time dissemination research conducted by the U.S. National Bureau of Standards (NBS) and by others during recent years. A variety of satellites have been employed in these studies, but the primary interest at NBS has been in the use of geostationary satellites containing transponders which relay a time signal from a reference station to any user in common view of the satellite. The signal from a single geostationary satellite can be received over approximately one-third of the earth's surface: Three such satellites would provide nearly worldwide coverage. Present NBS emphasis is on time dissemination techniques offering better reliability and coverage than is commonly available from HF time and frequency services such as WWV. Earlier work was devoted to techniques providing greater accuracy.

REVIEW OF SOME SATELLITE TIME DISSEMINATION EXPERIMENTS

The first satellite time experiments were conducted in August 1962 using Telstar [1]. The purpose of these experiments was to compare the clocks at the U.S. Naval Observatory (USNO) and at the Royal Greenwich Observatory. Signals were relayed between the locations by the Telstar microwave transponder. A two-way exchange resolves the round trip path delay if the paths are reciprocal (see Fig. 1). If the satellite motion is negligible, which is usually the case for geostationary satellites, the one-way path delay is one-half the round trip delay. The major advantage of the two-way exchange is that knowledge of the location of the satellite and of the ground stations is not required. The disadvantage is that both ends of the path must have both a transmitter and receiver and that only one user may be synchronized at a time. Similar experiments were carried out with the Relay communications satellite in February 1965 [2]. The experimenters reported the accuracies to be 1 microsecond and 0.1 microsecond, respectively, for the Telstar and the Relay experiments. Both of these experiments were conducted in the microwave region using wide bandwidths. Although great accuracy can be obtained under these conditions, the equipment costs are beyond the range of many users. The need for a lower cost technique led NBS to conduct two-way experiments using the National Aeronautics and Space Administration (NASA) ATS satellite VHF transponder [3]. Accuracies of about 5 microseconds were achieved using inexpensive receiving and transmitting equipment. It is believed that accuracies better than 1 microsecond are possible. The accuracy is limited by ionospheric effects.

A different class of satellite experiments involves one-way transmissions only (see Fig. 2). Users compare the received time signal to their local clock time and correct for path delay using information provided in connection with the time service or computed from orbital elements. An example of a satellite in the latter category is TRANSIT [4], a low altitude polar satellite designed primarily for navigation. The 2-minute TRANSIT frame includes time information and updated orbital elements. With this information and a measurement of the satellite Doppler a user can

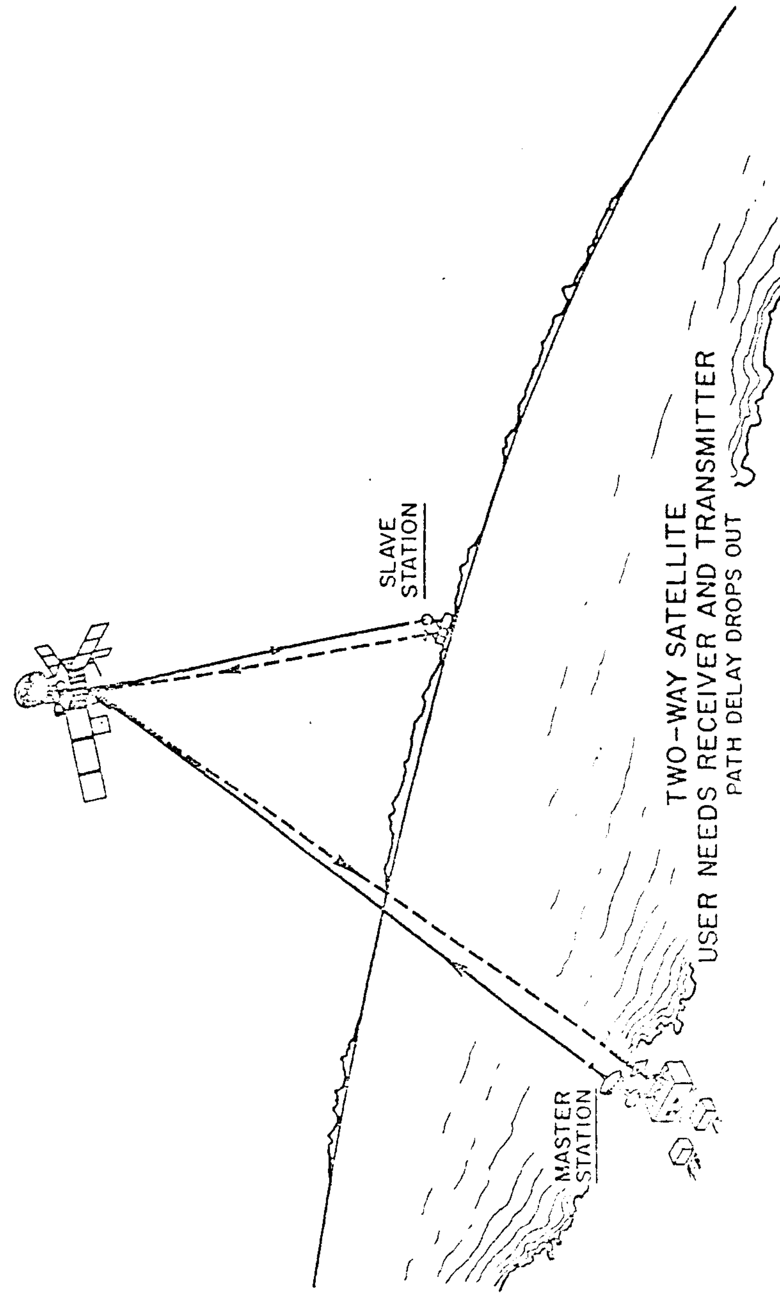

FIG. 1

1. Two-way satellite--User needs receiver and transmitter--Path delay drops out.

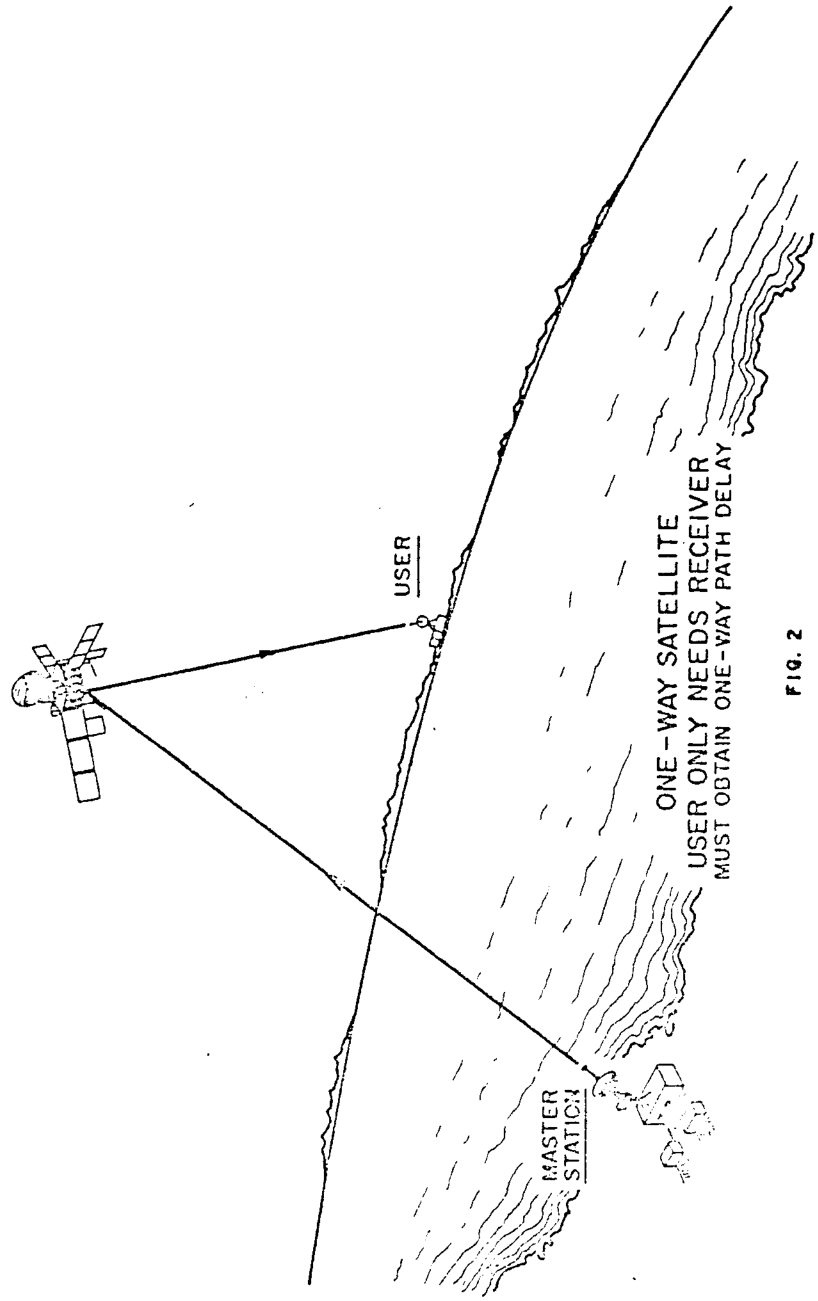

FIG. 2

2. One-way satellite--User only needs receiver--Must obtain one-way path delay.

determine his location and then determine the range to the satellite to correct the received time information. In principle high accuracy time synchronization is possible but the cost is high since a special purpose computer is required. User cost can be reduced if high accuracy is not required.

GEOS [5] is another low orbit satellite used by NASA to synchronize tracking stations. Time pulses are provided at intervals of 1 minute. Receiving station locations are accurately known with respect to satellite position. Accuracy of about ± 25 μsec has been reported.

NBS has conducted tests with several satellites using the one-way mode [6], [7]. These tests were conducted with geostationary satellites containing transponders to relay the signal from a master station to any user in common view of the satellite. Experiments have been conducted with the NASA satellites ATS-1 and ATS-3 and with the U.S. military communication satellites LES-6 and TACSAT. These satellites contained transponders which operated in the frequency range 130 to 300 MHz. The accuracy was limited primarily by errors in the path delay predictions (even geostationary satellites drift in position). For satellite time transfers made within a few days of updating the orbital elements, accuracies of 10 to 25 μs were typical. For older orbital elements the accuracy range was 60 to 150 μs.

These experiments were conducted at sites in Alaska, Hawaii, Ohio, Massachusetts, Colorado, and South America. To check the accuracy of the time transfer, the stations were equipped with cesium standards independently synchronized [6], [7] to within a few microseconds.

RECENT RANGING EXPERIMENTS

Determination of satellite position in NBS experiments has been based on orbital information supplied by agencies controlling the satellites. An alternative (and simpler) approach has recently been investigated at NBS and found adequate for the needs of many users [8].

The range to a satellite from three known locations was measured simultaneously while a time signal was being relayed from one of the three locations to the other two. The accuracy of the range measurements depended on the accuracy of synchronization at the station clocks and on the range measurement resolution. For these experiments the resolution was about 3 km which is modest compared to results obtained at modern tracking ranges. However, using this simple trilateration arrangement to determine satellite position, clocks at other locations were synchronized to about 40 μs. Using more accurately synchronized clocks at the trilateration stations and with improved ranging resolution, it is estimated that the technique is capable of providing synchronization in the accuracy range of 1 to 10 μs. Note that ranging and clock synchronization are done simultaneously using the same timing signal.

INFORMATION TO BE RELAYED

The signal format used in the recent experiments was designed primarily to measure the accuracy of time transfers using geostationary satellites in one-way and two-way modes. If wide band microwave satellite transponders are available, fast rise pulses can be used. NBS has been more interested in exploiting the narrow band UHF-VHF transponder capability since the required equipment complexity and cost is lower for potential users. As an alternative to the wide band, fast rise pulses, the "side tone ranging" technique commonly used at tracking ranges was chosen.

A 10 kHz tone is derived from the time standard with zero phase displacement from the time tick. This tone is gated by the clock to give sequential 10-second tone bursts at the rates of 1, 10, 100, and 1,000 pulses per second, followed by 10 seconds of the 10 kHz tone and a 10-second quiet period. The period of a complete time frame is 1 minute. The leading edge of all pulses are aligned to have zero phase displacement from the 10 kHz tone, which is already phase coherent with the time tick.

A carrier modulated by this time information is relayed by the satellite transponder to a user who compares it to a similar sequence derived from his clock. The amount by which the user must delay his own sequence to bring it into alignment with the received sequence is equal to the sum of the radio path delay and the time difference between the clocks. The resolution of the measurement is the resolution of the comparison of the 10 kHz tones. The ambiguity of the measurement is 1 minute, the period of one time frame.

Some users might like a signal which is less ambiguous than 1 minute. To this end, the NBS is working to initiate an experimental satellite time dissemination service which would include voice announcements of time of day similar to the present format on standard broadcasts such as WWV or CHU. A 1-minute time frame would include voice announcements of time and a BCD time code giving years, days, hours, and minutes. This BCD code would be modulated onto a 100 Hz subcarrier (essentially inaudible to a listener interested only in voice announcements). This same 100 Hz subcarrier time code will be available on WWV and WWVH on or about July 1, 1971, so that the same decoding equipment could be used with both the satellite and the HF signals.

Should a 24-hour, dedicated satellite, standard time service ever be instituted, it would have an important advantage over HF services in that users will not need high quality clocks to carry the BCD decoders through HF fades. Correspondingly voice announcements and audio tones would be free from fading.

OTHER ADVANTAGES OF SATELLITES OVER HF

The entire earth (except for the Poles) can be covered by three geostationary satellites. Many HF stations are required for global coverage since the range of HF signals is limited. Since many HF standard time broadcasts are on the same frequency there are interference problems in areas of overlapping coverage. This could be avoided in a satellite service by assigning a different frequency to each satellite.

Satellites can provide accuracy a hundred times better than the 1 millisecond accuracy typically obtainable from HF.

HF users in weak signal areas often employ very large antennas in order to get satisfactory signals. UHF-VHF satellite users could employ antennas similar to residential television receiving antennas.

Below is a summary of features of a UHF or VHF satellite time broadcast service which would be attractive to many users.

1. Unambiguous time signals. (Date and time of day provided.)
2. Not generally subject to propagation fade outs (except at high latitudes).
3. High accuracy.
4. Nearly worldwide coverage with three satellites.
5. Not subject to interference due to overlapping coverage (frequencies would be staggered).
6. Low cost to users.

TIME AND FREQUENCY DISSEMINATION IN COMMUNICATION AND NAVIGATION SYSTEMS

Time and frequency dissemination is an integral part of many communication or navigation systems. The TV format, for example, contains sync pulses whose sole purpose is to keep the crystal oscillator in the home television receivers at the same frequency and phase as the TV system oscillator. The Loran-C navigation system requires, for proper operation, that the Loran-C master and slave stations be synchronized in time. Another consideration of time dissemination associated with the Loran-C navigation system concerns the Loran user: In effect, the user measures the difference in distances between himself and three Loran stations by measuring the time difference between pulses received from the respective stations. Systems which employ time division multiplex techniques must have coordinated clocking. Clocking can be coordinated externally or internally. In some cases frequency is coordinated externally (by monitoring standard frequency broadcasts) and timing is coordinated internally (by the use of sync pulses). In these examples, clocks are coordinated with each other within a system. It is arbitrary whether the system clock is set to the correct "time of day" as determined by a time standard external to the system.

Apparently, many communication and navigation systems (e.g., television) are already disseminating system time and frequency quantities. Communication satellite systems now in the conceptual or design stages will also communicate their system time and frequency. Whether or not system time and frequency information communicated will be related to standards external to the systems is a decision that will be made consciously or otherwise by the systems designers.

Referencing system time and frequency to external (international) standards offers three opportunities to designers of communications systems. The first is related to spectrum conservation. Many existing communication systems (e.g., television) allocate a significant portion of their communication capacity to system time and/or frequency coordination. In some cases, externally disseminated time and frequency information could be utilized provided suitable clocks were incorporated into the system. This could free for other uses that portion of the channel capacity being used for system clocking. Similarly, that portion of system operation cost allocated to time and frequency dissemination could be reduced. Designers of satellite communication systems must be especially conscious of the opportunity to improve communication efficiency because of the high operating costs involved.

A second opportunity concerns the capability for privacy. Modern cryptographic techniques permit the sending of messages which can be received by anyone but which have meaning only to those with synchronized clocks and knowledge of the time at which significant messages will be sent.

A third opportunity is related to the resource that would exist should major systems reference their time and frequency information to external standards. Good time and frequency information could then be available almost everywhere. Under those circumstances new systems which depend on well disseminated time and frequency information could be implemented. For example, a data communications system to handle banking transactions in a completely private fashion would be a possibility.

There are two opportunities for navigation systems designers who reference their time and frequency quantities to external standards. The first is related to redundancy. If all clocks of a Loran-C chain as well as a clock on board a user's ship were on time with respect to external standards and, therefore, with respect to each other, a navigator could use the Loran system as a range-range system in addition to using it as a hyperbolic system [9]. Additionally, he could determine his position unambiguously from only two stations [9], effectively extending the range of the system. This can constitute a significant improvement in navigation accuracy in some areas.

Designers of both communication and navigation systems referencing their system time and frequency to external standards would have a common advantage. Should a network station operator experience a failure of his standard, he could resynchronize it either internally to the network or by reference to an external standard disseminated by some other means (e.g., by some other externally referenced system).

SUMMARY

The utility of communication satellites for disseminating time and frequency information has been demonstrated. The cost to the user is related to the accuracy he requires. A satellite standard time service appears to be attractive to many users.

Many existing and planned communication and navigation systems communicate time and frequency information necessary for system operation. Referencing the timing of such systems to a primary standard would create opportunities for spectrum conservation, private communication, and timing redundancy.