RECENT VHF/UHF SATELLITE TIMING EXPERIMENTS AT THE NATIONAL BUREAU OF STANDARDS

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GENERAL

The work to be described is concerned with satellite timing systems that would serve a large number of users. This is in contrast to other types of time systems that involve a very small number of users. The work referenced here has been published [1,2] or is in the process of publication[3,4]. For those who are interested, copies may be obtained of the published material upon request. This work has been supported by the Air Force Cambridge Research Laboratory.

CURRENT PROGRAM

The current satellite timing research program at the National Bureau of Standards (NBS) has been in progress for about four years and is part of a continuing program to examine useful ways of disseminating time and frequency, useful meaning that the end product must be applicable to a large number of users.

The NBS goal in satellite timing has been to obtain a relatively inexpensive, simple-to-operate, easily understood system. There should be a consistency in the timing system design. That is, the accuracy obtained should be consistent with the cost, the amount of effort expended, and the amount of time the user must wait to obtain the answer. This general approach is often discussed in literature dealing with time dissemination in general. The usual tradeoffs discussed are between ambiguity and precision.

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ENVIRONMENT DESIGN

Experiments have been conducted on the NASA-ATS satellites, the Lincoln Laboratories LES-6, and the military TACSAT satellite, all of which were in geostationary orbits. These satellites operated at frequencies in the range of 100 to 300 MHz. These characteristics permit the use of relatively small "TV like" antennas. For each of the satellites mentioned, the signal level was high enough to produce a good signal-to-noise ratio at the receiver.

The system operates as follows. The satellite transponds signals sent from the master station and the several user stations receive the satellite signal. Notice that the satellite itself has no clock or oscillator on board, it simply retransmits whatever it receives. The signal transmitted from the master station is a series of sine wave tone "bursts." These are sent at rates of 1 pps, 10 pps, 100 pps, 1000 pps and finally a continuous tone of 10 KHz. The user station receives these tones, measures their phase shift relative to derived tones from his clock, and computes the total delay. By subtracting the known path delay, it is possible to compute the clock difference. This entire operation is very simple and can be done repeatedly to ensure accuracy. The receiver equipment cost is estimated as $500.

The maximum ambiguity resolved is 1 pps. To obtain time more coarsely, the user needs to know the time to the nearest second (from WWV or other method). The ambiguity could easily be resolved by using the satellite to relay voice announcements of minutes, hours, and days.

The limiting factor in timing accuracy is a knowledge of the total system delay. The motion of even a geostationary satellite is large enough to cause significant timing errors.

The satellite timing error contributed by lack of knowledge of exact satellite position can be very large. To compute its position, the satellite orbital elements should be used. Most satellites are "ranged" by their respective operating agencies at frequent intervals, but unfortunately, experience has shown us that (except in special cases) most satellite positions are not known with sufficient accuracy for the needs of time dissemination. Several methods have been tried to circumvent this problem. One, the timing accuracy of the system has been carefully checked immediately after a ranging measurement and the daily increase in error has been noticed from that time until the next range measurement. Two, the timing stations have been used as a point where the time is known and the results from the timing signals used to "range" the satellite have produced great success. By this second method of subsequent timing measurements, the results are much improved.

The stations used in the NBS experiments were in Massachusetts; Boulder, Colorado; Ohio; and South America. Each station maintained accurate time using a cesium standard. Under the best conditions, the results approached an accuracy of 40 μsecs. However, when the satellite had not been ranged for some weeks, the accuracy was about 150 μsecs.

PLANS FOR FUTURE SERVICE

Based upon what has been learned from experiments to date, NBS has concluded that a satellite timing service is possible in a few years. This service would meet the criteria mentioned -- simple operation, low user cost, and an accuracy of about 10 μsecs. The customer would be expected to have receiving equipment, a divider with coherent outputs, and an oscilloscope; the operation would most likely be manual. If it were possible to use voice transmission over the satellite, the problem of time ambiguity could be resolved by sending time announcements, similar to those of WWV.

SUMMARY

The work described here has shown that a satellite timing system can be implemented at very low user cost. The best accuracy obtained is about 40 μsecs. This figure can be improved by a simple and practical modification of the standard technique. Most important, the user cost and time involvement is proportional to the accuracy requirement. Thus, the recent experiments at the NBS on VHF/UHF satellite timing indicate that a future service is both possible and practical.

REFERENCES

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[4] D.W. Hanson and W.F. Hamilton, "One-Way Time Synchronization Via Geostationary Satellites at UHF," (to be published).