Aircraft Localization with a Time-Frequency System

Jean Besson* and Jean Boillot†
Office National d'Etudes et de Recherches Aérospatiales (ONERA), Chatillon, France

Theme

TIME-frequency systems may be used in numerous domains[1]: trajectography,[2] aerial or maritime collision avoidance systems,[3] air traffic control,[4] aircraft approach and landing guidance. They have been evaluated for satellite navigation, aircraft CAS, clock synchronization[5,6,7]; communications networks. This time-frequency technique was experimentally applied by ONERA for precise localization of aircraft and helicopters for research on noise certification.

Contents

Principle

The clock trajectography system is based on the determination of distances of the mobile to a number of ground stations; these distances are deduced from the measurement of propagation times of a signal transmitted by the clock on the mobile. Ground stations and mobile are equipped with clocks made of an ultrastable frequency standard and of electronic units delivering recurring pulse trains called "time scales."

The diagram of Fig. 1 gives the principle of the slant range measurement: the mobile time scale H_A is received as H_A' by each station, whose clock delivers a time scale H_B. If d is the difference $H_B - H_A$ between the time scales, τ_T and τ_R the delays in the transmitting and receiving units, and m the time interval between H_B and H_A', as measured in the station, the propagation time is

$$\tau_p = m - d - (\tau_T + \tau_R)$$

A complete trajectography system includes of least three ground stations, from which the slant range of the mobile is given by τ_p/c, where c is the velocity of light. For each station, $(\tau_T + \tau_R)$ is a constant which can be known by construction or calibration. Difference between mobile and station time scales is determined by one of the synchronization methods mentioned later.

Hardware

As seen in Fig. 1, the mobile carries a clock delivering a time scale H_A, and a transmitter; each station includes a receiver and a decoder delivering the signal H_A', a clock giving its own time scale H_B, a chronometer giving the difference m, and a recorder or a transmitter. The data from the various stations may be processed by a simple computer giving the mobile position in real time. If the measuring base is not too large, the various stations may include only a receiver and a decoder, linked to a central station including the clock H_B and a multichronometer delivering the various values of m relative to the respective stations; the values of τ_R take then into account the delays due to the transmission lines.

The clocks are made of a very stable frequency generator associated with an encoder generating the time scale. According to the precision required, the generator may be a very good quartz, a rubidium or cesium atomic clock or, in the future, a hydrogen maser or other frequency standard, e.g., ion pump.

The time scale pulses are transmitted on an appropriate carrier wave (e.g., 2300 MHz) with a broad bandwidth, in the order of 10 MHz. To restitute the pulse fronts in the domain of one nanosecond and to offset the influence of spurious signals, the time scales are transmitted as trains of ten 1-μsec pulses, spaced every 100 μsec and repeated every 0.1 sec After reception, the trains are decoded so as to provide single pulses defining the H_B time scale. Time scale differences d are measured with a 1-nsec resolution chronometer.

Exploitation of the System

In the clock trajectography system, the position of the mobile is given by the intersection of spheres centered on the ground stations, and whose radii are the slant ranges at a given instant. The best precision is obtained when the mobile altitude is of the same order as the sides of the polygon formed by the stations; as a consequence, the station positions must be decided by taking into account two important factors: length of the trajectory to be measured and expected precision.

Clock trajectography systems do not require any fixed installation: even electric energy can be supplied by a mobile plant. It is however mandatory to know the antennas position within a few centimeters.

Calibration can be ensured by accounting for the known delays of the various elements. But it may be quicker to make an over-all calibration by using the hardware of the mobile, or a similar one, placed at a location well known relative to the stations.

The main causes of error can be listed as follows[7]: 1) error due to atmospheric refraction, from one to a few tens of nanoseconds; 2) error due to pulse rise fronts, i.e., the system bandwidth: 5 to 10 nsec; 3) error due to chronometer resolution, which may be better than 1 nsec; 4) error due to time scale comparison; this error depends on the quality of the clocks and on the means used for their synchronization.[8]

Example of Use

The clock trajectography system was used by ONERA for helicopter and aircraft noise measurements at a remote airstrip in Southern France in September 1971. The station layout was as shown in Fig. 2.

In view of the small distance between stations, a single clock was used on the ground, and all measurements were read in a single station. The symmetrical positioning of stations 3 and 4 permitted to check in real time the aircraft flight path and to help the pilot's navigation.

More than 100 overflights were recorded during the tests, over a length of not more than 1500 m.

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*Subdivision Head, Systems, Physics Dept.
†Research Scientist.

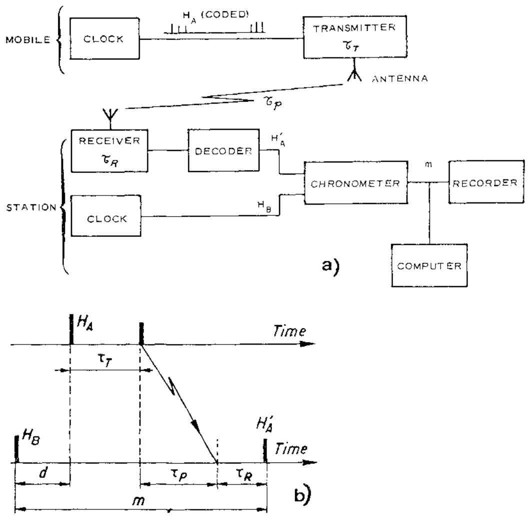

Fig. 1 Principle of operation with one station.

Table 1 Some computed standard deviations

Test n°	Altitude m	Number of points	Standard deviation (m)	Product of standard deviations m^3
111	100	34	$\sigma(X) = 0.76$ $\sigma(Y) = 2.55$ $\sigma(Z) = 2.85$	5.5
113	150	97	$\sigma(X) = 1.29$ $\sigma(Y) = 2.72$ $\sigma(Z) = 1.40$	4.9
420	130–280	188	$\sigma(X) = 0.60$ $\sigma(Y) = 3.01$ $\sigma(Z) = 3.11$	5.7

Results concerning precision are given Table 1 for a few typical tests. The standard deviation remains under 3 m for each coordinate; it may be noted that the product of the three standard deviations is independent from the station positioning and from the altitude of the mobile: this means that the mobile can be located at each instant within a 5 m^3 parallelepiped, which corresponds to a mean standard deviation of 1.7 m.

Conclusion

The advantages of this system can be listed as follows: 1) easy installation, without any infrastructure, 2) quick installation, in the order of one day, 3) station location easily modified, 4) simplicity of operation, as the stations do not need to be pointed toward the mobile, 5) good reliability, as the stations are independent and redundancy is easy, 6) real time display is possible with a small, portable computer, 7) absolute precision of a few meters, and 8) the hardware is modular, so that more or less elaborate systems can be deployed according to needs; temporary operation of units of common use (clock, chronometer, recorder, computer, etc.) can also be considered. The modular characteristics of the system permit to consider its use, without important modifications, to other operations, such as guidance of mobiles from the ground or air traffic control in congested areas.

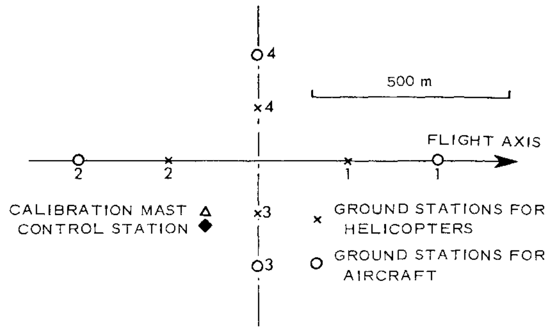

Fig. 2 Layout of the trajectography system used for noise certification of helicopters and aircraft.

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