AN AERONAUTICAL BEACON SYSTEM USING PRECISE TIME

T. S. Amlie
Federal Aviation Administration

ABSTRACT

An experimental system using precise time techniques is presently under construction and will be tested in 1974. It will provide accurate surveillance data to the ground based ATC sensors, high capacity data link ground-to-air and air-to-ground, navigation services and air-to-air collision avoidance and proximity warning service. The design takes into account the large disparity in electronic equipment among the various classes of users. The user of the airspace installs only that equipment required for the services he needs.

BACKGROUND

The aircraft using the civil airspace of the United States may be divided roughly into 2600 air-carrier aircraft, 140,000 general aviation aircraft and 20,000 military aircraft. The general aviation aircraft range from very well equipped Gulfstream II and Learjet corporate aircraft down to very small general aviation aircraft with almost no electronic equipment. However, the vast majority of the general aviation fleet is comprised of single engine aircraft of 300 Horsepower or under with an electrical system and a fair market value of perhaps $10,000. The military fleet also ranges from superbly equipped C-5A's and C-141's down to primary and basic trainers which are not really equipped to venture into civil airspace and do not do so.

The problem facing the FAA is that of implementing and operating a system that gives this wide spectrum of users the services they require at a price they are willing and able to pay. An air carrier turbojet costs between $5 million and $25 million to buy and between $500 and $2,000 an hour to operate. A typical general aviation aircraft, as noted above, is worth $10,000 and costs $20 - $30 per hour to operate. Within reason, the cost of avionics is not important to the air carrier so long as it reduces delay and/or increases safety. Delay is not particularly important to the typical general aviation operator but cost, both initial and maintenance, is very important.

The present civil air traffic control system is based on the Air Traffic Control Radar Beacon System (ATCRBS). This system is essentially identical to the military IFR system except that FAA interrogators do not transmit any of the cryptographic messages used by the military. The ATCRBS is based on World War II technology and is beginning to reveal shortcomings as more and more aircraft are equipped with transponders and begin to use the airspace. Many of these difficulties arise from the fact that all aircraft which receive a valid interrogation answer it. This causes interfence or, in FAA jargon "fruit and garble." The interference becomes worst when aircraft are flying close together which, of course, is just when high quality surveillance data are required.

There are other factors which influence the choice of a system. The present air traffic control system is very costly to operate because it is very labor intensive, meaning that there are many controllers watching traffic displays and issuing control instructions and advisories via VHF or UHF voice radio. It would be very desirable to use computers to aid the controllers in their tasks. If the computers are to provide a useful service that increases safety they will have to be able to communicate with the aircraft directly and send short digitally encoded messages. This, of course, implies a data link both ground-to-air and air-to-ground. The air-to-ground link is nessary to verify that the correct message was received in the aircraft as well as for the pilot to send simple messages such as "emergency" and "radio failure."

Navigation in the civil airspace is based upon the Very High-Frequency Omnirange (VOR) and Distance Measuring Equipment (DME). The DME is essentially identical to the military TACAN except that civil DME equipment reads out only range and/or range rate to the selected station instead of the range and bearing read out by a military TACAN set. The FAA installs both VOR and TACAN at most navigational fixes. Such an installation is called a VORTAC and provides service to civil and military users. Carriage of DME equipment is mandatory now for flight above 24,000 feet and this level will probably come down in the near future. Further, a larger percentage of the general aviation pilots are beginning to fly under Instrument Flight Rules (IFR) and find DME a convenience. Much like the ATCRBS, as more and more aircraft are equipped with DME the ground portion of the system begins to saturate. The actual saturation point depends upon the pulse repetition frequency of the airborne equipment but a typical number for today's system is that around 100 aircraft interrogating a given VORTAC begin to degrade its performance. It is reasonably clear that this could become a serious problem in busy airspace such as the Los Angeles Basin or anywhere in the corridor from Washington, D. C., to Boston. Another problem with the DME system is cost. The least expensive airborne DME is $1500. Air carrier sets run well above $10,000.

Yet another facet of the problem facing the FAA is the real possibility that an air-to-air collision avoidance or proximity warning system will be made mandatory by Congress. There are bills in both the Senate and the House directing the FAA to select such systems and require their installation and use in all aircraft; air carrier, military and general aviation. The systems presently being proposed are expensive and complex and would impose yet more maintenance problems on aircraft operators. This rather lengthy statement of the FAA problem of selecting a design can thus be summarized as follows:

a. A new surveillance system is needed which is more accurate and reliable and does not exhibit interference problems as the density of traffic builds up.

b. A reliable, high capacity digital data link is needed which will permit increased use of automation to reduce controller workload and also to increase safety.

c. A non-saturable DME is needed as more operators use this service.

d. An air-derived collision avoidance and/or proximity warning system will probably be made mandatory by Congress.

e. The cost must be kept as low as possible so that general aviation operators can afford to participate in the system.

PROPOSED SOLUTION — GENERAL REMARKS

It should be no surprise that a paper prepared for a Precise Time and Time Interval Planning Conference should propose a solution which is based upon the powerful properties of a system using precise time. As will be seen below, the system is carefully tailored to meet the cost constraint. The precise timekeeping is done by the ground-based system. Thus the basic general aviation transponder is essentially the same as a present ATCRBS transponder and only speaks when spoken to. The more sophisticated users of the airspace would install more complex avionics if they desired the DME and the collision avoidance or proximity warning service. An aircraft with this equipment would receive and process signals with only the basic transponder.

The FAA is already well underway to solving the improved surveillance and data link problems. It appears that most of the difficulties with the present ATCRBS system can be overcome by a discretely addressed beacon system wherein each aircraft responds only when interrogated with its unique digital identity. This technique would reduce the number of interrogations per aircraft by a factor of at least 10, would eliminate synchronous garble, and would also permit the transmission of shourt digital messages to each aircraft. These messages would be encoded as part of the discretely addressed interrogation and only the addressed aircraft would decode the message and display its contents to the pilot. A discrete-address beacon system (DABS) is presently being developed by the FAA.

Historically, the FAA and the aviation community at large have been slow to implement new ground or airborne systems. It can be anticipated that DABS will be implemented slowly, beginning at a few large airports. Thus it will be difficult to convince the aviation community to purchase and install DABS transponders unless these transponders would also perform the ATCRBS function in outlying areas that were not yet DABS-equipped. The ATCRBS is widely installed in aircraft and protected by treaties; hence, ATCRBS equipped aircraft will have to be serviced for a long period in the future. Thus it appears that any new DABS ground installations must be compatible with ATCRBS transponders, and new DABS transponders must function in the ATCRBS mode when flown in areas not yet converted to DABS. In addition, it is desired to keep the transponder design as simple and inexpensive as possible in order to not impose an unnecessary financial burden on the owners and operators of the 135,000 general aviation aircraft in the present U.S. civil fleet. The dual constraints of compatibility with the ATCRBS system and low cost imply strongly that the DABS system should use the same frequencies as the ATCRBS; viz., 1030 MHz for interrogation and 1090 MHz for aircraft response.

The present ATCRBS interrogation of aircraft is relatively undisciplined. Care is taken to adjust the pulse repetition frequencies (PRF) of neighboring interrogators so that they are different, assuring that the condition known as "synchronous fruit" will be only momentary. Other features such as sidelobe suppression and reply-rate limiting are included in the ATCRBS to reduce interference. Nevertheless, many of the present problems of the ATCRBS are due to the lack of discipline in the ground-based system.

The DABS concept envisions sending digital data from the ground to the aircraft and from the aircraft to the ground. It is clear that the addition of a DABS to the present ATCRBS system without imposing some form of discipline on the interrogation scheduling would have an adverse effect on the ATCRBS system and also provide a low message reliability in DABS unless design techniques employing different modulation and error detecting or error detecting coding were employed. These techniques would add to the cost of the transponder and do little to solve the present ATCRBS problems.

PROPOSED SOLUTION — SPECIFIC CONCEPT

One of the concepts being examined by the FAA has a name derived from synchronized discrete address beacon system, SYNCHRO-DABS. The basic concept is straightforward. The ground-based system adjusts the timing of the transmission of an interrogation such that it reaches the particular aircraft addressed; it is received and decoded; and the aircraft begins its response at selected periodic intervals. The effect is as if the aircraft carried on board a cesium or rebidium clock of great precision. It is thus possible to use some of the powerful techniques associated with common precision timing without requiring complex airborne equipment.

Figure 1 shows one form of the possible overall timing of the system. A precision 400 Hz PRF is chosen. Each $2500\mu s$ pulse repetition period (PRP) may be thought of as beginning with a "time-zero" timing pulse.

Consider each $2500\mu s$ PRP to be divided into four $625\mu s$ segments of time. The segment just before time zero is used to send out discretely-addressed ground interrogations; the segment after time zero is used to receive the response elicited from the aircraft, which were discretely addressed. (Rather than impose periodicity on the ground transmissions of the interrogations, the system imposes periodicity when an aircraft received the interrogations.) The remaining two segments are used for transmitting ATCRBS interrogations and receiving ATCRBS replies. The time of transmission of the ATCRBS interrogation is shown dotted to indicate that the time of transmission is jittered at each site to preclude neighboring sites from having the same instantaneous PRF and causing the phenomenon known as synchronous fruit. This is necessary because, unlike the present ATCRBS system, all sites have exactly the same average PRF in the SYNCHRO-DABS system.

Figure 2 shows in more detail the activity during the time devoted to the SYNCHRO-DABS function. Assume that four aircraft, whose ranges are precisely known to the ground system, are to be interrogated during the particular PRP shown. Aircraft 1 is the farthest away; aircraft 4 is the nearest. The discrete interrogations are transmitted in the order shown with timing such that they reach the aircraft, are decoded, and each aircraft begins its response at time zero. These responses are received at the ground in the inverse order to that with which they had been transmitted. It is clearly necessary, when deciding which aircraft to interrogate during a single PRP, to choose aircraft whose ranges from the interrogator differ by more that the message length times the velocity of light, in this case approximately 5 nmi. The time separation of the DABS and ATCRBS functions thus eliminates interference between these two modes at least as far as the one ground site is concerned.

Next, assume that all ground sites are similarly synchronized in time and, further, that the airport surveillance radars (ASR) with a nominal rotation period of 4 s are also synchronized in azimuth as indicated in Figure 3. The dotted lines indicate the area over which each site performs its surveillance function. Except when handing off an aircraft from one site to another and when a facility fails and neighboring facilities must pick up the load, each interrogator would only address aircraft within its assigned area. The combined effects of synchronizing both time and azimuth angle will reduce interference between adjacent sites to a minimal level. Any garbled replies that might still occur would be resolved by reinterrogation. The scheduling of interrogations as depicted in Figure 1 will give a non-ambiguous radar range of 104 nmi. The FAA also operates air route surveillance radars (ARSR) that have a requirement for 200 nmi range and typically have a rotation period of 15 s. These facilities would require back-to-back antennas, one doing ATCRBS full time and one doing DABS full time. The timing of the interrogations would be synchronized as in the case of the ASR's and any garbled replies would be resolved by reinterrogation.

The format of the possible DABS interrogation transmission is as shown in Figure 4. Interrogation is conducted at 1030 MHz (as in the present ATCRBS system), is amplitude modulated, and at a nominal 500 W level. The coding is based on 0.25 μs b widths. FR_1 and FR_2 are 3 b pulses that serve the functions of suppressing the ATCRBS transponders receiving the signal and also of providing level setting and bit synchronizing signals to the DABS decoding circuitry. The identity block contains 24 b that permit upwards of 4,000,000 discrete addresses. The next 5 b are "housekeeping bits" and their individual functions will be decribed shortly. The following 5 b are used for messages type and allow for up to 32 different message types. The next 42 b are for message. (The number 42 allows for transmission of seven alphanumeric characters per interrogation using a truncated ASCII code of 6 b/character.) This is followed by a 3 b framing pulse FR_3.

Figure 5 shows the aircraft response to a discrete interrogation. The reply begins 3 μs after the leading edge of FR_3, to be consistent with present ATCRBS practice. The aircraft transmits at 1090 MHz and repeats the interrogation exactly as received and decoded except for the change in carrier frequency from 1030 to 1090 MHz. After repeating the interrogation, the aircraft can add on 7 b of aircraft-generated message, 11 b encoding the aircraft barometric altitude, and a final framing pulse. The error checking thus is done by the ground-based system and if the response does not match exactly the interrogation that was sent, the aircraft is reinterrogated.

A design goal is to make aircraft entry into the system automatic without adding to either the pilot or controller workload. A "general-call" signal format is shown in Figure 6. The 24 identity bits are all set at "1" and the message type indicates that this is a general call. Any aircraft that had not been discretely addressed within the last 20 s would respond to this general call and would insert its own identify in the identity block in place of the 24 ones. It would also add its altitude bits. The interrogator would add this identity and postion into the memory of the ground system and begin to interrogate the aircraft discretely. The aircraft would no longer respond to the general call.

A method of resolving garbles in replies to general calls would also be needed when, for instance, one surveillance site suffered a failure and an adjacent site was instructed to pick up the load. If a site detected a garbled reply to a general call, it would revert to a semidiscrete interrogation mode whereby it would begin setting some of the 24 ones to zero in the identity block. Those aircraft, which had ones in the corresponding position of their own identity, would not answer this general call.

In the system described above, each DABS-transponder-equipped aircraft flying in airspace covered by the ground-based interrogator will periodically transmit, at a precisely defined time, its identity and altitude. Any aircraft operator who desired a collision avoidance system based on air-derived data could install a 1090 MHz receiver in this aircraft. Each aircraft is ground-synchronized whenever it is interrogated, and it is then possible to install a crystal-stabilized oscillator to maintain synchronization and predict the times of occurrence of time zero in the interval between interrogations. An aircraft that listens at 1090 MHz and also has such a crystal-stabilized clock can then compute the range of other aircraft based upon the time of arrival of their signals. Further, the receiving aircraft can compare the present range of another aircraft with its range measured at a prior response and calculate range rate. The altitude of the other aircraft is also known because it is encoded in its transmission. An aircraft receiving these signals thus derives the range, range rate, and altitude of other aircraft around it and makes determinations as to which, if any, of these aircraft constitute a threat.

It is also feasible to install a small direction-finding antenna on the listening aircraft so that the relative bearing of each nearby aircraft can be displayed to the pilot. Figure 7 shows such an antenna, which is now being tested for this purpose at 1090 MHz. Figure 8 shows the antenna on a light aircraft.

The proximity warning or collision avoidance system described in the preceding paragraph has shortcomings in that it fails if the ground-based system fails, and it only functions in that airspace that has radar coverage. Present planning is that an automated ground-based collision-avoidance service using the DABS data link to send ground-calculated collision-avoidance messages will also be available wherever adequate radar coverage exists. The SYNCHRO-DABS concept can eliminate this shortcoming by putting simple "gap-filler" interrogators and data-processing equipment at very high frequency omnirange (VOR) stations of which there are almost 1000 covering the U. S. These interrogators would have fixed antennas with omnidirectional azimuth coverage. The primary function of these stations would be to send out discrete interrogations to keep DABS-equipped aircraft transmitting and properly sychronized. This is possible since azimuth does not enter into the timing adjustment for airborne synchronization. No use would be made of the range data on the ground nor would air traffic control messages be sent on the data-link channel. An aircraft equipped with the 1090 MHz receiver could now get an independent air-derived collision-avoidance separation service from all transponder equipped aircraft as long as it flew in airspace within line of sight of a VOR (which takes in most of the usable airspace).

The interrogations transmitted by these facilities placed at VOR sites and the responses elicited from aircraft would not interfere with the operation of the DABS facility that was performing a surveillance function for ATC purposes. As an example, consider a VOR site located in a valley 50 mi from a DABS site. The VOR site would use only, for instance, every 1/10 or 1/20 PRP of the 400/s available. The DABS site computer would be programmed to not use those PRP's while working the airspace over the valley in which the VOR was located. Neighboring VOR's would be assigned different PRP's to avoid interference. The interrogators at the VOR sites could also provide the synchronizing service in an area served by a DABS site if the DABS site failed and there were either no neighboring DABS sites to pick up the load or the neighboring DABS site also failed.

The requirement for, and use of, the housekeeping bits shown in Figure 4 can now be discussed. It is desired that the DABS sites, i. e., those using the responses for surveillance inputs to the ATC system, should take precedence over the VOR sites. The DABS bit in the discretely addressed interrogation and in the general call interrogation means that these signals are transmitted by a DABS facility rather than a VOR facility. A transponder being interrogated discretely by a VOR facility would still respond to a DABS general call and be acquired automatically by the DABS. After being interrogated discretely by the DABS, it would no longer answer the VOR, and the VOR would drop the track after a few tries. Similarly, an aircraft flying from airspace covered by a DABS into airspace covered only by a VOR would cease to receive the DABS interrogations and would answer the VOR general call automatically and be picked up and tracked in range by the VOR.

The synchronized bit in the interrogation also requires some explanation. The 4 s rotation period of the ASR antenna and the 10 s period of the ARSR indicate that any tracking and prediction system will have at least 4 s between data samples.

This will not allow the prediction of range with an accuracy such that the timing of the aircraft response will be within some nominal error, such as 100 ns. In addition, the azimuthal estimation on the ground is to be done by monopulse techniques. The interrogator antenna beam shape changes with elevation angle so that it appears prudent to get a target response on each side of the monopulse difference null and perform interpolation to estimate the azimuth. The SYNCHRO-DABS will send two interrogations per scan. The first interrogation will not have the synchronized bit set and will be used to obtain true present range to the aircraft. The second interrogation occurs a few PRP's later and on the other side of the antenna null and will be a properly timed interrogation with the synchronized bit set at one. The aircraft that carried clocks would use this interrogation to reset their clocks. Each aircraft retransmits the interrogation as received, including the synchronized bit. Aircraft that were equipped to receive at 1090 MHz would only process those signals from other aircraft which had the synchronized bit set.

OTHER FUNCTIONS

The availability of precise time makes it possible to offer other services to the aircraft operator at a very modest increase in cost and complexity of the airborne equipment. The signal shown in Figure 9 would be broadcast ten times per second at zero time 1030 MHz from the omnidirectional antennas located at the VOR sites. The identity is the identity of that particular navigational fix; the message type indicates it as a VOR navigational signal; the message contains the latitude and longitude of the VOR to a precision of 100 ft; and the altitude is the altitude of the VOR. The identity code of the VOR would be published in the various aeronautical navigation documents and also keyed to the VOR VHF frequency in a manner similar to the present practice with distance-measuring equipment (DME). The pilot of an aircraft that had this feature installed would simply select, with thumb-wheel switches, the identity of the fix of which he wished to know the distance and the transponder would decode that signal and display the range based upon time of arrival of this signal after zero time. The identity could also be selected automatically by simply tuning the VOR receiver, exactly as in present practice.

A more sophisticated aircraft could receive and process signals from several VOR facilities and compute its position by triangulation. The pilot of this more sophisticated aircraft does not have to manually enter the location of the fix because this information is contained in the received signal. The computer in the aircraft would select those three locations that gave the best geometry and compute position and course including altitude correction. Thus a precise area navigation function would be provided wherever reception of signals from two or three VOR facilities was available.

PILOT'S DISPLAY

The information sent from the ground or derived in the transponder from receipt of other signals must be displayed to the pilot in a clear and unambiguous manner such that it does not add to his workload. The displays shown here represent only one possible implementation. Presumably, any other suitable display that a manufacturer offered for sale and an owner wanted to buy would be satisfactory. (The SYNCHRO-DABS transponder would be available in several levels of performance and cost.) Figure 10 shows the proposed display for the minimum-level transponder. This transponder would respond to ATCRBS interrogations if not being discretely addressed and would decode collision-avoidance messages from the ground-based system. The array of lights on the periphery indicates the relative bearing and relative altitude of nearby aircraft as perceived and relayed-up by the ground-based system. There are 12 azimuthal positions corresponding to the presently used "o-clock" system. Each azimuthal position has three relative altitude lights. The middle light indicates traffic within 500 ft. of own altitude, the upper light indicates traffic 500-2000 ft. above, and the lower light indicates traffic 500-2000 ft. below. These lights would be energized when nonthreatening traffic was within, say 1.5 mi of a low-speed aircraft. If the range rate of the traffic was such that it could cause a collision within 30 s, the appropriate light would be flashed. Just as the outer lights indicate the position of traffic, the inner lights indicate recommended action. The pilot can be told to either DO or DON'T DO certain maneuevers. The DON'T DO crosses are in red and the DO arrows are in green. In the general case when a maneuver command is given to a VFR aircraft, two choices will be given whenever possible. This is done so as not to vector the pilot into a cloud in order to avoid a collision. In the example shown, the pilot is told to turn right (standard rate turn) but that a dive maneuver is acceptable if a right turn is not desirable. The command indicator lights will be flashed if the command is from the ground and is mandatory. They will be simply turned on if the command is advisory or an acceptable alternative to a mandatory command. Each maneuver (climb, dive, left, right) can have either a green arrow or a red cross displayed.

Figure 11 shows a display that combines the collision-avoidance messages and ATC vectoring and frequency information on a single 3-1/8-in instrument. Any ATC messages would be displayed by flashing the numerals until the pilot pushed the WILCO button to acknowledge that he had received and would follow the instructions. Other possible displays would include alphanumeric readouts that could also display short clearances. It is expected that the ATC system of the future will be highly automated and that those aircraft with the ATC data link display could file for better routing and get better service. In a few of the major terminals, viz., New York, it will probably be necessary for an aircraft to have such a display for using the major airport facilities.

The aircraft owner who purchases a DABS transponder with a synchronized clock would also be provided with the DME service or, as an alternative, area navigation. The owner who purchased the updated clock and the 1090 MHz receiver plus direction-finding antenna would also have displayed the location of all nearby transponder-equipped traffic and those aircraft that constitute a possible threat. This information would be displayed on the same instrument as the information from the ground-based system. However, the service would be available in airspace not covered by the surveillance system and would also be available if the ground-based collision-avoidance function failed. (There would be a hiatus lasting for a few seconds after the ground-based system failed and while the VOR's pick up the interrogation load.)

MODULATION AND CODING

Amplitude modulation with nonreturn-to-zero format is shown for SYNCHRO-DABS because of the constraints of compatibility with the present ATCRBS system and low cost. It is clear that any of the constant-envelope phase-modulation schemes (PSK, DPSK, FSK, Quadriphase, etc.) would give 6-8 db better performance in the presence of receiver noise or random interfering signals. However, the signal-to-thermal-noise ratio will generally be in excess of 20 db, the discipline of interrogations should reduce the incidence of interfering signals to a minimal level, and the reinterrogation procedure will resolve remaining problems. Further, interference, if it occurs, can be over a 40 db dynamic range with respect to the desired signal so that it is not at all clear that the added cost of the 6-8 db improvement of a constant envelope system would be justified. It can also be shown, with reasonable assumptions, that the signal-to-noise ratio of the signals used for monopulse azimuth estimation would be approximately 20 db higher for a constant envelope system than for an amplitude-modulated system (more energy, coherent detection). However, it appears that the azimuthal estimation errors due to thermal noise in a system using amplitude modulation will be smaller than errors caused by antenna imperfections and possible multipath effects. The same general arguments apply to the decision to not include error-detecting or error-correcting codes. These codes increase cost and reduce capacity. In the case of error detection, the transponder would simply not reply and would be reinterrogated. In the absence of an error-detecting system, the interrogator would receive a reply different from the interrogation that was transmitted and would reinterrogate. The effect is the same in either case. Simply coding on urgent messages, such as collision-avoidance maneuver messages, is being considered. This coding would consist of repeating the message twice during the 42 b message block and designing the transponder logic circuitry so that it required both message segments to match before energizing the display.

PROGRAM STATUS

The FAA is sponsoring the construction of the experimental SYNCHRO-DABS system described above. The Naval Weapons Center, China Lake, California, will provide three sets of airborne equipment and the DOT Transportation Systems Center at Cambridge, Massachusetts, is fabricating an omni-directional interrogator which will also transmit navigational signals as described above. Testing of this system will be conducted at our National Aviation Facility Experimental Center near Atlantic City and will begin in the spring of 1974. The testing will explore the accuracy and convenience of the air-to-air mode and the accuracy of the DME function.

A few points about the evolving design may be of interest. It is desired to keep cost as low as possible. Thus the use of a cesium, rubidium or methane clock in the aircraft is out of the question. The clock will use a quartz crystal controlled oscillator which must be within 10 ppm of the nominal frequency. Such an oscillator does not need to be in an oven and can use a $1.50 crystal. Simple digital counter circuitry then adds or substracts pulses such that the clock error is never more than 50 nano-seconds, assuming that a synchronizing signal is received at least every 15 seconds from the ground-based system. The displays being procured use light emitting diodes for the traffic warning lights and incadescent bulbs for the "DO" and "DON'T" commands and for the digital indicators. These displays are expensive and consume a lot of power. The newly emerging liquid crystal technology appears to offer an attractive, reliable and low-cost alternative for such displays and experimental units are being procured for test.

SUMMARY

The SYNCHRO-DABS provides a method of introducing the DABS function into the ATC system so that it is completely compatible with the ATCRBS. It also provides additional navigation and collision-avoidance services to those operators who desire it. A key point is that the location of all aircraft with the basic minimum DABS transponder can be displayed to the pilot of any aircraft that has the optional air-derived collision-avoidance equipment.

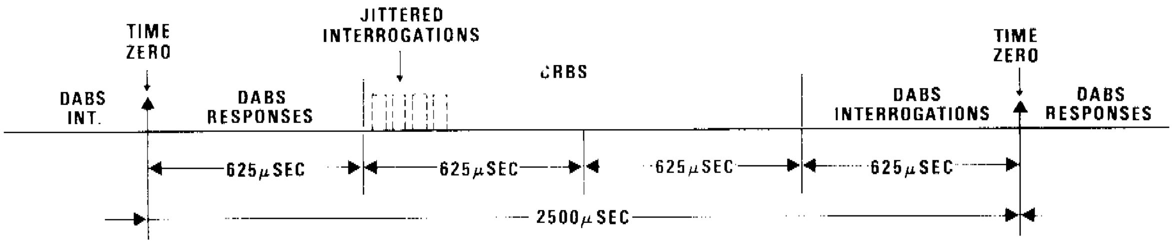

Figure 1. Division of Time Between Functions at Ground Station

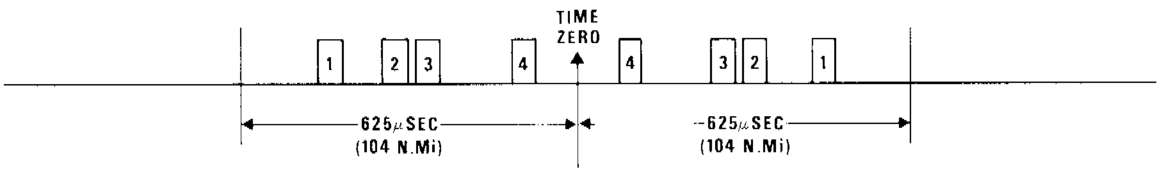

Figure 2. SYNCHRO-DABS Interrogation Timing

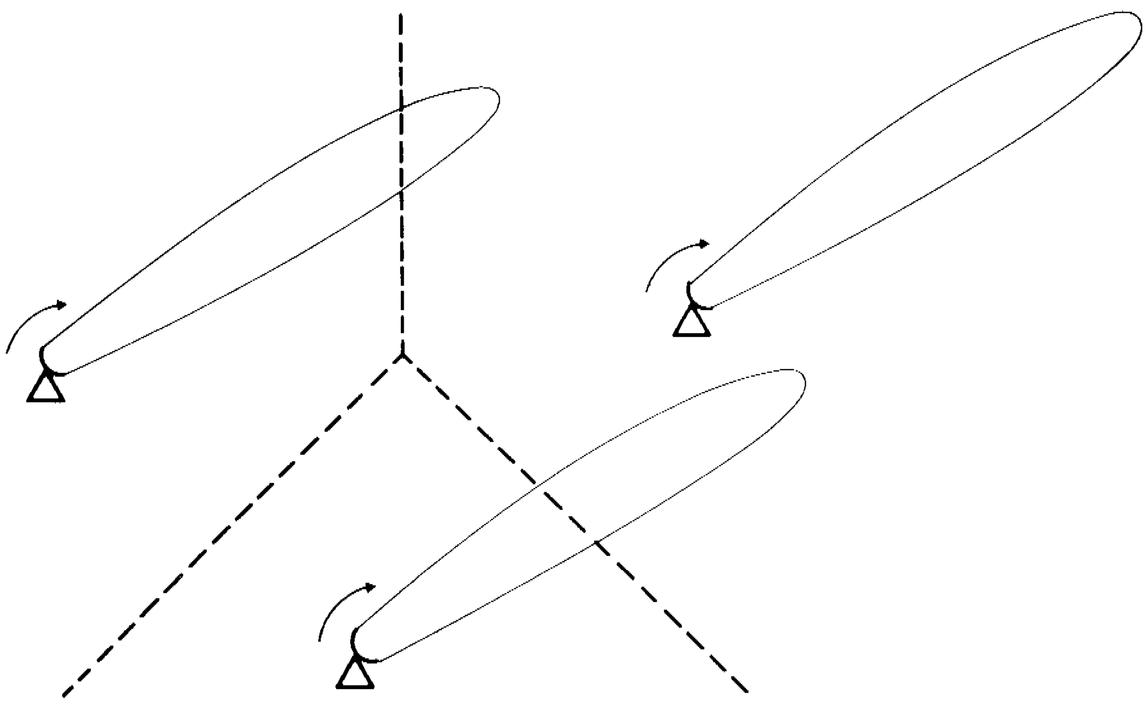

Figure 3. Distribution of DABS Sites

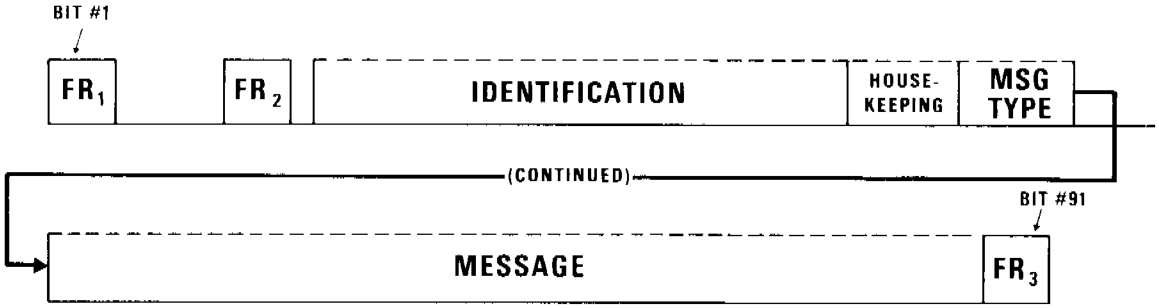

Figure 4. SYNCHRO-DABS Interrogation

Note: 91 Contiguous Bits, Each 0.25 μsec Long (23.75 μsec Total Length), 1030 MHz, Non-Return to Zero Amplitude Modulation, Housekeeping Bits Are: (1) Synchronized (2) DABS (3) Lock-In (4) PCA (5) IPC

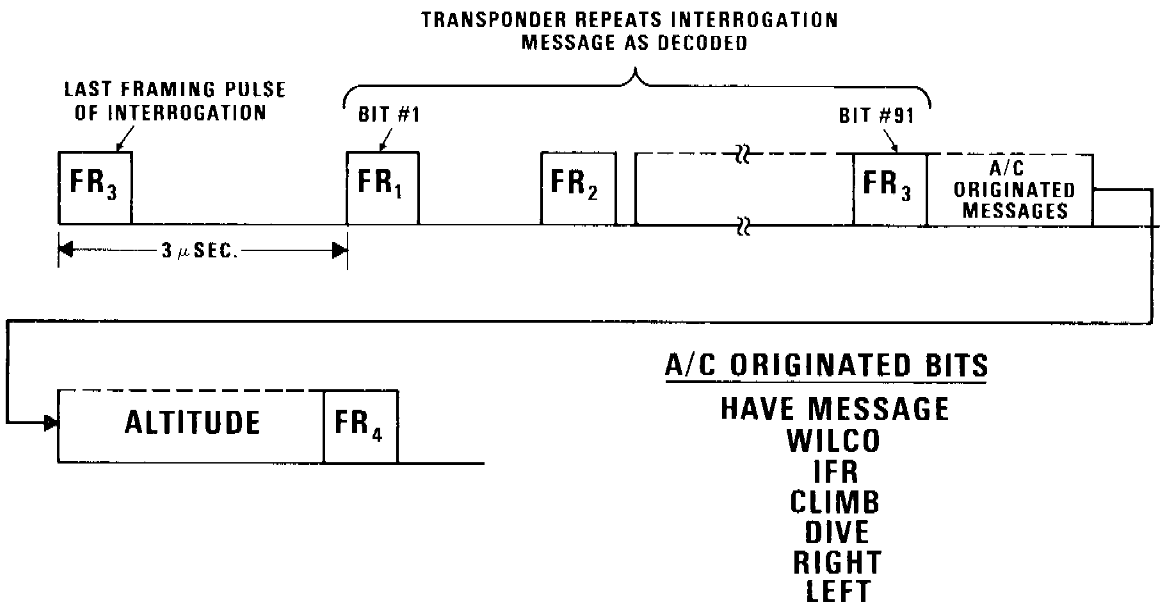

Figure 5. Aircraft Response to DABS Interrogation

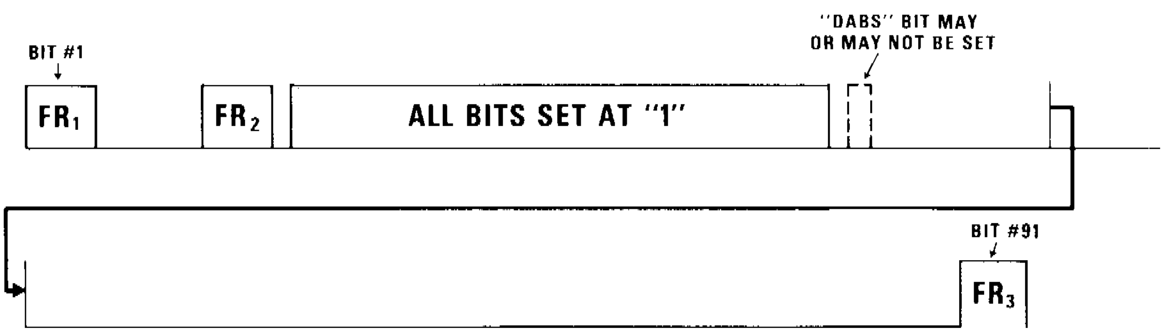

Figure 6. General Call Message Format

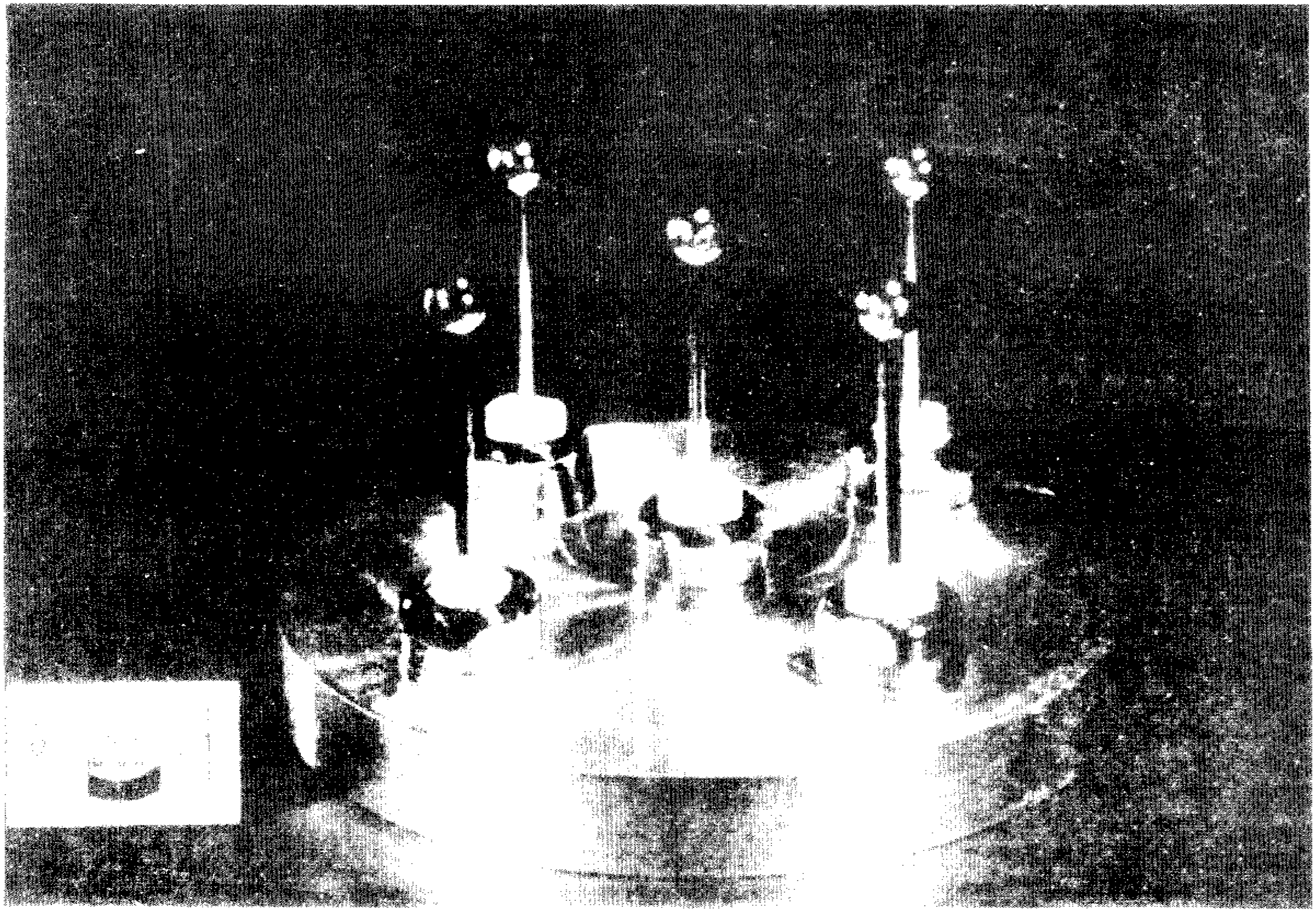

Figure 7. Phase-Sensitive Direction Finding Antenna

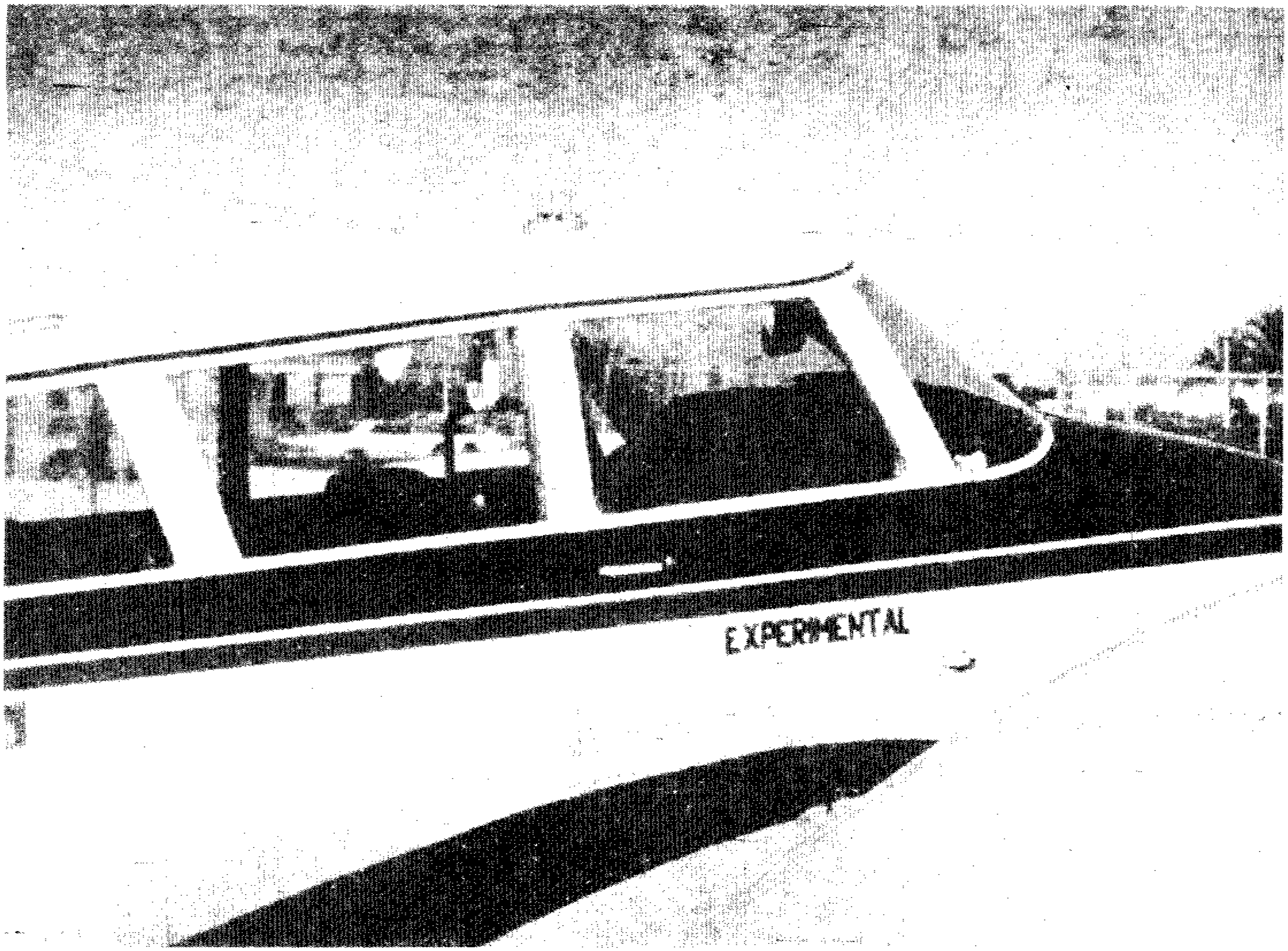

Figure 8. Direction-Finding Antenna Mounted on Light Aircraft

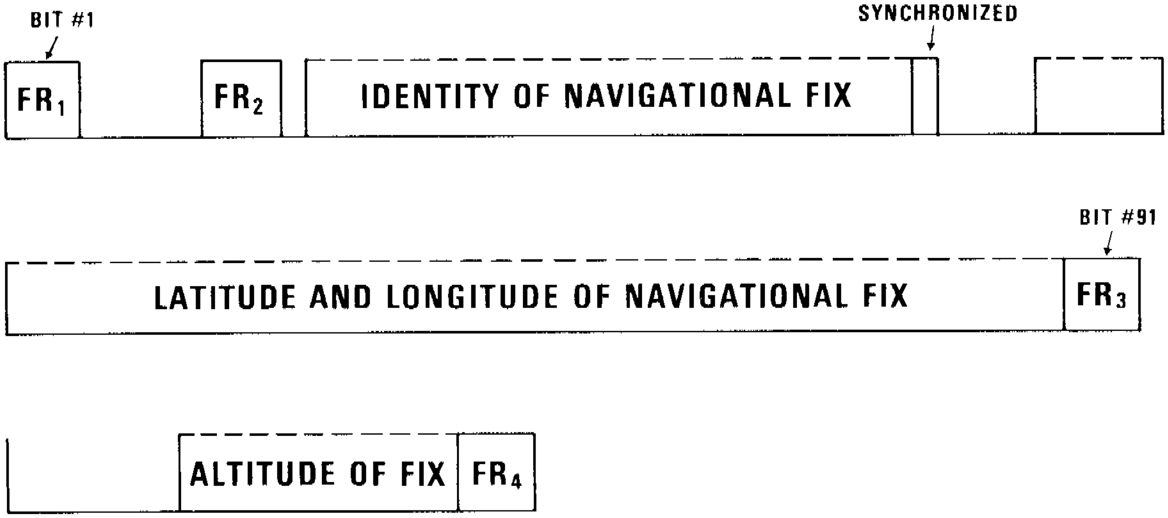

Figure 9. Navigation Signal Broadcast by Ground Stations

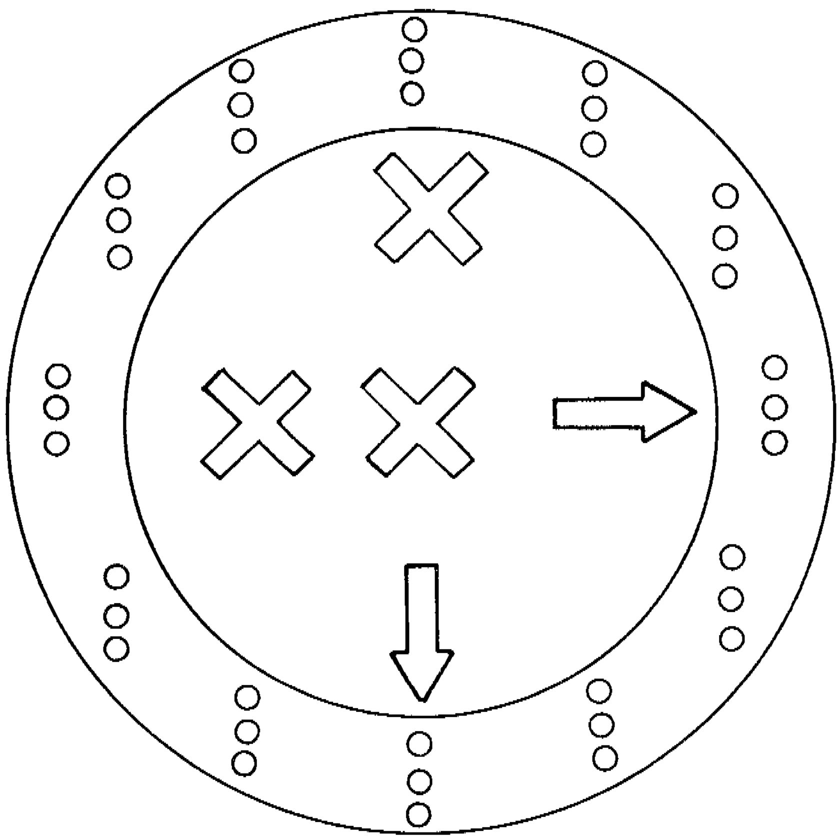

Figure 10. IPC and PWI Indicator

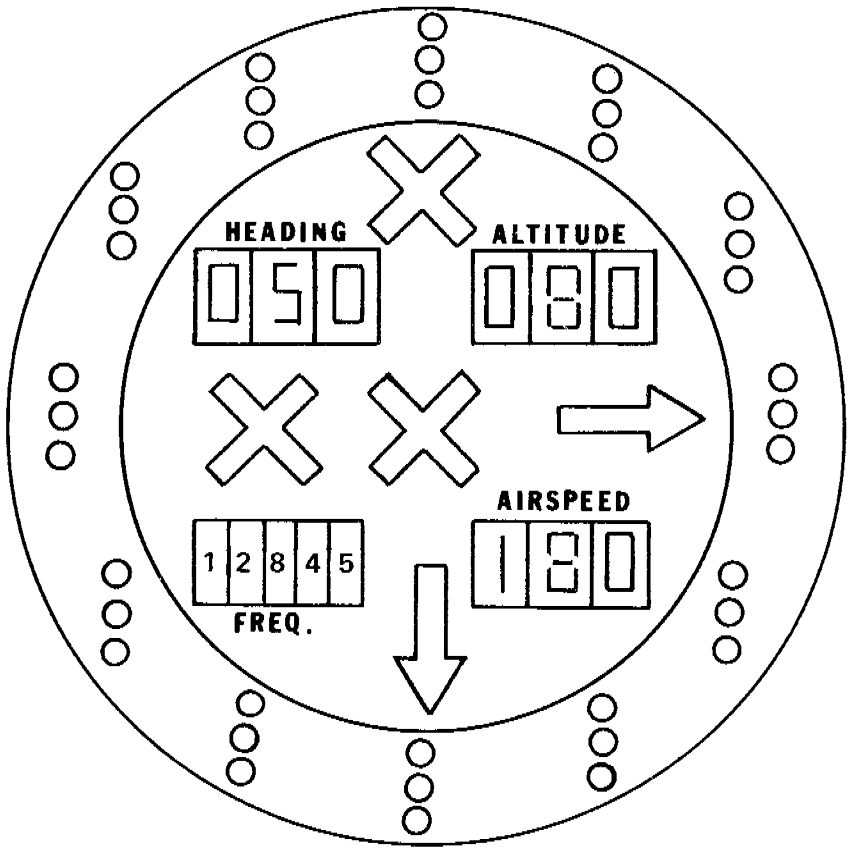

Figure 11. Display of IPC, PWI, and ATC Messages

QUESTION AND ANSWER PERIOD

DR. REDER:

Does anybody have any questions of Mr. Amlie's paper?

MR. MOHR (McDonnell-Douglas):

I didn't really understand how you got the airplane synchronized with the ground station. Maybe you didn't go into it or maybe I missed it.

MR. AMLIE:

The ground station knows the range of the aircraft, and transmits — backs off the time of interrogation so that the interrogation is received at the aircraft at zero time. The ground does the timing.

MR. MOHR:

Thank you.

DR. REDER:

Any other questions? Yes, please, Dr. Henderson.

DR. HENDERSON:

My question is very simple.

Have you any references to present publications which describe your system?

MR. AMLIE:

As a matter of fact, I have a briefcase full of IEEE articles I wrote.

DR. HENDERSON:

I will see you later.

DR. REDER:

Any other questions?

(No response.)