TIME SYNCHRONIZATION *between* REMOTE

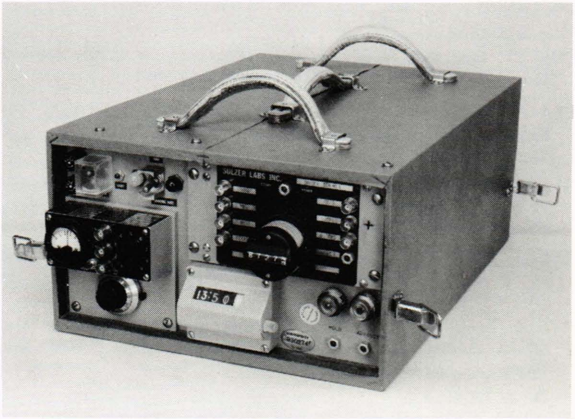
The Laboratory's interest in time synchronization evolved from its various activities in space R & D. There is a specific need, for example, for precise synchronization of time and for exact measurement of time deviations in tracking stations throughout the world. An immediate aim, of course, is to remove biases from the time systems of remote satellite tracking stations.

Because none of the existing methods of time synchronization had the accuracy and flexibility that are required for tracking operations, APL, through the efforts of L. J. Rueger, B. W. Shaw, and G. S. Hartong,* proposed the development of a precision portable clock. The actual physical transfer of a timing device between widely separated locations is the oldest known method of time synchronization.

Other methods of time transferral and synchronization have been used successfully and with accuracies that satisfy most technological requirements. While some time transfers, such as those by satellite, VLF transmission, and as signalled by WWV, can be accomplished with accuracies of 100 μsec or better, most methods produce characteristic accuracies in the *millisecond,* rather than the microsecond, range. Such methods usually have one or more features that prove to be shortcomings under some circumstances: limitations of range (such as Loran C); a need for some form of fixed installation; and varying errors due to changes in the propagation path.

It was determined that in order to achieve maximum accuracy of measurement, the displacement of a clock from one location to another should take place in the shortest practicable time period; for that reason commercial air is the logical means of transportation. Further, a time transfer should involve the smallest perturbation enroute, which again suggests air transport as being the most desirable. These requirements gave rise to others. The Laboratory had to determine the specifications for the clock, establish a method for predicting closely the frequency drift rates of the unit, and determine the effects of several environmental factors.

The Laboratory's general specifications for a portable clock were met by Sulzer Labs Inc., in a clock weighing 54 lb (somewhat reduced in subsequent models) and consisting of a stable, 5-mcps crystal-controlled oscillator, divider circuits to provide pulse outputs at various rates (including 1 pulse/sec), and a battery power supply for continuous operation up to 24 hr while in transit. The frequency drift rate of this equipment was tested to be 10 parts in 10^{11} per day and was linear to better than 1 part in 10^{11} per day. The instrument, as shown in the accompanying illustration, was designed specifically to be carried aboard an aircraft. Its outside dimensions are such that it can be



Precision portable clock manufactured for APL by Sulzer Labs Inc.

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LOCATIONS

placed under a seat in the passenger compartment of most commercial aircraft. While in transit the unit must be kept in continuous operation and be held in an upright position. It was found by experiment that tilting the unit as much as 30° for more than a few minutes substantially reduces the accuracy of a transfer. Smaller tilt angles over long periods of time produce similar errors. Accelerometers mounted directly on the clock record unusual bumps that can also seriously affect the accuracy of measurements.

Prior to undertaking transfers aboard commercial aircraft, it had to be demonstrated that operation of the clock would in no way interfere with the aircraft's radio or navigation equipment. A program of testing at APL and in aircraft on the ground under precisely controlled conditions provided commercial carriers with this assurance.

When a time transfer by means of a precision clock is to be made, the performance of the clock must be monitored for some time to determine the frequency drift rate of the unit and the linearity of that drift rate. These characteristics are determined in order to calculate the time offset that will be accumulated by the clock during the course of the time transfer operation.

Once the drift rate has been determined, the transfer of time can be undertaken. The procedure consists of five separate operations:

1. Determine the frequency drift rate of the precision oscillator.

2. Measure the time epochs and frequency of the portable clock relative to the standard of time and frequency at the initial location.

3. Transport the clock to a second location and then measure the time epoch of the portable clock relative to the epoch of the standard at the new location.

4. Return the portable clock to the initial location and remeasure its time epoch and frequency relative to the standard at that location. Departure of this last measurement from the value predicted from the drift rate is a check on the accuracy of the time transfer.

5. From the test data, the epoch error at the remote location is computed and made available to those concerned.

Time synchronizations between widely separated locations by means of air transport have been accomplished by APL on a number of occasions, covering distances as great as 3200 miles and periods of time up to 3.8 days. Although the accuracy of time transfers should, in the absence of environmental effects, be a function of time rather than distance, the significance of distance travelled in these investigations is in the increased extent of exposure of the clock to environmental changes that result from increasing distances. Such environmental factors, too, often account for the apparent discrepancies in accuracies measured over similar distances.

A recent time transfer from the Howard County site of APL to Austin, Texas, a distance of 1300 miles, was completed with a probable accuracy of 1.5 μsec in an elapsed time of 3.8 days. Another transfer, from APL to Boulder, Colorado, a distance of 1600 miles, was complete in 2.9 days. In this instance, the closure error was 5.5 μsec, indicating a probable accuracy of the time transfer of better than 5.5 μsec. (During the APL/Boulder operation it was determined that there was a 160-μsec departure in the equipment of the Boulder installation, relative to the Beltsville, Maryland, installation, of the National Bureau of Standards; operational procedures were instigated to achieve a much closer time synchronization of these stations.) The probable accuracies of time transfers over shorter distances, i.e. to Greenbelt, Maryland, and the Naval Observatory in Washington, D. C., have been fractions of a microsecond. Thus, it is concluded by Shaw and Hartong that a time synchronization between any two points in the world, if made in the least possible time permitted by commercial jet travel and with the least possible environmental change, could be made by means of a precision portable clock with an error of less than 10 μsec. This is an order of magnitude better than can be achieved by direct propagation techniques on a world-wide basis. Since initiation of the precision portable clock project at APL, units that are more compact have been designed by Sulzer Labs and are finding increasing use where precise time synchronizations in the microsecond range are of value. The National Bureau of Standards and NASA are among the organizations regularly using such equipment.