A SYNCHRONIZED DISCRETE ADDRESS BEACON SYSTEM

NEAL A. BLAKE
Office of Systems Engineering Management
Federal Aviation Administration

Summary. The Federal Aviation Administration is developing a Discrete Address Beacon System as a new air traffic control surveillance system. It will solve most of the problems of the present beacon system and will also provide an integral digital data-link for ground to air messages. This paper describes a particular implementation of the DABS concept which also provides air-to-air collision avoidance service and navigation service.

Introduction. In another paper in these proceedings David R. Israel of the FAA describes the development program leading to a Discrete Address Beacon System and also outlines some of the reasons why such a new surveillance system is needed. It is the purpose of this paper to describe an extension to the DABS concept which we call Synchro-DABS. The incorporation of the discrete address feature adds a new dimension to our system. We can control and effectively eliminate interference and we can also use the same equipment to provide a reliable high capacity data link at essentially no increase in cost either to us or to the airspace user.

The Synchro-DABS is a further refinement of the DABS concept which adds yet another dimension to the surveillance and communication system and which provides the users with additional services if they choose to use them. We are developing a Synchronized Discrete Address Beacon System, or with the inevitable FAA acronym---Synchro-DABS. The new dimension we add is precise time. The availability of precise time is a powerful tool to instill order and provide other useful functions.

The basic concept of Synchro-DABS is very simple. The discretely addressed interrogations are transmitted from the ground with timing such that the aircraft being addressed responds at a precise time as if it carried a cesium or rubidium clock of great accuracy. A numerical example may help to explain this better. Figure 1 shows the overall timing of the system. We will consider for the moment only one interrogator. Let us assume that we use a 400 Hz PRF and hence a 2500 usecond Pulse Repetition Period (PRP). The diagram shows the 2500 usec PRP divided up into four contiguous 625 usec segments. We will call the beginning of each 2500 usec PRP "time zero." The 625 usec segment just before time zero is used to send DABS interrogations, the segment just after time zero is used to receive the responses elicited from the aircraft which were discretely addressed. The remaining two segments are used to transmit ATCRBS interrogations and to receive the replies. The figure shows the ATCRBS interrogations dotted to indicate that the time of transmission is jittered randomly by a few lens of microsecond each PRP. This is necessary because, unlike the present ATCRBS practice, the average PRF's of all Synchro-DABS sites are identical and without this jitter to make the instantaneous PRF's at adjoining sites different we would have a high incidence of the interference called synchronous fruit. The jitter will permit the present defruiter equipment to perform its very necessary function.

Figure 2 shows in more detail the activity during the Synchro-DABS part of the cycle. Let us assume that we wish to interrogate four aircraft during this PRP and that aircraft #1 is the farthest away and aircraft #4 is the closest. Let us assume for the moment that we know precisely the ranges from the site of the aircraft to be interrogated. We now send the interrogations such that they reach the individual aircraft, are decoded, and the aircraft all begin their responses at exactly time zero. The duration of the aircraft response in the baseline system we are building is 30 usec. Now, 30 usec times the velocity of light is approximately 5 nautical miles. Thus, to avoid overlap or garble we must select aircraft whose ranges from the site differ by more than 5 miles when choosing which aircraft to interrogate during a PRP. If two aircraft are, say, only a mile apart we must interrogate them on alternate PRP's.

Figure 3 indicates diagramatically how the sites would interface with each other. The FAA short range or terminal radars totate at approximately 15 RPM, the long range radars at 5-6 RPM. We would synchronize the rotation of the short range radars so that they all point North at roughly the same time and also synchronize the long range radars in the same fashion. The dotted lines in Figure 3 are meant to indicate the area of influence of each interrogator. The computer at the site is taught to not discretely interrogate aircraft in its neighbors area except during hand-offs or if a site failed and the neighboring sites were instructed to pick up the surveillance load. The combination of precise synchronization in time, synchronizing of antenna angles and restricting each site to work only traffic in its own assigned area will reduce interference to a very low level. Any residual interference can be dealt with by reinterrogation as will be shown later.

Figure 4 shows the interrogation to be sent to the aircraft. The header is the normal P_1 and P_2 of the ATCRBS message. This is used by the DABS transponder for bit synchronizing or clocking and for level setting. It also serves to suppress ATCRBS transponders which may receive the transmission. This message format and modulation is what we are presently constructing in our experimental Synchro-DABS system. It uses non-return-to-zero amplitude modulation. We are also testing Differential Phase Shift Keying modulation and will pick the scheme which has the best performance and cost features. After the two header pulses we have 24 bits of identity, 7 bits called "housekeeping" whose functions will become clear later, 5 bits of “message type,” 42 bits of message and a 3 bit framing pulse at the end.

Figure 5 shows the aircraft response. If an aircraft detects its unique digital identity in the 24 bit identity block it simply repeats the complete interrogation back to the ground exactly as received and decoded except, of course, transmitting at 1090 MHz instead of the 1030 MHz it received. The aircraft also adds up to 7 bits of air-derived data, its barometric altitude and a final framing pulse. If the ground-based site does not receive back exactly what was sent it will reinterrogate the aircraft.

It will be seen that the system described so far is basically a Discrete Address Beacon System with a specific set of rules for range ordering and timing the interrogations addressed to the individual aircraft. These rules will greatly reduce the incidence of interference and garble. There are other functions that can also now be performed. Each aircraft, when it transmits, does so at a precisely defined time. Each aircraft also is told the precise time every time it is discretely interrogated with a synchronized interrogation---nominally every four seconds in a terminal area or every 10 to 12 seconds enroute. Thus a quartz crystal oscillator could readily be used in each aircraft for time keeping purposes because it would be updated every interrogation cycle. We now have the basis of a useful service for aircraft operators. Each aircraft transmits at a precisely defined time and each aircraft could have the updated crystal clock if the operator desired it. Thus an aircraft could have an extra receiver tuned to 1090 MHz which received the transmissions of other nearby aircraft. The time of transmission and the time of receipt, hence the range, to these aircraft is thus available. Further, the transmissions carry the identity of the various aircraft so that range-rate can be obtained by range differencing on successive transmissions. Knowledge of the range, range-rate and altitude of other aircraft will provide the information necessary for a Proximity Warning Indicator (PWI) or Collision Avoidance System (CAS) based on air-derived data. The FAA makes the (possibly artificial) distinction between a PWI and a CAS that a PWI tells a pilot about the traffic around him but not what maneuvers to make to resolve a hazardous situation and a CAS tells him what to do but not necessarily where the traffic is. It is also possible to mount a small direction finding antenna on the aircraft to detect the relative bearing of the aircraft whose transmissions are being received. The combination of range, range-rate, relative altitude and relative bearing of nearby traffic provides adequate data for a CAS, a PWI, or both. This system would thus provide a suitably equipped user with air-derived protection against all DABS equipped aircraft so long as they are within line-of-sight coverage of a DABS ground facility. However, present FAA plans are to provide a high grade automatic separation assurance service based upon computations performed on the ground using DABS surveillance information with both PWI and maneuver commands sent to the involved aircraft via the integral DABS data link. The result is thus that the air-derived CAS/PWI service would only be available in those areas which were in areas of the DABS surveillance and where the ground derived separation service was also available. To extend the area where the air-derived service is available we are considering putting simple interrogators with omnidirectional antennas at some or most of our approximately 1000 Very High-Frequency Omnirange (VOR) sites. The line of sight coverage of these facilities takes in most of the usable airspace. The function of these interrogators would be to elicit synchronized transmissions from those equipped aircraft which were not in the line-of-sight coverage of a DABS surveillance site. These sites would use, for instance, only every tenth PRP and neighboring DABS sites would be programmed to not use those PRP's while working the airspace near the omnidirectional sites. There would then be no interference between the DABS facility and these omnidirectional facilities. The interrogations transmitted from these facilities would be essentially identical with those transmitted from the DABS interrogator. These VOR sites would not send any messages to the aircraft.

Figure 6 shows another transmission which these omnidirectional sites would radiate a few times a second. The thought is that each aircraft being interrogated, by either an omnidirectional facility or a DABS facility, is given the correct time every few seconds and can keep an inexpensive oscillator synchronized. The signals shown in Figure 6 contain the identity of the VOR, its latitude and longitude and its altitude. A pilot would set thumb-wheel switches in his transponder to the identity of this fix and the transponder would read out the distance to the fix exactly as with present day Distance Measuring Equipment (DME). He would obtain the identity by referring to aeronautical navigation charts or references. Presumably the identities would be keyed on a one-to-one basis with the VHF frequency of the VOR much as the UHF frequencies of the present DME are keyed. Thus the act of tuning the VOR receiver would also automatically select the DME exactly as in present practice. The equipment in more sophisticated aircraft such as air carriers or corporate business aircraft would be designed so as to process the signals from two or more stations at once and compute position by multilateration. It should be noted that the latitude and longitude information contained in the signals allows the aircraft computer to pick those stations which give the best geometry for position fixing and also does not require the pilot to select any stations. The altitude information is used to perform slant range correction.

Some of the bits in the interrogation message shown in Figure 4 are called "housekeeping bits." The "SYNCHRONIZED" bit is set when the interrogation is precisely timed based on knowledge of true present range from the interrogator to the aircraft being discretely addressed. The interrogator will be tracking each aircraft and will first transmit an unsynchronized interrogation based upon the predicted position and will obtain true present range. Using this range it will then transmit a synchronized interrogation with the "SYNCHRONIZED" bit set. The aircraft transponder re-transmits the interrogation. Thus aircraft which had the extra 1090 MHz receiver installed would only use those signals containing the "SYNCHRONIZED" bit for air-to-air ranging purposes. The "DABS" bit means that the interrogation is from a DABS (i.e., ATC surveillance) facility as opposed to being from one of the "gap-filler" interrogators located at a VOR facility. We naturally wish the ATC surveillance function to have priority. Therefore, the transponder logic will be designed so that the transponder will not reply to a VOR interrogation if it is being tracked by a DABS facility but will reply to a DABS interrogation even if it is being tracked by a VOR facility. Other logic is included so that initial acquisition and "handoff" from site to site will be automatic and will not require controller attention.

In summary, it appears that by ordering the discrete interrogations in a articular way additional useful services can be provided to the aviation community at a low cost. simple omni-directional.ground station and three sets of avionics are being fabricated and flight tests will take place in the Spring of 1974.

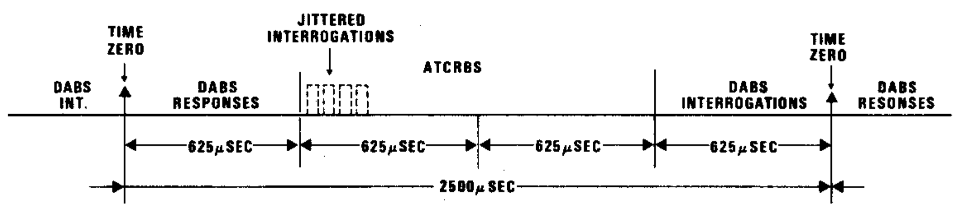

Figure 1. Division of Time Between Functions at Ground Station.

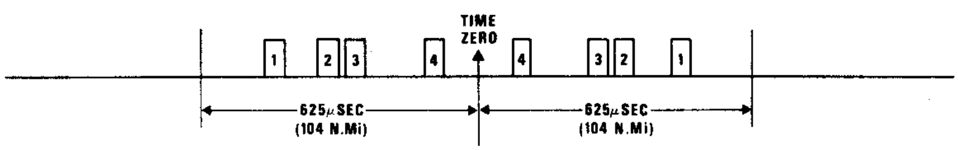

FIGURE 2
SYNCHRO-DABS INTERROGATION TIMING

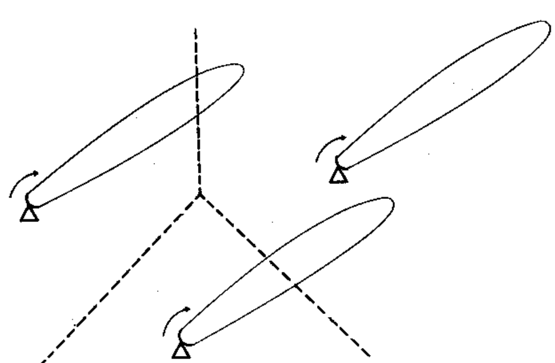

Figure 3. Distribution of DABS Sites

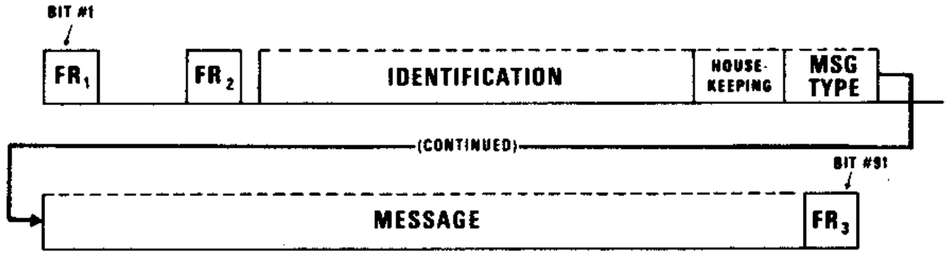

Figure 4. Synchrodabs Interrogation

NOTE: 91 CONTIGUOUS BITS, EACH 0.25μSEC LONG (23.75μSEC TOTAL LENGTH).
1030 MHz. NON-RETURN TO ZERO AMPLITUDE MODULATION
HOUSEKEEPING BITS ARE: (1) SYNCHRONIZED (2) DABS (3) LOCK-IN (4) PCA (5) IPC

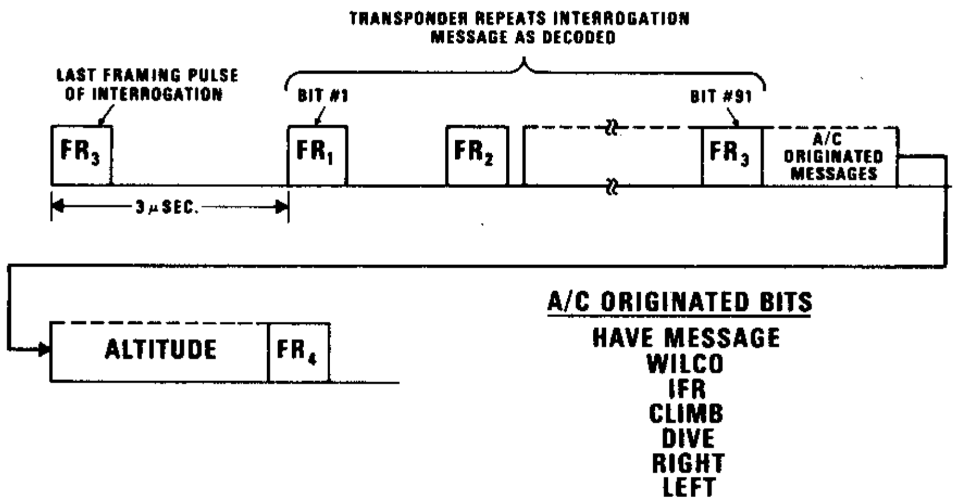

Figure 5. Aircraft Response to DABS Interrogation

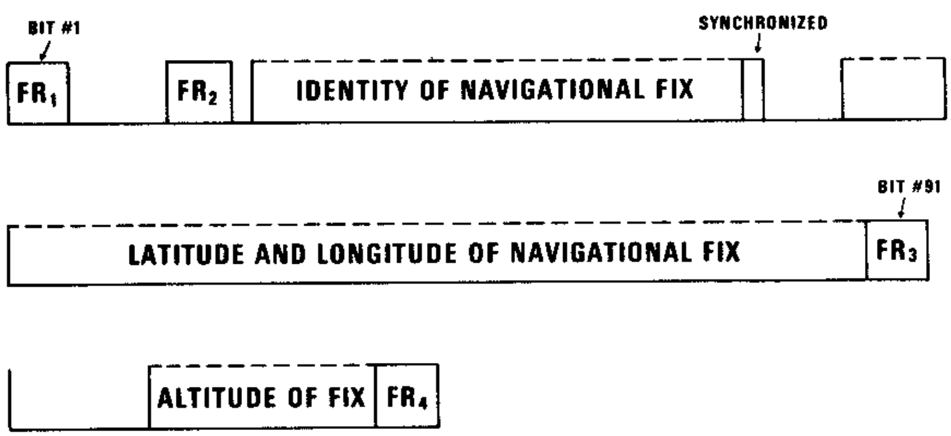

Figure 6
NAVIGATION SIGNAL BROADCAST BY GROUND STATIONS