# Synchronized Time and Frequency for Aeronautical Collision Avoidance, Communication, Navigation and Surveillance

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## Theme

THE Collision Avoidance System signal in space can provide enroute and terminal navigation, air space surveillance, data communication and collision avoidance from a universal signal in space for safe air space utilization and efficient air space management.

## Contents

During the early 1960's, the McDonnell Douglas Corporation developed a cooperative Collision Avoidance System (CAS) known as EROS (Eliminate Range 0 System) which employs a patented Resync technique for time and frequency synchronization of clocks in moving aircraft.

### Coarse Synchronization

A master station transmits to all systems a coded message that indicates the start of a system cycle and starts a new member's counter. The new member counts in a normal manner until his slot number is reached and transmits a signal at the beginning of the slot. Coarse synchronization assures the orderly reporting of 2000 members every three seconds on a common communication link without mutual interference.

### Fine Synchronization

When the aircraft signal is received at the master station, it will generally be late with respect to the proper start of the synchronized slot because of the propagation delays involved. At the ground station, the time interval between the start of the slot and the arrival of the pulse from an aircraft is measured. This time, which includes clock error and propagation delay, is subtracted from $t_s$ (synchronization time—known mutually at the aircraft to be synchronized and at the master ground station), and a "sync" pulse is transmitted at this point. Since the signal requires propagation time to return to the airplane, it arrives early relative to $t_s$ by a time equal to the clock error (or late if the clock is early). This information is used to make a digital correction to bring airplane time into synchronization with the master time. Frequency synchronization can be maintained by determining whether the sync pulses arrive early or late and tuning the frequency standard in small steps until the 5 MHz reference is reestablished.

Fine synchronization provides coherent time and frequency resolution sufficient to permit one-way range measurement to an accuracy of 200 ft, altitude comparison to an accuracy of 50 ft, and doppler to an accuracy of better than $\pm 60$ knots range rate.

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## Collision Avoidance Communications

Each member transmits two pulses during its message slot (Fig. 1). The first pulse has a duration of 200 μsec and is started within 0.2 μsec of the start of its message slot. Receiving members detect the time of arrival of its signal vs the start of the message slot and determine the range by dividing the velocity of propagation by the apparent propagation time. Range rate is determined by sampling the frequency of the incoming signal for 200 μsec for an apparent shift from the center frequency due to Doppler effect. Range is divided by range rate to determine the time to apparent collision. The altitude of the transmitting member is derived from the second pulse, 25.6 μsec in duration, which is positioned in time from the leading edge of the range/range rate pulse as a function of altitude referenced to 29.92 in. Hg (ATCRBS altitude digitizer output). These parameters are processed to evaluate threats and determine the appropriate maneuver instructions to avoid collision.

An interrogate-respond Backup Mode (BUM) is provided to meet the airline requirement that two air transport CAS equipped aircraft would be protected when flying within communication range regardless of synchronization availability. A BUM transmission is recognized by the decreased (16.6 μsec) duration of the altitude pulse. A receiving member would derive range rate from the signal and transmit a reply timed to arrive at the intruder in a mutually known time frame ($T_m$) if a collision threat exists. The actual time of arrival in the time frame tells the threatening aircraft which way to maneuver. The reciprocal transmission exchange will provide maneuver instructions to the second aircraft. The system capacity in BUM is 250 to 500 aircraft in mutual communication range.

Air-to-air synchronization is included in the air transport CAS to provide time dissemination during early implementation and, eventually, provide synchronization service to lower cost compatible units installed in general aviation airplanes. A hierarchy scheme is used to assure coherence between aircraft carrying time from different master synchronization stations.

Time hierarchy is coded in the range/range rate pulse to indicate a unit's time status based on automatic demotion of hierarchy as a function of the time since last synchronized. A system using a quartz frequency standard will demote to hierarchy 40 in approximately three minutes, and a system

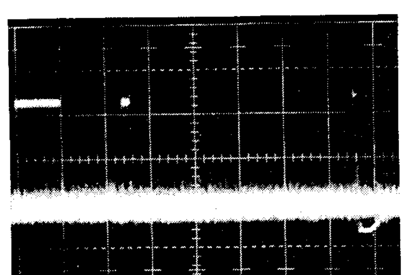

**Fig. 1 The collision avoidance system signal in space (range 31 miles, altitude 11,880 ft). The shorter signal at the far right is the resynchronization pulse sent to the aircraft to maintain system time.**

with a cesium frequency standard will demote to 40 in about 28 hr. When a member of inferior hierarchy receives a transmission from a member of superior hierarchy, the inferior member will request a resynchronization; and upon receiving this resync, will upgrade his status to one grade inferior to that of the synchronization donor. Resync is requested by encoding the superior member's message slot number during the requestor's range/range rate transmission. When a member's timing degrades completely, the CAS goes into the interrogate-respond backup mode. Hierarchy reporting and synchronization requests are accomplished with 17 one-microsec, biphase modulated data bits in the range/range rate pulse. Four more bits are provided for marker and parity, and an additional 99 bits are available for personal identity and future air-to-ground digital data communication.

## Collision Warning and Avoidance

The collision threat criteria are 0.5 nautical mile range and coaltitude, or coaltitude within 25 sec; or 25 sec to 0 range and coaltitude, or coaltitude within 25 sec.

A 40-sec alert zone precedes the collision warning maneuver command zone with turning and vertical speed restrictions. Maneuver commands include climb, descend, level off, or hold altitude.

In a time ordered system, one aircraft will detect the threat before the corresponding aircraft. The avoidance maneuver is determined by the first aircraft threatened and uses the apparent altitude difference between conflicting aircraft to assure vertical separation.

A climbing or descending aircraft spreads its altitude threat band to cover the altitudes it will pass through during 30 sec. If a threat occurs in the expanded band, the pilot is instructed to level off. Hold altitude is indicated in a threat situation involving more than two aircraft.

## Surveillance

The normal signalling processes in EROS provide range, altitude, and through message slot assignment, personal identification at a receiving unit. An instantaneous direction finding subsystem was developed and integrated with a ground flight following console, shown in Fig. 2, to provide air space surveillance. Aircraft position is shown as a target on a Plan Position Indicator (PPI). All aircraft transmitting EROS CAS signals in the area will appear on the PPI. Discrete target information is available through message slot selector switches on the console panels. When a message slot is selected, the altitude for that aircraft will be read-out as a three-digit flight level. This information is renewed every cycle.

If the operator wants to locate a particular aircraft, he presses the augment button next to the message slot, and the scope will "ring" the selected aircraft during the next cycle. A target can be identified by holding a light pencil over the blip; and when the scope repaints the target, the detector triggers logic illuminating the augment button next to the message slot selector of the target.

Altitude sorting is available by selecting an altitude with a two-digit switch and pressing the augment button next to the switch. During the next cycle, all blips from aircraft operating within 1,000 ft of the selected altitude will have a ring painted around the target.

An EROS airplane operating in the area but not selected on one of the selector switches will have the slot number appear in the "bogie" window. When a bogie is selected, the window will clear within a cycle and be available for another bogie. Thus the surveillance essentials for ground based traffic monitoring are provided by simply eavesdropping on the collision avoidance channel and synchronizing with the system.

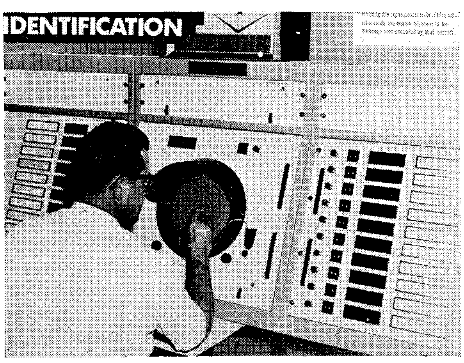


**Fig. 2 The collision avoidance flight following ground station. Implemented in 1965 to provide track, position, identify, and altitude information of CAS-equipped aircraft operating in the St. Louis area.**

## Navigation

The ground flight following function was applied to air-to-air navigation for station keeping. Here the basic CAS is augmented for a forward looking D/F antenna/receiver mounted on the airplane nose. This provides bearing detection from 60° right to 60° left and approximately 10° above and below the aircraft centerline. The cockpit control/indicator will provide the electrical interface between the collision avoidance equipment and the direction finder.

The pilot selects the identification of the aircraft he wants to keep station on and the equipment will display the slant range, altitude (or altitude difference) measured by EROS and the bearing of the selected aircraft.

Thus, the simple eavesdropping technique can be used in the sky to provide a sensible means of reducing aircraft separation in remote air space such as the transoceanic regions. Should a station keeping aircraft create a collision hazard or be threatened, the CAS will provide timely warning and maneuver instructions.

## Obstacle Avoidance

Nonprecision airport approach is also facilitated by operating a CAS on the ground in a dedicated message slot which enables the airborne equipment to recognize the transmission as being ground based and command climb, level off, or vertical descent speed limits in the cockpit. Unfortunately, the onboard ATCRBS altitude information is too coarse to provide vertical navigation to the runway threshold, and the approach guidance function is not suggested as a replacement for ILS. It should, however, improve operational safety in VOR and ADF approaches.

## Position Location

Very precise position determination can be achieved for navigation and surveillance by using multiple range and time-of-arrival calculations at the aircraft and ground, respectively. The common time base of EROS enables the airplane equipment to determine range from selected ground stations and, by trilateration, establish its X-Y position with an accuracy of 200 ft. The ground stations can be identified by the intrapulse biphase modulated data or through the use of dedicated message slots as in the case of obstacle avoidance.

Ground stations can locate an airplane with even greater accuracy because they will see the same transmission from the airplane and can provide slant range or time-of-arrival measurements for trilateration or delta TOA calculations. Accuracies of 60 ft to 125 ft CEP should be obtainable in this mode, since finer resolution range and signal thresholding circuitry can be included in the ground equipment.