CLOCK SYNCHRONIZATION EXPERIMENTS AT VHF UTILIZING THE ATS-1 TRANSPONDER

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FOREWORD

A need for microsecond time dissemination in several Environmental Science Services Administration (ESSA) components gave rise to the suggestion that an experiment be devised to demonstrate the effectiveness of a clock synchronization system utilizing the VHF transponder on board the ATS-1 earth synchronous satellite. The feasibility of this suggestion was confirmed by the Frequency and Time Dissemination Research Group of the National Bureau of Standards (NBS). A preliminary test was conducted jointly by the NBS group and three ESSA groups; the ESSA Research Laboratories (ERL), the United States Coast and Geodetic Survey (USCGS) and the National Environmental Satellite Center (NESC). Additional tests were conducted by USCGS and NBS and continuing tests are planned by NBS.

Precision and accuracy of better than ten microseconds have been demonstrated. The present report describes an experiment performed to explore extension of the existing technique. Preliminary results are mentioned.

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ABSTRACT

Experiments are described which repeat demonstrations of the effectiveness of a technique for synchronizing widely separated clocks to better than 10 μs, and which investigate extensions of this technique. Preliminary results are described. These experiments utilized the VHF transponder on ATS-1.

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DESCRIPTION OF EXPERIMENT

Ground terminals for these experiments were located at Goldstone Dry Lake, California (Stadan and Venus Sites), Pitcairn Island, Anchorage, Alaska and Boulder, Colorado. Equipment difficulties experienced by NASA at the Stadan terminal necessitated moving the master control function from Stadan. Boulder, Anchorage and Venus assumed the master function at various times during the experiment. This permitted the Round Robin mode of operation (described below) to be studied.

A number of clock synchronization methods were investigated. These methods are referred to as Mode I-A, Mode I-B, Mode II, and Mode II Round Robin, respectively. All of these techniques depend on stable propagation delay. Propagation delay at VHF is known to be sufficiently stable for the accuracies discussed in this experiment.[1] Experimental results were verified by two independent clock synchronization methods in addition to the redundant methods investigated. First, portable atomic clocks were carried from all stations to the time origin. Second, a microwave moonbounce clock synchronization system designed y Jet Propulsion Laboratories was operated between two of the ground terminals.

MODE I-A

The time interval between a received master tick and the slave clock tick was measured at the slave terminal (see figure 1.) This time interval includes equipment, transponder, and propagation delays, and the time offset between the master and slave clocks. Equipment delays are known, and propagation delays are computed using predicted values of the range from the satellite to the ground stations. The accuracy of Mode I-A is affected by uncertainties in the range predictions. This method is useful in a time distribution network with many users. It also has application to a user who does not wish to reveal his location by radio transmissions.

The range predictions could be made available in advance of synchronizations to specific users with known geographical coordinates, and they could also be published in a form appropriate for any number of general users.

In the latter case predictions would probably be made for various regions of the world and would be less accurate than for specific users.

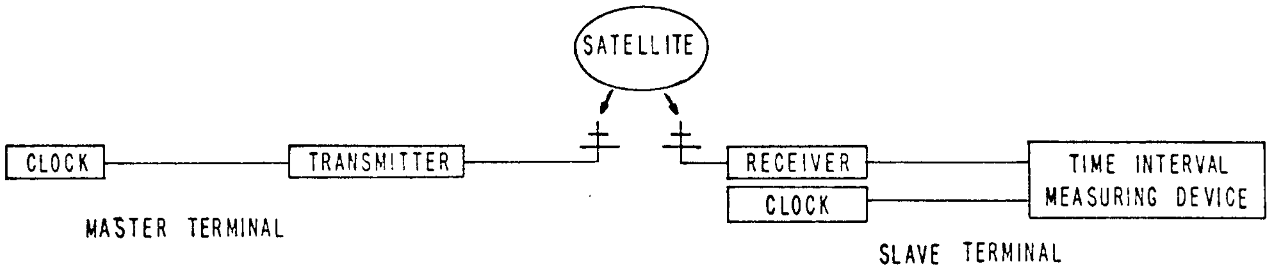

Figure 1

MODE I-B

The satellite range was measured by the NASA ground control station during the clock synchronization experiments. To the extent that the measured range is different from the predicted range, the propagation delay can be computed more accurately than in Mode I-A, and a better synchronization effected.

This mode is useful for stations wanting the best synchronization possible and having receiving capabilities only.

MODE II

This method of clock synchronization has been reported before[1], but was repeated in more detail during the course of these experiments.

Timing information is exchanged between pairs of ground stations by two-way communications via the satellite. The propagation delay is measured directly. The time interval measured at the slave clock, as in Mode I-A, can then be adjusted most accurately for propagation delay and equipment delay.

MODE II ROUND ROBIN

If a network comprising three or more stations is synchronized simultaneously, a redundant synchronization verification is inherent.

Consider stations A, B, and C. First the time difference is measured between clocks A and B, next between B and C, and finally, between C and A. We see that $A - B = -[(B-C) + (C-A)]$ for valid synchronizations.

RESULTS

Mode II clock synchronizations with precision and accuracy better than 10 μs were routinely obtained.

Mode II Round Robin synchronizations yielded cumulative errors of less than 10 μs.

Final results in Mode I-A and Mode I-B will be calculated using predicted nd measured values for satellite range when these range values are available rom NASA.

The time differences between ground stations were measured by transporting portable atomic clocks from all other ground stations to NBS, Boulder, Colorado. An independent measurement of the time difference was effected by operation of the JPL moonbounce link from the Goldstone Venus site to NBS Boulder.

DISCUSSION

The master terminal equipment installed at the Mojave Stadan terminal was left intact for continuing experiments. A slave station has recently been installed at station WWVH, NBS, in Maui, Hawaii. These stations are staffed by personnel trained in the operation of the equipment. Together with the slave station at NBS, Boulder, Colorado, these stations form an experimental network whose function is to provide the basis for continued experiments.

Preliminary experiments with tracking filters were run by USCGS and NBS in January and February 1968. Although inconclusive, they point the way for future tests. An improved operating format, designed to minimize the effect of satellite motion has been tested on a preliminary basis. Many verified synchronizations in the vicinity of one microsecond have been effected. It is hoped that future work will justify confidence in the technique to that accuracy.

ACKNOWLEDGEMENTS

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REFERENCES

[1] "Satellite VHF Transponder Time Synchronization," J. L. Jespersen, L. E. Gatterer, P. F. MacDoran and G. Kamas, submitted to the Proceedings of the IEEE, December 20, 1967.