WORLD-WIDE CLOCK SYNCHRONIZATION USING A SYNCHRONOUS SATELLITE

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An experiment has been conducted in which three remotely located clocks were synchronized through exchanges of timing information derived from the clocks. The timing information was transmitted between clocks by utilizing VHF radio propagation relayed by the transponder on board NASA's ATS-1 satellite, an earth-stationary satellite.

A number of synchronization techniques are investigated. These techniques are referred to as Mode Ia, Mode Ib, Mode II, and Mode II Round Robin, respectively. All of these techniques depend on the stable propagation delay which exists at VHF. 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 by Jet Propulsion Laboratories was operated between two of the ground terminals.

Mode Ia

The time interval between a received master tick and the slave clock tick was measured at the slave terminal (see figure). This time interval includes the equipment delay, the propagation delay, 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 Ia 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 coordinates, and they could be published in a form appropriate for 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. The range predictions used in Mode Ia were furnished by the ATS Group of NASA.

Mode Ib

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 Ia, 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, 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 Ia, can then be adjusted most accurately for propagation delay and equipment delay. Clock synchronizations better than 10 microseconds are routinely obtained using Mode II.

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. Cumulative errors around the loop of less than 10 microseconds were observed.

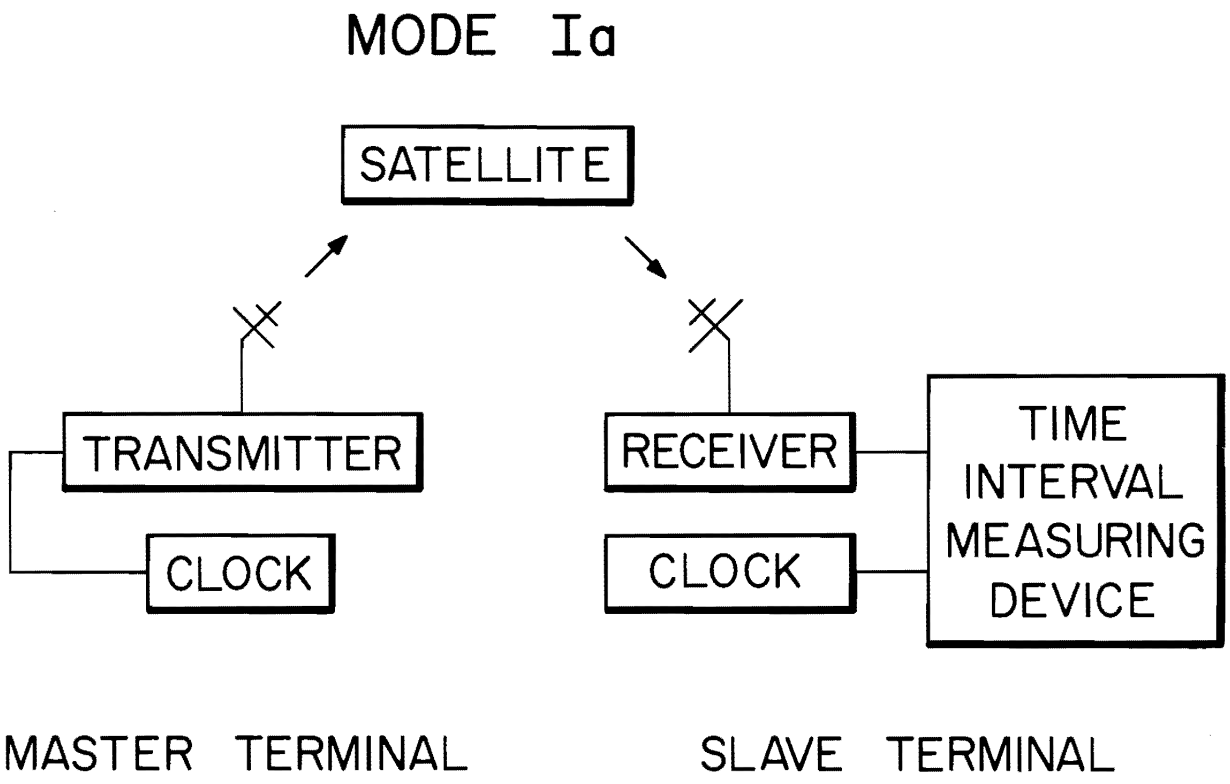

Figure 1. *Mode Ia Time Synchronization Method.* Master clock transmits time signals to satellite at 149.22 MHz which transponds back to earth at 135.60 MHz