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DABS: A System Description

P. Drouilhet

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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16. Abstract

The Discrete Address Beacon System (DABS) is a cooperative surveillance and communication system for air traffic control. It employs ground-based sensors (interrogators) and airborne transponders. Ground-to-air and air-to-ground data-link communications are accommodated integrally with the surveillance interrogations and replies. DABS has been designed as an evolutionary replacement for the current Air Traffic Control Radar Beacon System (ATCRBS) to provide the enhanced surveillance and communication capability required for air traffic control in the 1980s and 1990s. Compatibility with ATCRBS has been emphasized to permit an extended, economical transition.

A principal feature of DABS is that each aircraft is assigned a unique address code. Using this unique code, interrogations can be directed to a particular aircraft, and replies unambiguously identified. Channel interference is minimized because a sensor can limit its interrogation to targets of interest. In addition, by proper timing of interrogations, replies from closely-spaced aircraft can be received without mutual interference. The unique address in each interrogation and reply also permits the inclusion of data-link messages to or from a particular aircraft. DABS uses the same frequencies for interrogations and replies as ATCRBS (1030 and 1090 MHz, respectively). The DABS interrogation is transmitted using DPSK at a 4 Mbps rate, and comprises 56 or 112 bits including the 24-bit discrete address. The reply also comprises 56 or 112 bits including address, and is transmitted at 1 Mbps using binary pulse-position modulation. Coding is used on both interrogations and replies to protect against errors.

The DABS sensor provides surveillance of DABS- and ATCRBS-equipped aircraft, and data-link service to DABS aircraft. In addition, it performs radar/beacon correlation of radar target reports from a collocated radar. The DABS sensor transmits surveillance data to, and exchanges messages with, air traffic control facilities (TRACONs and ARTCCs) via low-rate digital circuits. The DABS sensor communicates directly with adjacent DABS sensors to hand off targets and to provide surveillance and communication backup in the event of momentary link failures. Each DABS sensor includes an intermittent positive control (IPC) function which provides automatic PWI and conflict resolution service to DABS-equipped aircraft via the ground-air data link.

The DABS transponder replies to both ATCRBS and DABS interrogations, and interfaces with a variety of data-link message display and input devices. The rms surveillance accuracy provided by DABS is the order of 100 ft and 0.1° in range and azimuth, respectively. Surveillance and data-link communication capacities exceed by a substantial margin projected ATC requirements through the remainder of this century.

17. Key Words

Air Traffic Control
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CHAPTER 1

OVERVIEW/SUMMARY

BACKGROUND

Surveillance and communication are essential for safe and efficient air traffic control. In today's air traffic control system, surveillance is provided primarily by the Air Traffic Control Radar Beacon System (ATCRBS) and communication by VHF voice radio between pilot and controller.

However, increasing automation of the air traffic control process to accommodate the projected growth of air traffic during the coming decades will place greatly increased demands on both the integrity and capacity of surveillance and communication. Following an examination of various techniques for meeting these demands, the Air Traffic Control Advisory Committee[1] recommended the development and implementation of an improved beacon interrogator/transponder system, with an integral ground-air-ground data-link, as an evolutionary replacement for ATCRBS. This combined beacon and data link is called the Discrete Address Beacon System, or DABS.

The two central objectives guiding the design of DABS are:

(a) provide surveillance and data-link communication adequate to support automated ATC, including intermittent positive control (IPC), in the projected 1995 traffic environment;

(b) permit evolutionary implementation at low user cost.

The requirement for supporting IPC substantially increases the requirements for ATC surveillance and communication service. Today, ATC is primarily concerned with controlled, or IFR, aircraft. IPC provides automatic ground-based conflict detection and resolution to VFR aircraft, and backup service to IFR aircraft. To support IPC, all aircraft in the airspace served, VFR as well as IFR, must be provided reliable surveillance and communication.

A central consideration in the design of a new element of ATC, such as DABS, must be the ability to implement it on a time scale and at a cost acceptable to the aviation community. By the time deployment of DABS could begin, approximately 1980, there will be on the order of 200,000 aircraft equipped with ATCRBS transponders, and approximately 500 ground interrogators. DABS must be designed to operate in this environment, and in a way which permits a gradual, economic transition to an all-DABS operation over a 10-to-15 year period.

This has been achieved by providing a high degree of compatibility between DABS and ATCRBS. DABS uses the same interrogation and reply frequencies as ATCRBS, and the signal formats have been chosen to permit substantial commonality in hardware. This degree of compatiblity permits economic realization of two essential elements of a smooth transition:

(a) DABS interrogators provide surveillance of ATCRBS-equipped aircraft;

(b) DABS transponders reply to ATCRBS interrogators.

Thus DABS equipment, both on the ground and in aircraft, can be introduced gradually and continue to interoperate with existing systems during an extended transition phase.

THE DABS CONCEPT

The fundamental difference between DABS and ATCRBS is the manner of addressing aircraft, or selecting which aircraft will respond to an interrogation. In ATCRBS, the selection is spatial; aircraft within the mainbeam of the interrogator respond. As the beam sweeps around, all angles are interrogated, and all aircraft within line-of-sight respond. In DABS, as implied by its name, each aircraft is assigned a unique address code. Selection of which aircraft is to respond to an interrogation is accomplished by including the aircraft's address code in the interrogation. Each such interrogation is thus directed at a particular aircraft. Narrow-beam antennas will continue to be used, but primarily for minimizing interference between sites and as an aid in the determination of aircraft azimuth.

Two major advantages accrue from the use of discrete address for surveillance. First, an interrogator is now able to limit its interrogation to only those targets for which it has surveillance responsibility, rather than continuously interrogate all targets within line-of-sight. This prevents surveillance system saturation caused by all transponders responding to all interrogators within line-of-sight. Secondly, appropriate timing of interrogations ensures that the responses from aircraft do not overlap, eliminating the mutual interference which results from the overlapping of replies from closely-spaced aircraft (termed synchronous garble).

In addition to the improved surveillance capability, the use of the discrete address in interrogations and replies permits the inclusion of messages to or from a particular aircraft, thereby providing the basis for a ground-air and air-ground digital data link.

DABS ELEMENTS

As illustrated in Fig. 1-1, DABS comprises the sensors, transponders, and the signals-in-space which form the link between them. DABS provides surveillance and air-ground communication service to air traffic control facilities including en route (ARTCC), terminal (TRACON and TRACAB), and the unmanned, sensor-based intermittent positive control (IPC) function.

DABS' primary function is to provide these surveillance and communication services in support of air traffic control. However, by proper timing of the interrogations to all DABS-equipped aircraft, suitably equipped aircraft may utilize the DABS replies from other nearby aircraft to perform onboard proximity warning indication (PWI) and conflict detection. This air-to-air mode, termed Synchro-DABS, could operate as an air-to-air backup to the ground-based ATC and IPC functions. For a detailed discussion of Synchro-DABS operation, see Amlie[2].

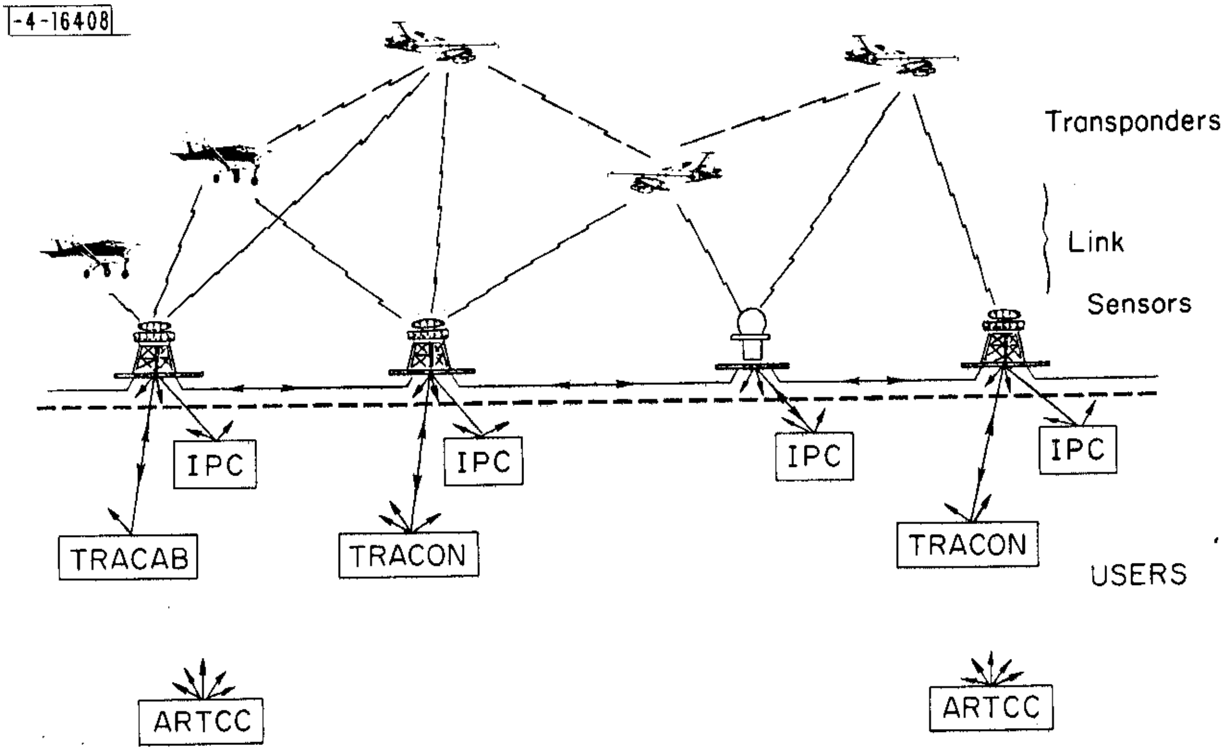

Fig. 1-1. DABS Elements.

The DABS Link includes the signals used for ATCRBS, and adds to these the signal waveforms and message formats for the acquisition of DABS-equipped targets and for discretely-addressed surveillance and data-link interrogations and replies. The principal characteristics of the DABS signals are as follows:

Interrogation	
Frequency	1030 MHz
Modulation	Differential Phase-Shift Keying (DPSK)
Data rate	4 Mbps

Reply	
Frequency	1090 MHz
Modulation	Pulse Position (PPM)
Data rate	1 Mbps

Interrogation and Reply

56-bit or 112-bit data block

24-bit parity check code (included in data block).

A more complete summary of the DABS signal formats is presented in Chapter 2.

The DABS Sensor provides surveillance of ATCRBS- and DABS-equipped aircraft, and operates as a store-and-forward communication relay for data-link communication between aircraft and ATC facilities. In addition, the sensor accepts digitized radar target reports from a collocated radar and combines these with the beacon reports into a composite surveillance output stream. When beacon and radar reports occur on the same target, the radar report is suppressed and the beacon report tagged as "radar-reinforced".

To discretely interrogate DABS-equipped aircraft, the sensor maintains a file of the identity and approximate position of all such aircraft within its area of coverage.

Each sensor's operation is controlled by a prestored map defining its coverage volume, both in normal operation and in the event of various system failures, e.g., the failure of an adjacent sensor.

Each sensor communicates directly with adjacent sensors to hand off targets as they pass from the region of one sensor's coverage to that of an adjacent sensor. In addition, in regions of overlapping coverage, this inter-sensor communication is used to assist in the reacquisition of a lost target*.

In general, each sensor will provide surveillance and communication services to several ATC facilities, i.e., all those whose area of control responsibility overlap the coverage area of the sensor. The interface between the sensor and each control facility comprises a one-way circuit for the transmission of surveillance data, both radar and beacon, and a two-way circuit for

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*Sensor-to-sensor communication improves the efficiency and reliability of DABS. However, it is not essential for system operation, and might not be employed in the initial stages of implementation.

the interchange of data-link messages. The latter circuit is also used to transmit reports of IPC activity to the ATC facility, and various status and control messages between the sensor and the ATC facility.

The DABS Transponder includes all of the functions of an ATCRBS transponder, and adds to these the ability to decode DABS interrogations and to format and transmit the appropriate replies. For data link, the transponder functions primarily as a modem. On receipt of a ground-to-air transmission, it verifies the correctness of the received message using the error-detecting code. Once verified, the transponder transfers the message contents to one or more external display devices. For air-to-ground messages, the transponder accepts the message contents from an external input device, and formats and encodes the data for transmission as part of the reply to a subsequent interrogation.

DABS SURVEILLANCE

The principal features of DABS surveillance are as follows:

Unique address
Range-ordered roll-call interrogation
Monopulse direction-finding
Adaptive reinterrogation
All-call acquisition
Positive handoff
Lockout
Multisensor coverage

Each DABS-equipped aircraft has a permanently assigned, unique 24-bit address. For convenience and simplification in aircraft identification, this address will be directly related to the registration number of the aircraft. This 24-bit address will be included in all discretely-addressed interrogations to that aircraft and all DABS replies from that aircraft.

The DABS sensor range-orders interrogations to DABS-equipped aircraft in such a way that the replies do not overlap. The use of monopulse direction finding on the reply permits the sensor to provide surveillance of

DABS-equipped aircraft, generally with a single interrogation/reply cycle per rotation (scan) of the interrogator antenna. If a reply to the interrogation is not received, or is received but can not be successfully decoded, the interrogator has the capability of reinterrogating the aircraft during the time the aircraft is in the antenna beam.

In order to be discretely interrogated, an aircraft must be on the sensor's roll-call, i. e., the sensor must know its address and approximate position. To acquire targets not yet on any sensor's roll-call, each sensor transmits all-call interrogations. A DABS-equipped aircraft will respond to such an interrogation with its unique address, and be added to the sensor's roll-call. Aircraft already on one sensor's roll-call are handed off to an adjacent sensor via direct sensor-to-sensor transmission of the aircraft's address and position.

Once on a DABS sensor's roll-call, the DABS-equipped aircraft may be locked out from replying to ATCRBS interrogations and to DABS all-call interrogations. By eliminating unnecessary replies, lockout minimizes the interference on the air-to-ground channel. Lockout is under the positive control of the DABS sensor and, if desired, its use can be limited to situations where the resulting interference reduction is necessary. In particular, lockout can be inhibited if for any reason it is desired that DABS-equipped aircraft continue to reply to ATCRBS interrogations. (For example, so that a military ATCRBS interrogator continues to see all targets in a particular region of airspace.)

If for any reason an aircraft ceases to receive discretely-addressed interrogations for a period of approximately 16 seconds (corresponding to a few interrogator antenna scans), any existing lockout lapses so that the aircraft may be acquired by a DABS or ATCRBS sensor.

In regions of airspace visible to more than one DABS sensor, each DABS target will generally be simultaneously on the roll-call of at least two sensors to provide continuity of surveillance and data-link service in the event of a link or sensor failure.

ATCRBS MODE OF DABS

The DABS sensor will provide improved surveillance quality on ATCRBS targets over that achieved by presently-operating techniques. This is important because of the high density of ATCRBS-equipped targets which will be experienced during the early years of the ATCRBS-to-DABS transition.

The principal characteristics of the ATCRBS surveillance by a DABS sensor are:

Reduced interrogation rate
Monopulse direction-finding
Improved reply degarbling
False target identification

The use of monopulse direction-finding on ATCRBS replies permits operation at a reduced ATCRBS interrogation rate, nominally four interrogations in the 3 dB antenna beamwidth. Improved reply processing is used to minimize the effects of mainbeam and sidelobe interference. A major element of this is the use of pulse-by-pulse monopulse data to help decode overlapped replies.

A major current problem in ATCRBS is the appearance of false targets due to reflection from large objects such as buildings or hillsides. The DABS sensor is programmed to identify and flag such false targets using both target reply parameters (e.g., mode-A code) and prestored geometry of principal reflecting surfaces.

DABS DATA LINK

DABS provides both ground-to-air and air-to-ground data-link capability. Ground-to-air message types include IPC/PWI commands, ATC instructions, weather information, etc. Air-to-ground messages may be either pilot-initiated, e.g., a request for a clearance change or for weather information, or ground-initiated, e.g., to read out onboard instrumentation such as weather sensors or MLS-derived position.

The critical nature of many of the messages to be carried by DABS requires a high degree of message integrity; both sender and recipient of any message must know that the message has been received correctly before the transaction can be considered complete. The required message integrity is ensured by providing for:

Error detection,
Technical acknowledgment, and
Pilot acknowledgment

Error-detecting codes are used on both interrogations and replies to essentially eliminate the acceptance of a message containing an error. When the presence of an (uncorrectable*) error is detected, the whole transmission is rejected. Instantaneous technical acknowledgment of the correct receipt of a downlink message is provided by an acknowledgment bit set in a subsequent interrogation. If an error had been detected, no acknowledgment would be received and the message would be repeated. Separate provision is included in the message formats for requesting a pilot acknowledgment when desired, and for receiving this pilot acknowledgment in the response to a subsequent interrogation.

Three classes of messages are accommodated by DABS:

Surveillance data,
Standard message,
Extended-length message.

Surveillance Data

A 16-bit surveillance data field is part of each DABS interrogation and reply (with the exception of the special extended-length message and all-call reply formats). Normally, in a reply this field includes an altitude report identical to the ATCRBS mode-C report. However, either the ground or the pilot may initiate the inclusion of the ATCRBS mode-A code in place of the altitude report, e.g., to indicate an emergency condition. In an interrogation, this field normally contains an altitude echo (ALEC), which is the most recently reported value of the aircraft's altitude (adjusted by the sensor prior to

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*The sensor can correct certain types of error occurring in replies. Since the transponder has no error-correction capability, any error occurring in an interrogation is uncorrectable.

retransmission for local barometric pressure for aircraft flying below 18,000 feet). ALEC provides the pilot with a complete loop check on the accuracy of his altitude report. The continuous availability of such a check is highly desireable when automatic altitude reporting is used for separation assurance for VFR aircraft, as there is normally no other link between VFR aircraft and the ground control system to provide periodic validation of the accuracy of the altitude reporting.

Standard Message

Most DABS data-link transmissions will be handled as one or a succession of 56-bit standard messages included as part of a 112-bit interrogation or reply; e.g., a PWI or IPC transmission occupies a single such message. These transmissions include the surveillance data field in addition to the data-link message, and thus will generally be used in place of, rather than in addition to, a surveillance interrogation and/or reply.

In order to prevent interference between DABS replies from different aircraft, the control field of each interrogation specifies the allowed reply length. Thus the interrogator must know in advance when a long (112-bit) reply is to be transmitted. When an air-to-ground data-link message is to be sent, a bit is set in the control field of a reply which requests the interrogator to schedule a long reply in response to a subsequent interrogation. The long reply, containing the data-link message, is then transmitted when directed by the interrogator.

Extended-Length Message

While longer messages can be transmitted as a sequence of standard messages, each standard message must be acknowledged before the transmission of the next one. In order to provide for the more efficient transmission of longer messages, an extended-length message (ELM) capability is incorporated. Using this, a sequence of up to sixteen 80-bit message segments can be transmitted, either air-to-ground or ground-to-air, and acknowledged with a single reply or interrogation. This acknowledgment indicates which, if any, of the message segments were not received (or received in error), so that only those need by retransmitted.

Extended-length messages do not contain the surveillance data field and thus cannot substitute for a surveillance interrogation and/or reply. As in the case of the air-to-ground standard message, the transponder must request permission to transmit an air-to-ground ELM, and then does so under interrogator control. It is expected that ELM capability will be included only in relatively sophisticated airborne installations, e. g. , air carrier aircraft, and may share input/output devices with other onboard data-link systems.

SURVEILLANCE MANAGEMENT

DABS limits its surveillance to targets of interest, i. e. , to those within a defined coverage volume. This contrasts with ATCRBS in which all targets within line-of-site are interrogated. Control of the DABS sensor's surveillance and communications functions is based upon a prestored map which defines the action of the sensor for the regions of airspace within its visibility.

For an isolated sensor (one for which there are no other DABS sensors with contiguous or overlapping coverage), the surveillance management functions are quite simple. They consist of defining the regions of airspace in which

(a) the sensor provides surveillance and data-link service, and
(b) the sensor locks out DABS-equipped aircraft from responding to ATCRBS interrogations and all-call interrogations.

As an aircraft approaches the boundary of the coverage volume of the DABS sensor, the transponder will be unlocked to permit adjacent ATCRBS sensors to acquire and track the target. For this isolated sensor, all acquisition of DABS targets would be in response to all-call interrogations.

As DABS sensors become widely deployed, so that over large portions of the country coverage exists down to altitudes of two to three thousand feet, extensive multiplicity of coverage will exist at higher altitudes. DABS includes a network management function to control the operation of the DABS sensors in this environment. Adjacent sensors communicate directly with each other, both to hand off targets as they cross surveillance boundaries, and to assist one another in maintaining continuity of surveillance and data-link service.

As in the isolated sensor case, the basis for network management is a map prestored at each sensor which defines its responsibilities for targets in each region of airspace. Not only does this map defined the actions of the sensor itself, it also designates which adjacent sensors provide coverage of the same region of airspace and defines the location of coverage boundaries. Thus by reference to the map the sensor can determine which adjacent sensor can give it assistance in maintaining track on a given target, and when a sensor should initiate a hand off of the target to another sensor.

Multiple sensor coverage is exploited in DABS to assure a continuity of both surveillance and data-link service. Where such multiple coverage is available, a target is always maintained simultaneously on roll-call of at least two sensors, thereby providing instantaneous backup in the event of the failure of one sensor or the sensor/aircraft link. If for some reason a sensor loses contact with an aircraft, it calls on the adjacent tracking sensor for assistance in reacquiring the target.

In order to preclude possible ambiguities which can occur when two sensors simultaneously have an aircraft on their roll call, a single sensor is designated "primary" in each region of airspace. The special functions which are the responsibility of the primary sensor are:

(a) readout of air-to-ground data-link messages,
(b) synchronous interrogation, and
(c) altitude echo transmission.

If the primary sensor loses contact with an aircraft, the primary responsibilities are temporarily handed off to another sensor which already has that target on its roll call. When the normal primary sensor reacquires the target, it resumes its primary functions.

DABS/ATC INTERFACE

The DABS/ATC interface is particularly simple in the case of an isolated DABS sensor interacting with a single control facility, e.g., a sensor at an airport interconnected only with the local TRACON. In this situation the sensor provides surveillance data to the TRACON, and operates as a relay point for data-link messages between aircraft and ATC.

In general, however, each sensor will provide surveillance and communication service for more than one control facility, and in turn each control facility will receive data from more than one sensor. This greater connectivity permits control facilities to take advantage of multiple coverage to maintain surveillance and data-link service in the event of an equipment or link failure at a particular sensor. Surveillance boundaries between adjacent sensors are determined primarily by coverage geometry; these will not be the same as the control boundaries between adjacent ATC facilities, which are determined by air traffic flow patterns.

In general, a control facility will use at any one time the data from only one sensor to maintain its track on a particular aircraft. The data on the same aircraft from another sensor is available as instantaneous backup. Typically the data from the sensor designated as primary would be used, as presumably this sensor would have best coverage in a particular region of airspace. The control facility may use any sensor which has an aircraft in its track file for the transmission of ground-to-air data-link messages to that aircraft. In the case of a particularly urgent message, more than one sensor can be used simultaneously for ground-to-air message delivery to minimize the possibility of any delay in its reception.

SYSTEM PERFORMANCE SUMMARY

Surveillance	
Capacity	> 2000 aircraft per sensor
σ (Azimuth)	$\sim 0.1^{\circ}$
σ (Range)	~ 100 feet
Data Update Interval	~ 4 seconds
Data link	
Capacity	All identified ATC messages require a few percent of available capacity
Delivery Reliability	> 0.99 in 4 seconds
Undetected Error Rate	$< 10^{-7}$
System reliability	
Multiple Coverage	
Automatic Monitoring and Network Reconfiguration	

The available interrogation time is sufficient to permit a sensor to maintain discrete-address surveillance of more than 2000 targets. This is considerably in excess of the maximum expected target load. A typical sensor would be sized with the processing capability or track file storage to accommodate a much smaller number, e.g., 400 targets.

Similarly, all presently envisioned ATC data-link requirements occupy a small fraction of the available channel capacity. For example, a 56-bit message can be included as part of each interrogation, thereby permitting one or two such messages every four seconds to each aircraft with no additional burden on the system over that needed for surveillance alone.

The achieveable range measurement accuracy is dominated primarily by transponder turn-around time uncertainty.

The indicated values of azimuth accuracy and data update interval are those of a nominal DABS sensor. These are sensor design parameters and can be modified as necessary to meet special requirements.

CHAPTER 2

THE DABS LINK

SIGNAL FORMATS

There are four signal types used by DABS for surveillance of ATCRBS- and DABS-equipped aircraft and data-link communication with DABS-equipped aircraft. These are:

(a) The ATCRBS/DABS all-call interrogation, used for surveillance of ATCRBS-equipped aircraft and acquisition of DABS-equipped aircraft not already on a sensor's roll-call.

(b) The ATCRBS reply, used by ATCRBS transponders in replying to ATCRBS and ATCRBS/DABS all-call interrogations and by DABS transponders in replying to ATCRBS interrogations.

(c) The DABS interrogation, used for roll-call surveillance and data-link communication to DABS-equipped aircraft.

(d) The DABS reply, used by DABS transponders in response to DABS interrogations and ATCRBS/DABS all-call interrogations.

To maximize hardware compatibility between DABS and ATCRBS, DABS interrogations and replies use the same frequencies as are used for ATCRBS interrogations and replies, i.e., 1030 and 1090 MHz, respectively.

The characteristics of these signal types are summarized in the following paragraphs, together with the most common DABS data block formats. A more detailed description of the DABS interrogations and replies is presented in FAA-RD-74-62[3].

ATCRBS/DABS All-Call Interrogations

The ATCRBS/DABS all-call interrogations are similar to the corresponding ATCRBS interrogations as defined in the United States National Standard for ATCRBS[4] but with an additional pulse P4 following P3 (Fig. 2-1).

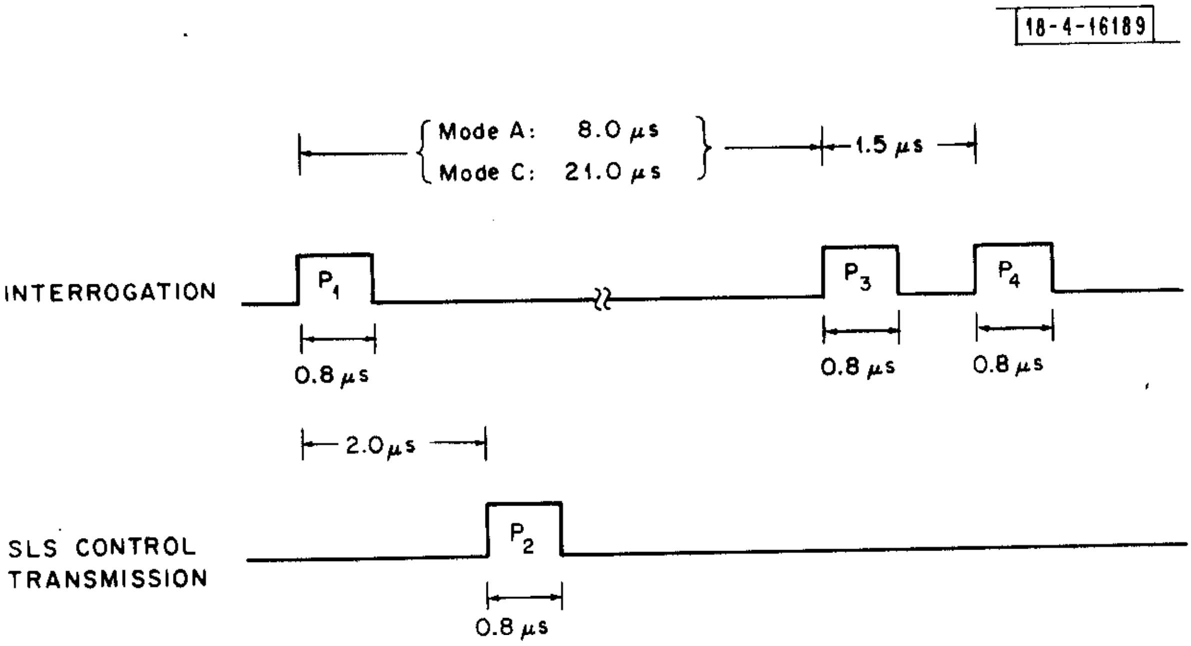


Fig. 2-1. ATCRBS/DABS All-Call Interrogation.

An ATCRBS transponder will be unaffected by the presence of the P4 pulse. It will respond with a normal ATCRBS reply. A DABS transponder will recognize the interrogation as a DABS all-call interrogation and will respond with a DABS all-call reply.

As in ATCRBS, transmit sidelobe suppression (SLS) is accomplished by the transmission of a control pulse P2 on an SLS control pattern (usually omni-directional in azimuth). If this pulse is received by the transponder at an amplitude exceeding that of the P1 pulse of the interrogation, the transponder does not reply.

ATCRBS Reply

The ATCRBS reply signal characteristics are as defined in the United States National Standard for ATCRBS. The signal format is depicted in Fig. 2-2.

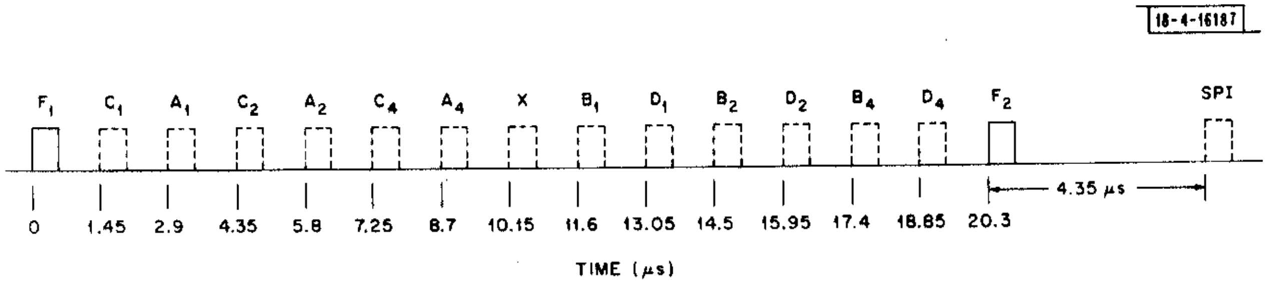


Fig. 2-2. ATCRBS Reply.

DABS Interrogation

The DABS interrogation consists of a preamble followed by a data block containing 56 or 112 data bits. The signal format is depicted in Fit. 2-3.

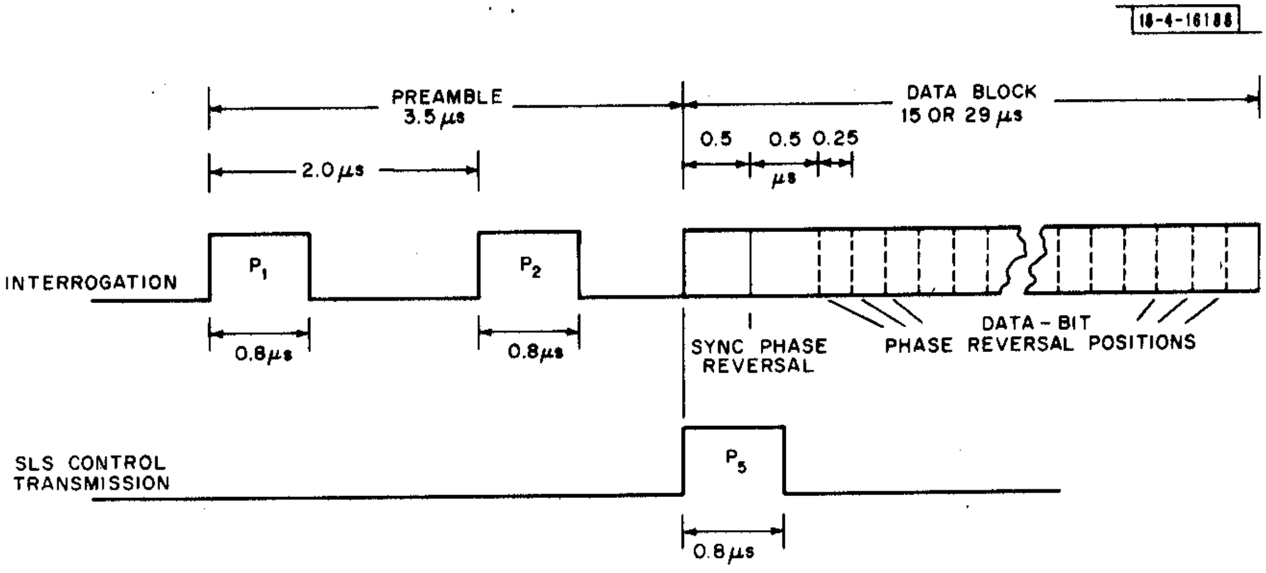


Fig. 2-3. DABS Interrogation.

The preamble consists of a pair of pulses, spaced 2.0 μs apart. An ATCRBS transponder which receives the interrogation will interpret this pulse pair as an ATCRBS sidelobe suppression, causing it to be suppressed for the remainder of the DABS interrogation. Without such suppression, the subsequent DABS data block would, with high probability, trigger the ATCRBS transponder, causing a spurious reply.

The data block consists of a single RF pulse of duration 15 or 29 μs. Data modulation at a 4 Mbps rate is accomplished by phase reversals of the RF carrier. Differential phase shift keying (DPSK) modulation is used, with a phase reversal of the RF signal at the beginning of a bit interval representing a binary one and no phase reversal representing a binary zero.

The 4 Mbps rate permits transmission of 112-bit message within the minimum available ATCRBS suppression interval. DPSK provides superior interference immunity, increased fade margin, and greater multipath immunity than pulse amplitude modulation (PAM). These advantages, which are realized at a small increment in transponder cost, will provide valuable performance margins in the uplink interference environment in which DABS will have to operate.

Transmit sidelobe suppression is accomplished by the transmission of a control pulse (P5) on an SLS control pattern. If the control pulse amplitude received by the transponder exceeds the amplitude of the interrogation, the sync phase reversal will be obscured and the interrogation will be rejected. With discrete address interrogations, transmit SLS is not required to prevent sidelobe replies, as in general an aircraft will be interrogated only when in the mainbeam of the interrogator antenna. However, transmit SLS on discretely-addressed interrogations minimizes the probability of an aircraft erroneously accepting an interrogation directed to another aircraft; most such interrogations will be received through an interrogator antenna sidelobe, and thus will be rejected by the transponder without decoding.

DABS Reply

A DABS reply consists of a preamble and a data block containing 56 or 112 data bits. The signal format is depicted in Fig. 2-4.

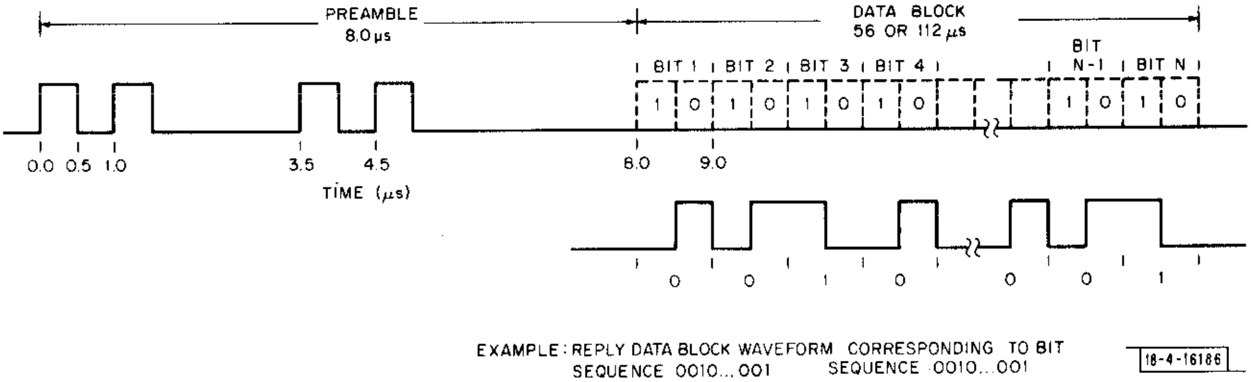


Fig. 2-4. DABS Reply

The preamble consists of a series of four 0.5 μs pulses. The data block begins 8.0 μs after the leading edge of the first preamble pulse. Binary data is transmitted at a 1 Mbps data rate using pulse position modulation (PPM) as follows: in the 1.0 μs interval corresponding to each data bit, a 0.5 μs pulse is transmitted in the first half of the interval if the data bit is a 1, and in the second half of the interval if the data bit is a 0.

Transponder cost considerations limited the choice of reply signal formats to ones which could be generated by the proven, low-cost, pulsed-cavity oscillator transmitters currently used in ATCRBS transponders. Within that constraint, the reply format has been designed to achieve reliable air-to-ground operation in the presence of heavy ATCRBS interference.

The four-pulse preamble is designed to be easily distinguished from ATCRBS replies. It can be reliably recognized and used as a source of reply timing in the presence of one overlapping ATCRBS reply, while at the same time resulting in a low rate of false alarms arising from multiple ATCRBS replies.

The choice of PPM for the data modulation permits reliable bit detection in the presence of ATCRBS interference. In addition, PPM results in a constant number of pulses in each reply, assuring sufficient energy for an accurate monopulse estimate.

Operation at 1 Mbps, in combination with the use of the 24-bit parity check coding described below, further enhances downlink reliability by permitting the correction of any error pattern which can result from a single ATCRBS reply interfering with the desired DABS reply.

DATA BLOCK FORMATS

The Normal Format

The normal format (Fig. 2-5) is used for DABS surveillance and standard message interrogations and replies. It includes a link control field, a surveillance data field, an (optional) standard message field, and an address/parity field.

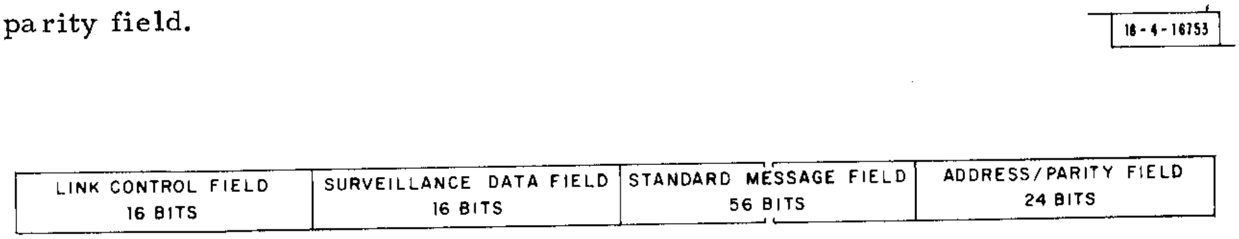


Fig. 2-5. Normal Data Block Format.

The 16-bit link control field is used to identify the type of transmission, to control transponder lockout, and to exercise control of data-link transmissions and acknowledgments. On synchronous (Synchro-DABS) interrogations and replies, it includes the requisite timing information.

The 16-bit surveillance data field usually contains the altitude code in a reply and the altitude echo (ALEC) in an interrogation. Other information such as the transponder mode-A code can be substituted on command.

The 56-bit standard message field contains the data-link message text and is included only when such a message is to be transmitted.

The 24-bit address/parity field contains the aircraft's 24-bit unique address code overlayed on (summed bit-by-bit modulo 2 with) 24 parity check bits generated on the preceding part of the transmission, as illustrated in Fig. 2-6.

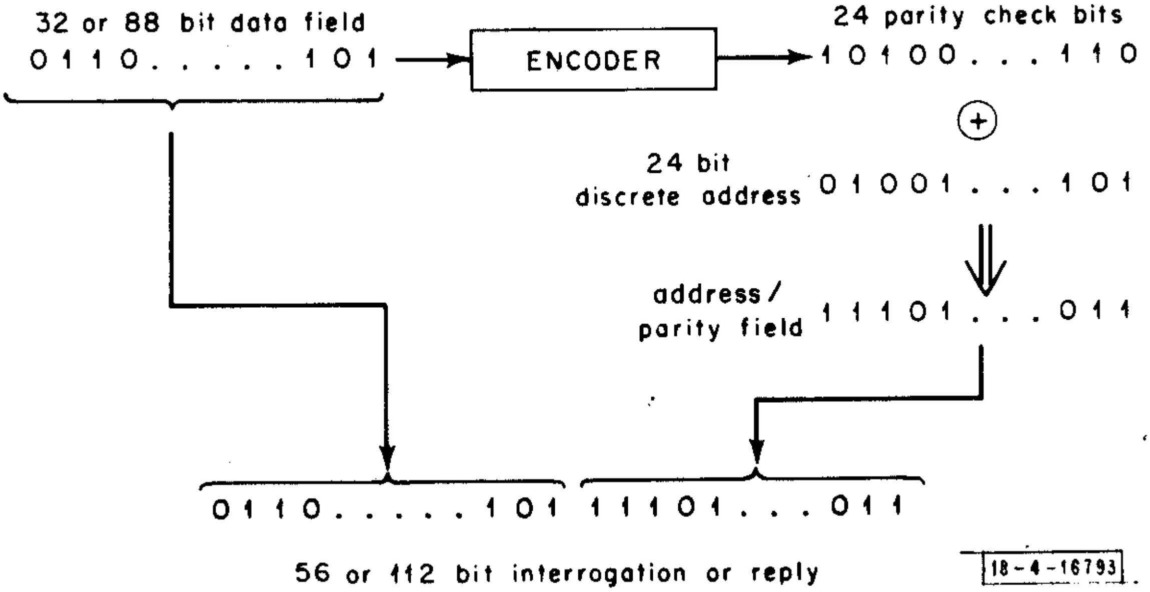


Fig. 2-6. Address/Parity Field Generation.

An error occurring anywhere in the reception of an interrogation or a reply will modify the decoded address. On the uplink, the transponder will not accept the message and will not reply, as the interrogation does not appear to be addressed to it. On the downlink, the interrogator will recognize that an error has occured, since the reply does not contain the expected address. Because the interrogator knows the address of the transponder replying to a discrete interrogation, the interrogator can perform a limited amount of error-correction. The code parameters have been selected to permit the correction of many error patterns which span no more than 24 bits. In particular, most bursts of errors caused by interference from a simultaneously-received ATCRBS reply can be corrected.

The All-Call Reply

The all-call reply (Fig. 2-7) is a 56-bit DABS reply used in response to an all-call interrogation. It provides the interrogator with the aircraft address and a 6-bit capability field indicating the level of data-link capability with which the aircraft is equipped, e. g., IPC/PWI display, ATC message display, extended-length message (ELM). In the all-call reply the address is transmitted separately from the parity field. This permits the use of error correction on the all-call replies also, even though the interrogator does not know in advance the address of the replying transponder.

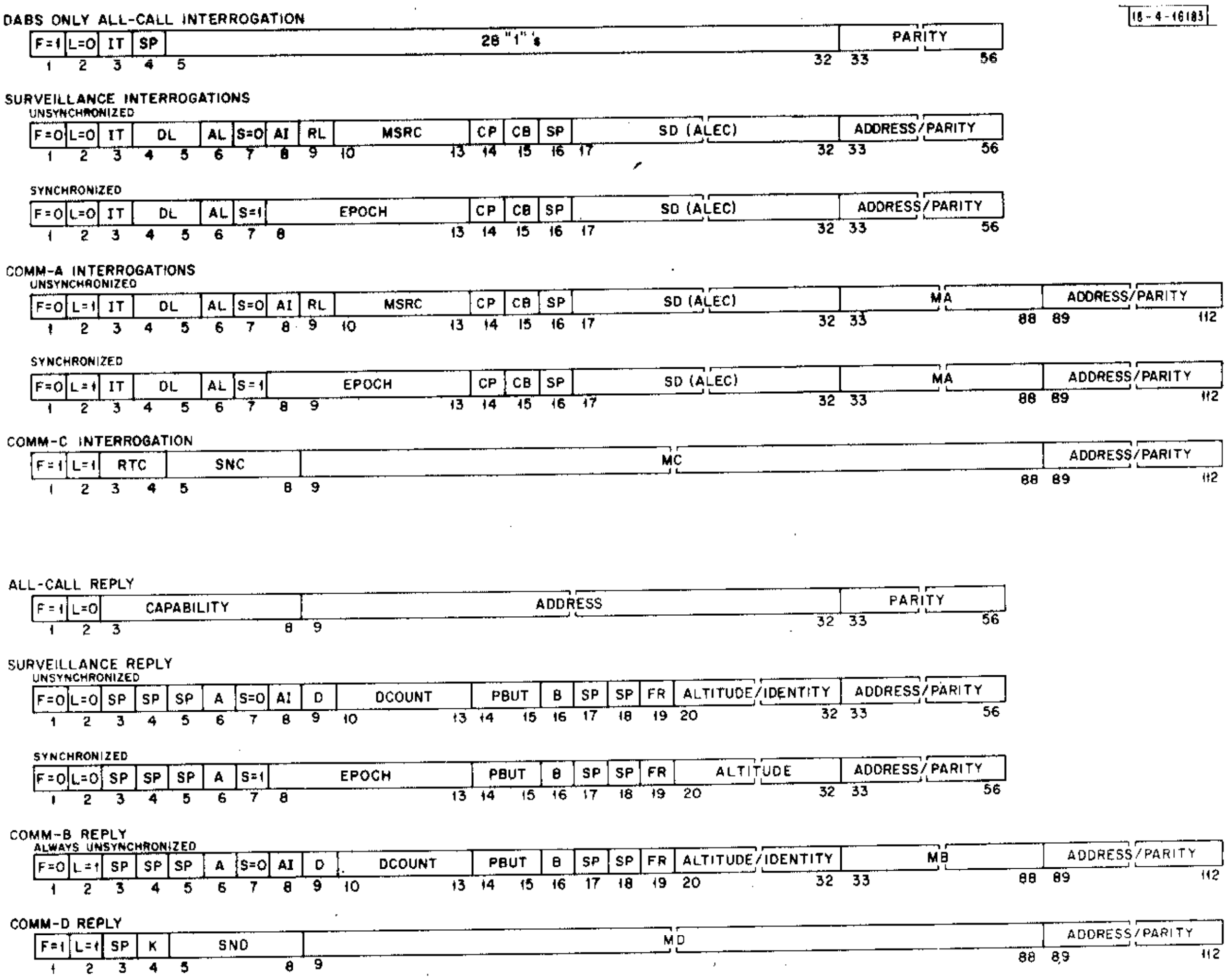
18-4-16754

10	CAPABILITY FIELD 6 BITS	ADDRESS FIELD 24 BITS	PARITY FIELD 24 BITS

Fig. 2-7. All-Call Data Block Format

Additional Formats

In addition to the data block formats discussed above, other formats have been defined for special functions, e. g., DABS-only all-call, and extended-length messages. For reference, the complete set of DABS data block formats, including detailed bit allocations, is illustrated in Fig. 2-8.



A:	Alert
AI:	Altitude/Identity Designator
AL:	ATCRBS Lockout
ALEC:	Altitude Echo
B:	Air-to-Ground Data Link Message Waiting
CB:	Clear Comm-B
CP:	Clear PBUT
D.	Air-to-Ground Extended-Length Message Waiting
DCOUNT:	Number of Segments in Air-to-Ground Extended-Length Message
DL:	DABS All-Call Lockout
EPOCH:	Synchronous Reply Time
F:	Format Type
FR:	Flight Rules
IT:	Interrogator Type
K:	Extended-Length Message Control Indicator
L:	Data-Block Length
MA:	Ground-to-Air Data Link Message
MC:	Ground-to-Air Extended-Length Message Segment
MD:	Air-to-Ground Extended-Length Message Segment
MB:	Air-to-Ground Data Link Message
MSRC:	Air-to-Ground Data Link Message Source
PBUT:	Pilot Acknowledgment Buttons
RL:	Reply Length
RTC:	Reply Type for Comm-C Interrogations
S:	Synchronization Indicator
SD:	Special Data
SP:	Spare
SNC:	Segment Number of Ground-to-Air ELM Segment
SND:	Segment Number of Air-to-Ground ELM Segment

Fig. 2-8. DABS Data Block Format

CHAPTER 3

THE DABS SENSOR

The DABS sensor performs surveillance of DABS- and ATCRBS-equipped aircraft within its assigned area of coverage, and acts as a communication relay for data-link messages between DABS-equipped aircraft and air traffic control facilities. In addition, the sensor accepts digital target reports from a collocated radar, and merges these into a common surveillance output stream, correlating the radar and beacon reports when both exist on the same target.

Each sensor includes an intermittent positive control (IPC) function which provides conflict detection and resolution service to DABS-equipped aircraft.

The sensor interfaces with the airborne transponders via the RF link, and with adjacent sensors and ATC facilities via low-rate digital communication circuits.

The functional architecture of the sensor is illustrated in Fig. 3-1. Most sensor functions are conveniently categorized according to the time scale on which they operate, as follows:

(a) Those which involve the generation and processing of signals, and therefore operate on a microsecond time scale; e.g.:

modulator/transmitter
multichannel receiver
DABS and ATCRBS reply processors

(b) Those which involve channel transactions, and operate at a millisecond time scale, commensurate with the dwell time of the interrogator antenna on a target; e.g.:

channel management
ATCRBS reply correlation

(c) Those which are paced by the antenna scan time, and therefore operate on a time scale the order of a second; e.g.:

surveillance processing
data-link processing
network management
performance monitoring
IPC

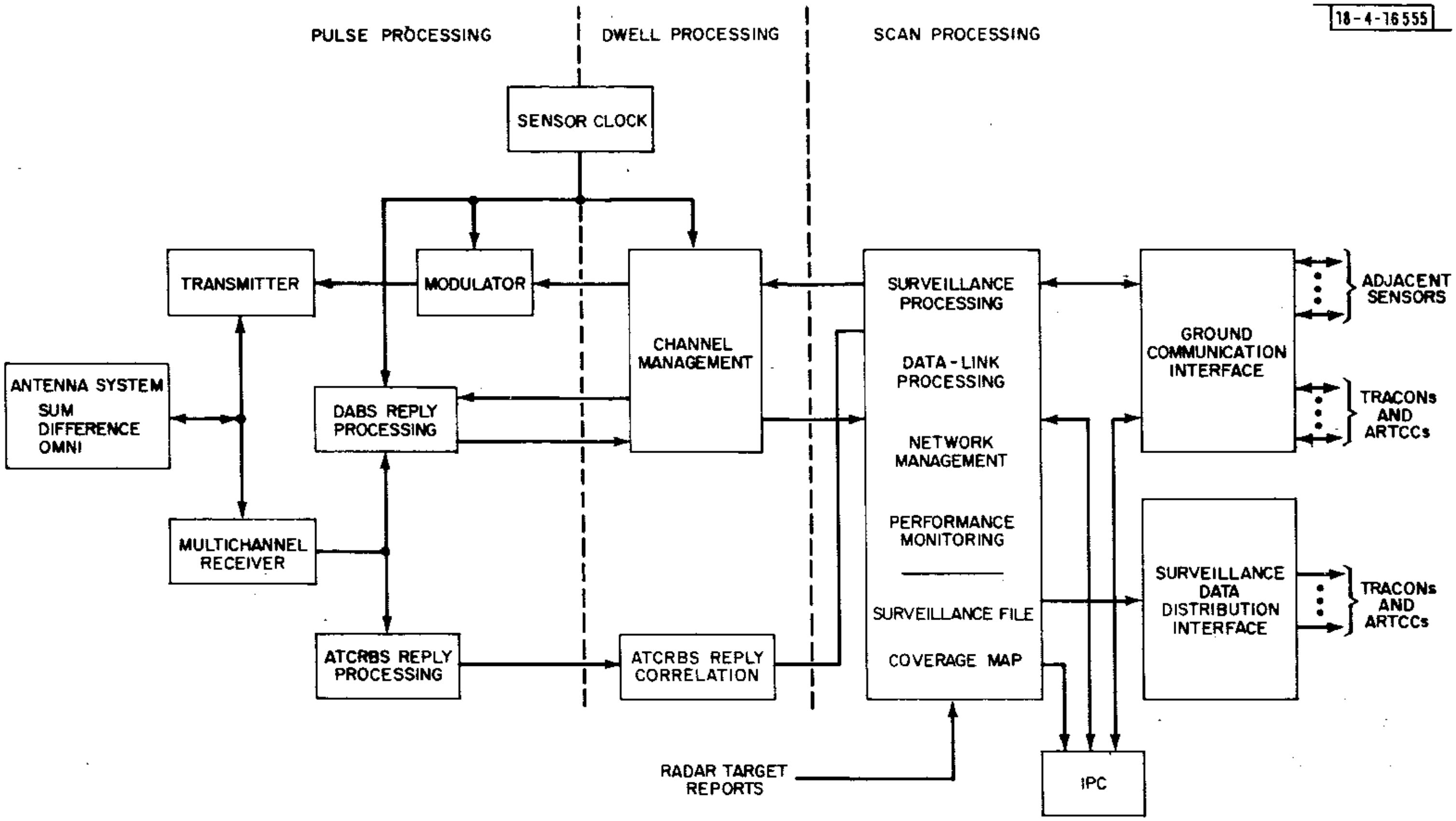


Fig. 3-1. DABS Sensor Functional Block Diagram.

Two additional functional elements, which do not fall into the above categories, are the antenna system and the clock.

The remainder of this chapter describes each of these functions in turn, and their major interactions. Because of its central importance to overall sensor operation, channel management is considered first, followed by those functions responsible for the generation and processing of channel signals, and finally those involved in surveillance and data-link message distribution and multisensor network coordination.

CHANNEL MANAGEMENT

Channel management regulates all activity on the RF channel through control of the modulator/transmitter and the ATCRBS and DABS reply processors. Its principal function is the scheduling of ATCRBS and DABS interrogations.

To provide surveillance of both ATCRBS- and DABS-equipped aircraft with minimal mutual interference, the RF channel is time-shared between the ATCRBS (and DABS all-call) modes and the DABS mode as illustrated in Fig. 3-2.

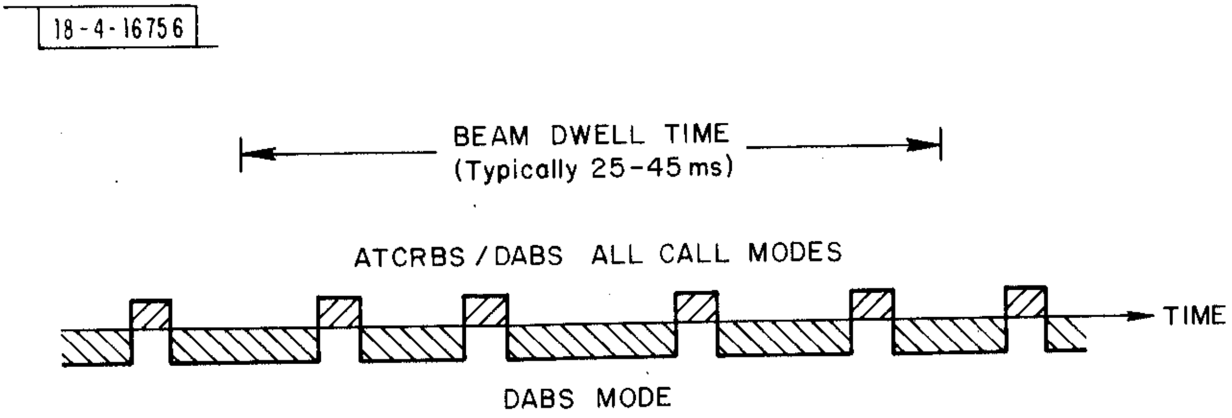


Fig. 3-2 ATCRBS/DABS Time Sharing

ATCRBS Scheduling

ATCRBS interrogations are scheduled according to one of several algorithms:

(a) constant interrogation rate;

(b) constant interrogation rate, with added pseudorandom jitter;

(c) prestored schedule, driven by sensor clock;

(d) externally triggered.

Algorithms (a) and (b) are the "normal" modes of ATCRBS scheduling; (c) and (d) are provided for experimental purposes. Mode (c) allows precisely-timed coordination of interrogation by adjacent sites, permitting control of air-to-air intersite interference for Synchro-DABS operation. Mode (d) allows the ATCRBS interrogation to be synchronized by a collocated radar, as in current radar/beacon installations.

In any of the above modes, a range of ATCRBS interrogation rates can be accommodated. In order to provide a maximum of channel time for DABS activity, the sensor has been designed for a nominal ATCRBS rate of four interrogations per 3 dB beamwidth. However, rates resulting in up to eight interrogations per 3 dB beamwidth can be employed with a corresponding reduction in DABS capacity.

Following each ATCRBS interrogation, the sensor processes ATCRBS replies for an interval corresponding to the maximum desired coverage range at the current antenna azimuth. When the desired coverage range is short, initiation of the subsequent DABS interval may be delayed to allow replies from longer-range ATCRBS targets to "ring out" so that they do not interfere with DABS replies.

DABS Scheduling

Scheduling of DABS interrogations and replies operates under the following principal ground rules:

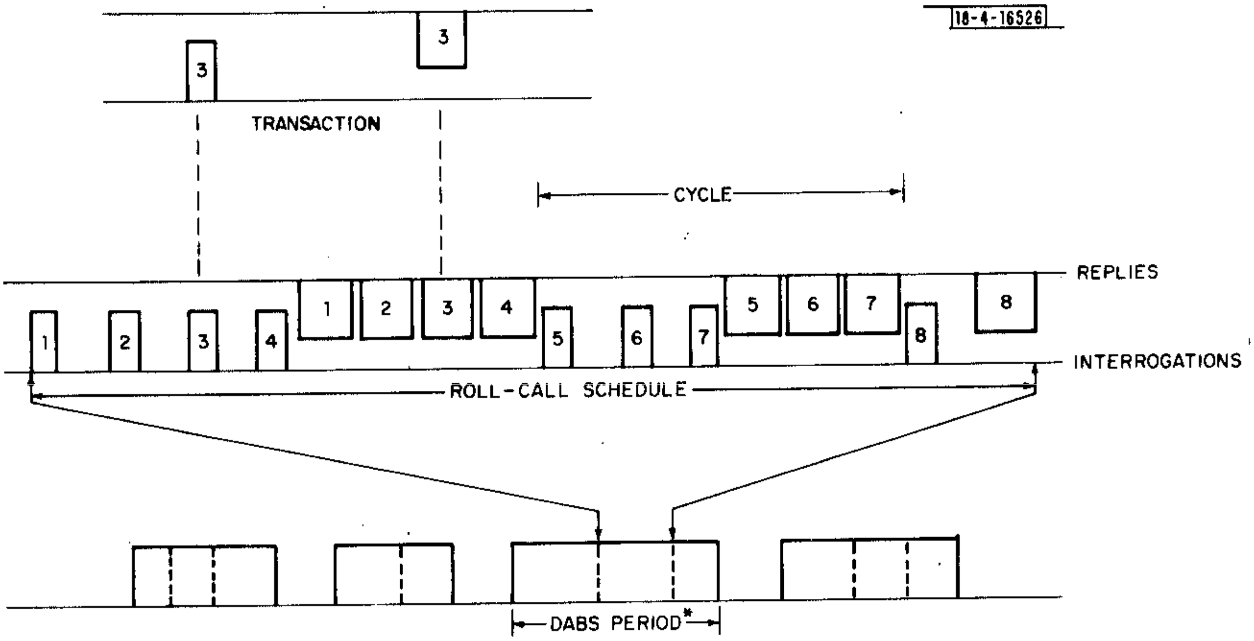
(a) DABS interrogations are addressed only to aircraft within the antenna beam.

(b) Channel time is allocated to each DABS interrogation and reply based upon a prediction of aircraft range.

(c) DABS surveillance and data-link procedures often require more than one interrogation to each aircraft. Therefore, the sensor must be able to reinterrogate an aircraft while it remains in the beam.

The sensor maintains an active target list, comprising those DABS targets that are within the antenna beam, and makes repeated passes through this list, scheduling discretely-addressed DABS interrogations and replies on a nonconflicting basis. A single aircraft may appear on one or more of the resulting schedules of interrogations and replies, so that multiple surveillance and communication tasks can be accomplished. In the case of a failure to receive a reply, the capability for repeated scheduling of interrogations to an aircraft provides a high overall surveillance/communication reliability.

The principal elements of DABS roll-call scheduling are illustrated in Fig. 3-3. The intervals of time devoted to DABS roll-call activity are called DABS periods. During a DABS period, one or more roll-call schedules are produced. A schedule is a set of interrogation and reply times which



*This DABS period comprises three schedules. The second schedule includes eight transactions, grouped in three cyles of 4, 3 and 1 transactions, respectively.

Fig. 3-3. DABS Roll-Call Scheduling.

allows the sensor to carry out one transaction per target to some or all of the targets on the active target list. The interrogations are timed so that nonoverlapping blocks of channel time are assigned to each individual interrogation and reply. If insufficient time is available to schedule all targets on the list, the time is allocated to targets according to a preassigned transaction priority.

Roll-call scheduling begins with the first (longest range) target on the list, scheduling an interrogation at the assigned start time of the schedule; next, the expected reply arrival time is computed and a suitable listening period provided. Subsequent targets are scheduled by placing their reply listening periods in sequence and computing the corresponding interrogation times. A cycle is completed when the next interrogation, if so scheduled, would overlap the first reply. This interrogation is deferred to start a new cycle.

Several types of transactions must be efficiently combined in forming a DABS schedule. Since the aircraft on the active target list are in various stages of completion, with respect to DABS activity, each one is likely to be represented on a given schedule by a different kind of transaction. Figure 3-4(a) illustrates a typical cycle comprised of long and short interrogations, coupled with long and short replies.

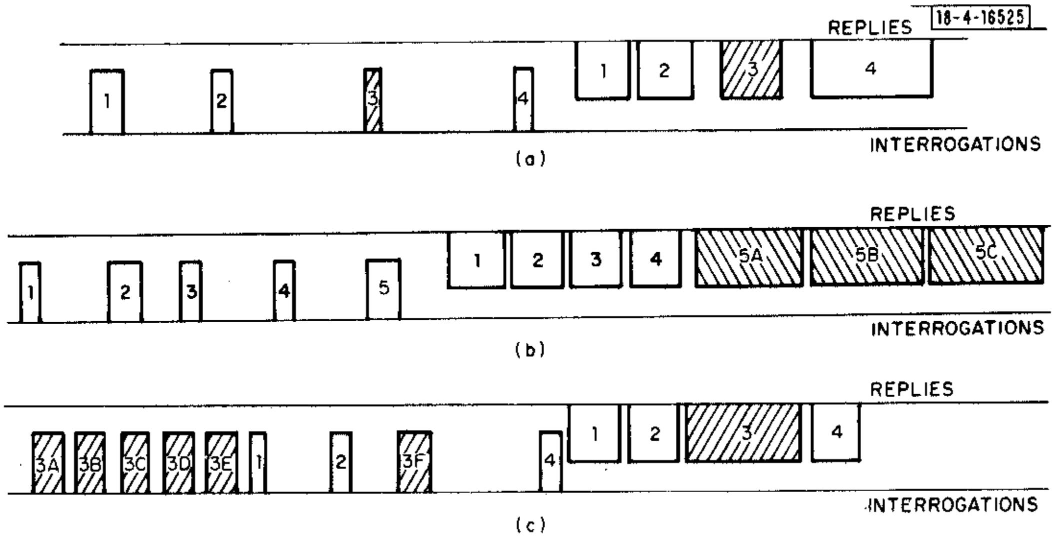


Fig. 3-4. DABS Cycles, containing:

a) A synchronized interrogation
b) A downlink ELM
c) An uplink ELM.

This cycle includes one synchronized transaction, shown crosshatched, which differs from the others in that the reply is separated from its neighbors by time buffers. These buffers are required for the prevention of interference on the Synchro-DABS air-to-air link.

The cycles shown in Figs. 3-4(b) and 3-4(c) illustrate the inclusion of downlink and uplink ELM transactions.

Channel Management Organization

The five subfunctions which comprise channel management are:

(a) Channel control
(b) Transaction preparation
(c) Target list update
(d) Roll-call scheduling
(e) Transaction update.

The data flow between these subfunctions, and their interfaces with other sensor functions, are illustrated in Fig. 3-5.

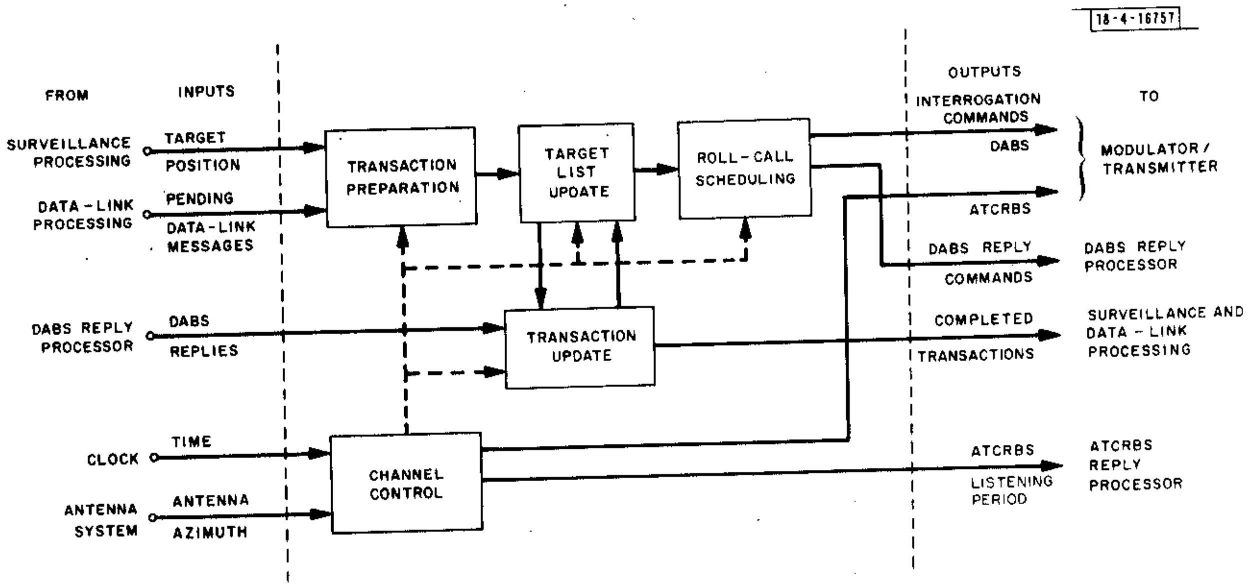


Fig. 3-5. Channel Management.

Interfaces: Channel management receives inputs from surveillance processing, data-link processing, and network management. Surveillance processing provides channel management with the predicted position (azimuth and range) of DABS aircraft. Data-link processing provides organized lists of pending uplink messages for each DABS aircraft. Network management controls the kinds of service, both surveillance and communication, to be afforded each aircraft.

Channel management has control over the modulator/transmitter unit and the DABS and ATCRBS reply processors. Channel management communicates with these units by generating interrogation and reply control commands and by receiving DABS reply data blocks. When a target leaves the beam a record of channel activity and downlink message content is passed on to the surveillance processing, data-link processing, and network management functions.

Channel Control: Channel control monitors the system real-time clock and the antenna pointing direction, seeing to it that all ATCRBS and DABS activities take place at the proper time and in the proper sequence. The other four channel management subfunctions are periodically activated by channel control. In addition, channel control regulates the flow of control commands to the modulator/transmitter and to the reply processors, and it directs the transfer of DABS reply data blocks from the DABS reply processor to channel management.

Transaction Preparation: At regular intervals, channel control directs transaction preparation to provide a list of targets about to enter the beam. Transaction preparation consults the surveillance file which contains predicted position, the pending uplink message data placed there by data-link processing, and control information generated by network management. If Synchro-DABS service, uplink messages, and/or downlink message requests are pending for a target entering the beam, transaction preparation will determine the number and type of transactions required to accomplish these tasks.

Transaction preparation creates a list of data blocks, one for each new target, containing a complete specification of the required set of transactions needed to accomplish all pending surveillance and communication tasks.

Target List Update: The active target list is updated regularly by the target list update subfunction. The entries on this list are the data blocks which have been formulated by the transaction preparation subfunction. Data blocks on new targets, supplied by transaction preparation, are merged into the list, while old targets, either leaving the beam or completely serviced, are removed.

In order to facilitate the computation of a nonconflicting schedule of interrogations and replies, the active target list is arranged in order of decreasing target range. This ordering is maintained each time the list is modified.

Roll-call Scheduling: As directed by channel control, roll-call scheduling operates on the contents of the active target list to produce DABS schedules according to the procedures described earlier. The outputs of roll-call scheduling are DABS interrogation control blocks specifying interrogation time, power level, and data-block contents, and reply control blocks specifying expected reply time and address.

Transaction Update: If a target enters the beam with several transactions to be carried out, these transactions will normally take place on successive schedules. The transaction update function examines each reply and, if the transaction was successful, modifies the target's data block so that the next pending transaction will be carried out in the subsequent schedule. If the transaction was unsuccessful, it will be repeated in the next schedule, and the next pending transaction delayed to a later schedule. Finally, transaction update indicates the completion of targets for which no further transactions are pending.

CLOCK

Each DABS sensor is equipped with a "time-of-day" clock which permits precisely-timed coordination of activities at different sensors. Site-to-site synchronization on the order of one microsecond is required for the air-to-air ranging measurements between aircraft under surveillance by different sensors. Certain ATCRBS and DABS interrogation modes used to control interference between sites also require precise site-to-site synchronization.

System time is continuously available to the modulator/transmitter, DABS and ATCRBS reply processors, and channel management. In addition, the sensor clock provides timing references for the generation of both DABS and ATCRBS interrogation waveforms, and the demodulation of replies.

MODULATOR/TRANSMITTER

The modulator/transmitter (Fig. 3-6) accepts digital control inputs from channel management and generates the requisite RF interrogation signals. For each interrogation to be transmitted, the control inputs specify the mode, the transmission time (with 1/16 μs resolution), low or high power (nominally 100 or 800 watts, respectively), and, for a DABS interrogation, the contents of the data block prior to encoding. The modulator generates the sequence of parity check bits and combines them with the specified discrete address.

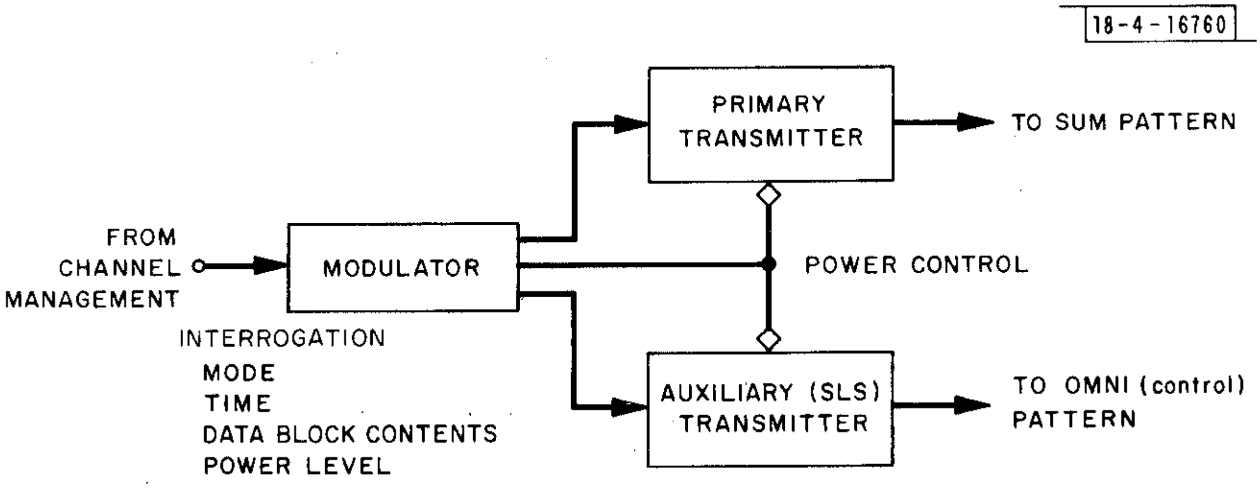


Fig. 3-6. Modulator/Transmitter.

An auxiliary transmitter is required for the generation of the SLS control pulses, since the DABS SLS pulse (P5) is transmitted simultaneously with the DABS interrogation.

ANTENNA SYSTEM

The DABS sensor employs a rotating fan beam antenna having two patterns, a sum (Σ) pattern and a difference (Δ) pattern (Fig. 3-7(a)). The interrogation is transmitted, and the reply received, on the sum pattern; the reply is also received on the difference pattern, and the ratio of the amplitudes of the signals received on the difference and sum patterns (Fig. 3-7(b)) is used to estimate the off-boresight angle of the target, i. e., the angular difference between the target position and the antenna pointing angle.

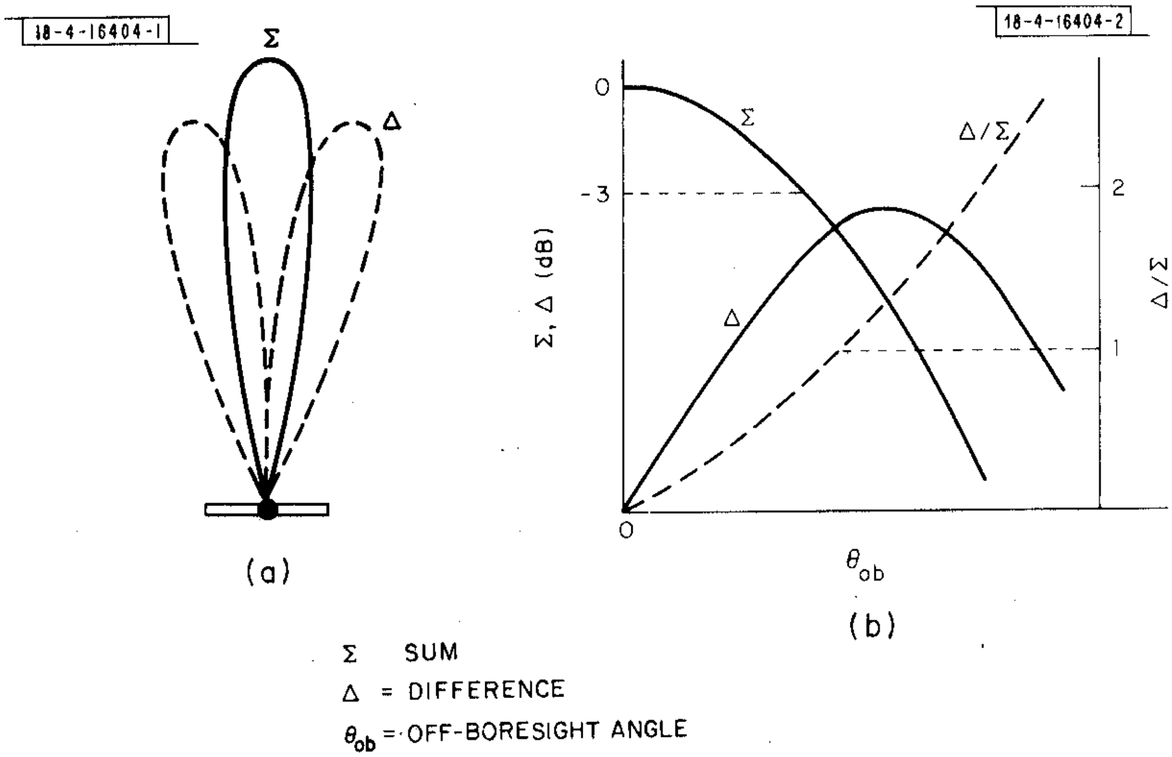


Fig. 3-7. Sum and Difference Antenna Patterns.

In addition to the sum and difference patterns, the antenna system includes an SLS control pattern. This pattern is used for the transmission of the P2 and P5 sidelobe suppression pulses. It is also used on receive, where comparison of the amplitudes of the same signal received on the sum pattern and the control pattern permits rejection of signals received via a sidelobe of the sum pattern.

To perform its function, the gain of the SLS control pattern should exceed that of the sum pattern in all directions except those corresponding to the main beam of the sum pattern, i. e., it should "cover" the sidelobes of the sum pattern. Typically, an antenna is used which has a constant gain as a function of azimuth, i.e., is omnidirectional in azimuth; the control pattern is thus referred to as the omni (Ω) pattern. However, other control pattern characteristics may be employed, such as a "high sidelobe" difference pattern, similar to the Δ pattern but designed to have sidelobes which cover those of the sum pattern.

Antenna Configuration

The DABS antenna system may either stand alone, mounted on its own pedestal, or it may share a pedestal with a radar sensor. The latter will generally be the case when a DABS and radar are collocated.

When sharing a pedestal with a radar antenna, the DABS antenna may employ a completely separate radiating structure, mounted, for example, above the radar antenna, or it may also share the radar reflector, using an integral beacon feed. On slowly rotating radar antennas (for example, long-range air route surveillance radars which rotate at 5 to 6 rpm), back-to-back beacon antennas can be used to realize a beacon data update rate twice that of the host radar.

Azimuth Pattern Characteristics

The choice of azimuth beamwidth is constrained by two conflicting requirements. A broad beam results in a higher target capacity, i.e., the sensor can provide discrete-address surveillance and data-link service to a larger number of aircraft (see Chapter 5). A narrow beam provides higher azimuth measurement accuracy. The most generally useful range of a 3-dB azimuth beamwidth for the DABS sensor appears to be 2 to 4 degrees.

Both sum and difference patterns should have low amplitude azimuth sidelobes to minimize the effects of sidelobe interference on reply detection and monopulse azimuth estimation.

Elevation Pattern Characteristics

A rapid cutoff of the antenna patterns at the horizon is desirable to minimize the energy incident on, and reflected by, the ground, and thereby to:

(a) decrease the magnitude of lobing; and

(b) reduce the error introduced in the azimuth measurement due to off-axis multipath signals.

While the specific requirements on lower edge cutoff are highly site-dependent, a cutoff rate of approximately 2 dB per degree appears adequate for most typical site environments.

Above the horizon, the DABS sensor must provide coverage to elevation angles of 30 to 40 degrees. Current beacon sensors use antennas having relatively constant gain with elevation angle (termed sector beams); used with sensitivity-time control (STC), this minimizes the dynamic range requirements of the receiver. A more tapered pattern (intermediate between the sector beam and the cosecant-squared pattern frequently used in radar applications) is preferred for DABS. The tapered pattern has greater gain near the horizon, providing a higher fade margin for long-range, low-elevation angle targets. Its lower gain at high elevation angles is balanced by the reduced range of aircraft at those elevations.

Figure 3-8 illustrates measured elevation patterns for two representative DABS antennas, both having a sharp lower-edge cutoff. The DABS Experimental Facility (DABSEF) antenna has a sector pattern characteristic, while the ASR-7 integral feed typifies the tapered pattern.

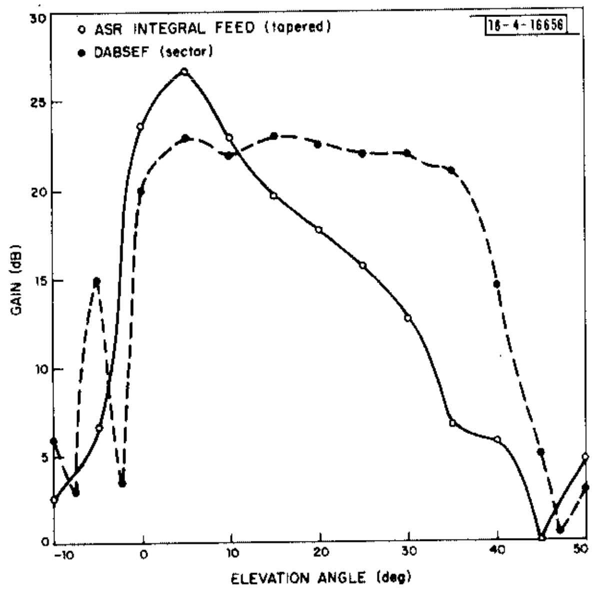


Fig. 3-8. Elevation Pattern Characteristics.

MULTICHANNEL RECEIVER

The multichannel receiver accepts the three RF signals from the sum, difference, and omni (control) patterns of the antenna system, and produces three outputs for use by the ATCRBS and DABS reply processors. These outputs are:

(a) $\log \Sigma$ - the log amplitude of the sum pattern signal;
(b) $\log \Omega$ - the log amplitude of the omni pattern; and
(c) $f(\Delta/\Sigma)$ - a bipolar video signal proportional to the ratio of the amplitudes of the difference to sum pattern signals.

The $\log \Sigma$ signal is the "principal" receiver output, used for the detection of reply pulses. Comparison of the amplitudes of the $\log \Sigma$ and $\log \Omega$ signals indicates whether a pulse detected in the $\log \Sigma$ output was received via the mainlobe ($\log \Sigma > T^{*} + \log \Omega$) or via a sidelobe ($\log \Sigma < T^{*} + \log \Omega$) of the sum pattern. The digitized value of the $f(\Delta/\Sigma)$ signal from each received pulse is compared with a prestored antenna/receiver calibration curve to provide an estimate of the angle of arrival of the signal relative to the antenna boresight.

Figure 3-9 is a block diagram of a possible realization of the multichannel receiver. To minimize the effects of transmission line loss and phase variation,

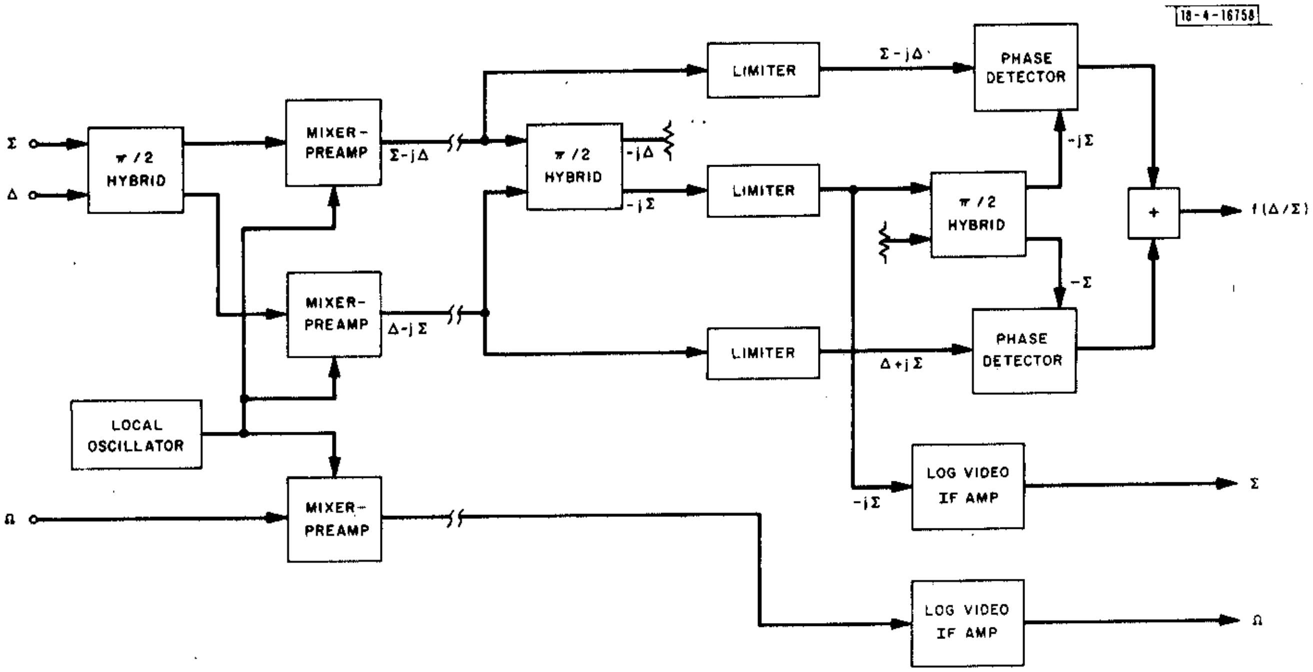


Fig. 3-9. Multi-Channel Receiver.

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[*] A preset threshold.

the "front end" of the receiver, including conversion of each channel to an intermediate frequency, is mounted remotely on or near the antenna pedestal. The figure illustrates the use of the so-called "half-angle monopulse processor" to generate a $f(\Delta/\Sigma)$ output which is unambiguous (i. e., single-valued) over the full range of values of Δ/Σ, approximately according to the relationship:

$$f(\Delta/\Sigma) \approx 2 \tan^{-1} (\Delta/\Sigma).$$

The half-angle monopulse processor provides a highly accurate and stable calibration characteristic over a wide range of input signal amplitudes.

DABS REPLY PROCESSING

DABS reply processing operates on the multi-channel receiver outputs to detect and decode DABS all-call and roll-call replies, and to generate an estimate of target range and azimuth from each detected reply. The principal steps in DABS reply processing are depicted in Fig. 3-10.

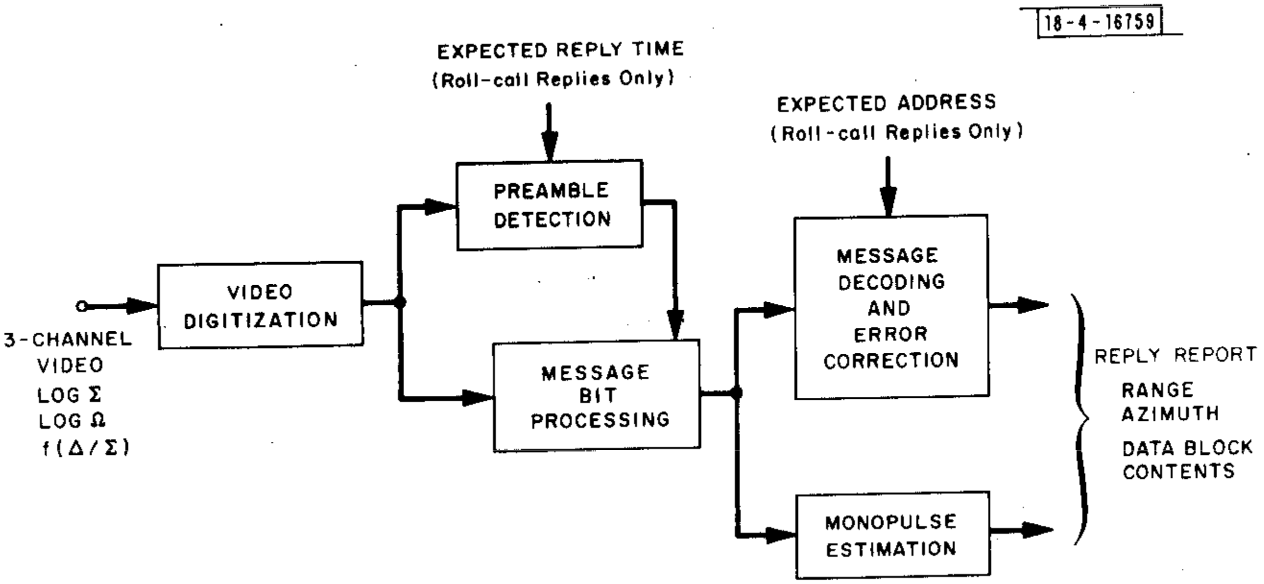

Fig. 3-10. DABS Reply Processing.

Preamble Detection

DABS replies are detected on the basis of the four-pulse preamble waveform preceding the reply data block. The preamble detector provides accurate time-of-arrival estimation for target ranging and for synchronization of message bit processing and reply decoding.

In the case of replies to roll-call interrogations, channel management provides to the preamble detector an estimate of expected reply time and an uncertainty window. A reply is accepted only if its preamble is detected within this window. Since the reply processor cannot start decoding a new reply when it is still decoding an earlier one, the use of this window minimizes the probability that the reply decoder will miss the desired reply due to DABS fruit.

Message Bit Processing

Message bit processing operates on sampled video waveforms to produce a sequence of demodulated message bits, and a confidence bit (high or low) for each demodulated message bit.

Since a message bit is transmitted as a pulse in a one of two possible positions, depending on whether the bit value is a 0 or a 1, bit decisions are based primarily on the relative amplitudes of the signals received in these two pulse positions. The sidelobe flag is used to help resolve ambiguous situations in which a signal is received in both pulse positions.

Bit decisions are indicated as high confidence only when a mainbeam signal appears in one pulse position, and either no signal or a sidelobe signal appears in the other.

Message Decoding and Error Correction

Message decoding uses the parity check code to detect errors on the demodulated message. Since in roll-call replies the parity check bits are combined with the transponder address, the decoder must know the expected address (supplied by channel management) in order to perform error detection.

Whenever a decoded reply contains errors, error correction is attempted if the total number of low-confidence bits in the reply does not exceed a preset threshold. The use of this threshold minimizes the possibility of erroneously "correcting" a reply which contains a very large number of errors. Error correction will be successful only if:

(a) all errors are confined within a span of 24 contiguous bits, and

(b) all errors occur in bits flagged as low confidence.

Garbling by a single, strong ATCRBS reply, which can result in bit decision errors spanning no more than 24 bits, usually results in a correctable error pattern. Thus, with high probability the DABS data block will be correctly decoded unless it is garbled by more than one strong ATCRBS reply.

ATCRBS REPLY PROCESSING

The ATCRBS processing subsystem has been designed to produce accurate, reliable target reports at low interrogation rates in order to maximize the channel time available for the DABS mode of operation. Monopulse information is used both to determine target azimuth and to assist in the decoding of overlapped replies. Sidelobe fruit replies are detected and rejected by comparison of the signal amplitudes received on the sum and omni patterns. ATCRBS modes A, C, and 2 replies are processed, and the extracted codes included in the target report.

ATCRBS reply processing takes place in three successive steps (Fig. 3-11):

(a) Reply decoding operates on the three video outputs of the multichannel receiver to detect ATCRBS replies, and, for each detected reply, provides an estimate of target range, azimuth, code and code confidence.

(b) Reply correlation attempts to combine all replies received from an aircraft during one interrogator antenna scan into a single target report containing target range, azimuth, code and code confidence for each mode (A, C, 2) in which the target responded.

(c) Report-to-track correlation edits, and corrects as necessary, target reports by comparing them with a track file generated from reports received on previous scans. This step assists in the elimination of main-beam fruit, the flagging of false targets, and the correction of missing and garbled code pulses.

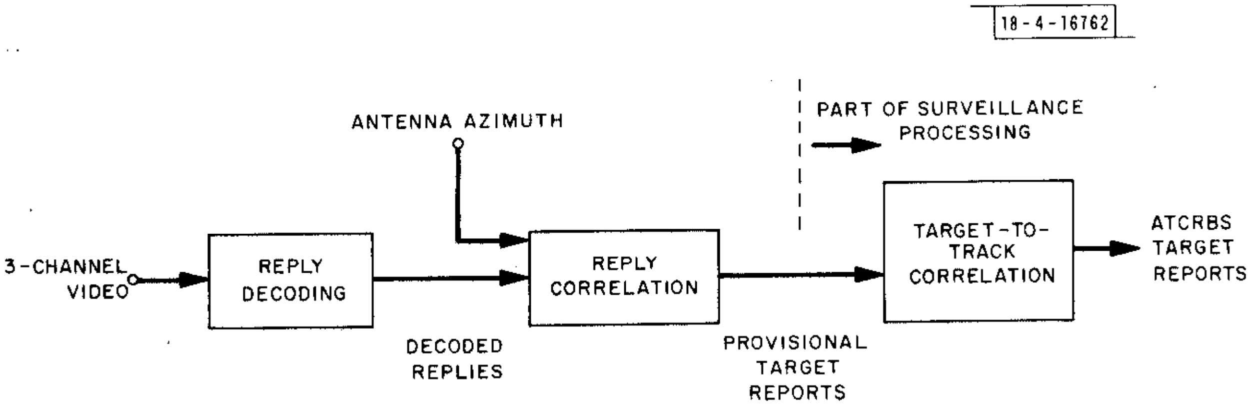

Fig. 3-11. ATCRBS Reply Processing.

The first two steps are described in the remainder of this section. The final step, report-to-track correlation, is discussed in a later section on surveillance processing.

Reply Decoding

The major elements of ATCRBS reply decoding are illustrated in Fig. 3-12.

Video Digitization provides a digital representation of pulses whose widths are within an acceptable range. This representation includes leading edge location, a monopulse sample, and a sidelobe flag. Overly long pulses are assumed to have resulted from an overlapping of pulses from two replies, and pseudoleading edges are inserted based on the observed trailing edge position.

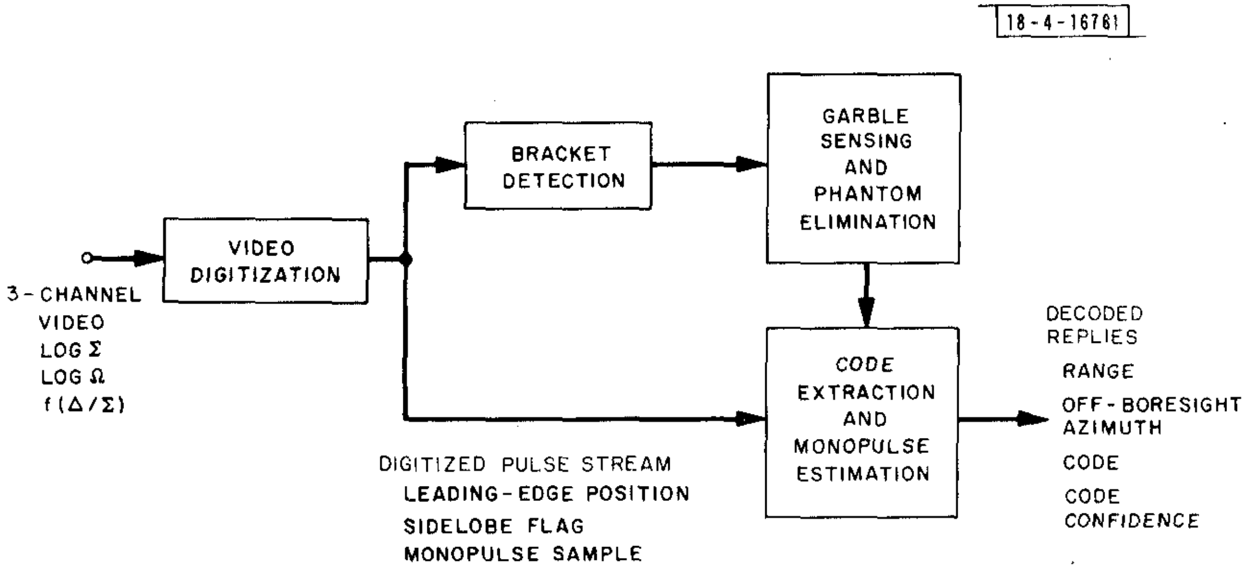

Fig. 3-12. ATCRBS Reply Decoding.

A monopulse sample is produced for each pulse of acceptable width, except for pulses which are overlapped enough to result in garbled monopulse samples.

Bracket Detection is based on the detection of two pulses in the leading edge data stream which have the appropriate spacing (~ 20.3 μs). Bracket pulse pairs for which both pulses are flagged as sidelobe pulses are not declared, the thus sidelobe replies are not decoded.

Garble Sensing and Phantom Elimination: Garble sensing is based on the time separation of two detected bracket pairs which would result in overlapping pulse decode regions for the two replies. The incorrect declaration of a bracket pair made up of pulses from two garbling replies is termed a "phantom". Phantoms produced by two garbling replies will be correctly eliminated if no additional garbling reply occurs for 20.3 μs.

Code extraction is initiated by the declaration of a bracket pair, which defines the possible information pulse locations. Information pulses are associated with a reply (bracket pair) on the basis of their leading edge location relative to the bracket pair and their monopulse sample values relative to a monopulse reference. The initial monopulse reference is the monopulse sample of the first framing pulse, except when that pulse is in a possible garble region of an earlier reply. If the first framing pulse may be garbled, the monopulse sample of the second framing pulse is used as the monopulse reference. This procedure establishes ungarbled monopulse references when only two replies are garbling each other.

Each information pulse decision is accompanied by a confidence bit (high/low confidence). A pulse is decoded as a high confidence '1' if it falls within one of the acceptable pulse decoding regions of a reply being decoded and its monopulse sample correlates with the monopulse reference of that reply. A pulse position is decoded as a high confidence '0' if no pulse is detected in its decode region and no pulse leading edge is detected in the sample position just ahead of this decode region.

Monopulse Estimation: Each pulse which lies within a valid information pulse position of a detected reply and which correlates with the monopulse reference of that reply is used to update the reference by averaging the reference value and the sample value. The monopulse estimate for a decoded ATCRBS reply is the final value of the monopulse reference for the reply at the time the F_2 pulse has been processed. In order to avoid an erroneous monopulse estimate because of a garbled reference sample at the start of pulse decoding, an ATCRBS monopulse estimate is not declared unless it includes at least two monopulse samples.

Reply Correlation

The function of reply correlation is to combine all replies received from a transponder in one scan into a single target report. Each reply received from reply processing is correlated (compared) in range, azimuth and high-confidence code pulses with existing target report files. If a new reply does not correlate with any existing target report file, a new file is started with the reply.

Code correlation is done by comparing only high-confidence code positions of a reply with the high-confidence code positions of the code estimate contained in the target report file. This code estimate (mode 2, A or C) is updated by forming a new estimate consisting of the composite of the current file code estimate and the high confidence code positions of the correlating reply. Likewise, the composite confidence bit sequence for each reply mode is updated by adding to the high confidence positions in the target report file any new high confidence positions in the correlating reply.

The azimuth estimate provided in a target report consists of the azimuth estimate of the reply closest to boresight when replies are received only on one side of boresight, or the average of the azimuth of the two replies which straddle boresight.

SURVEILLANCE PROCESSING

Surveillance processing maintains target files on all ATCRBS and DABS aircraft within the sensor's coverage volume. Its principal functions are:

(a) To predict next-scan position of DABS aircraft for interrogation scheduling;

(b) To edit and correct ATCRBS target reports based upon data from previous scans;

(c) To perform radar/beacon correlation of target reports from a collocated radar;

(d) To disseminate composite ATCRBS/DABS/radar surveillance data to ATC users.

The data flow between the principal elements of surveillance processing is illustrated in Fig. 3-13.

DABS Surveillance Processing

DABS surveillance processing (Fig. 3-14) operates on the set of DABS replies received from an aircraft during a scan to produce a target report on that aircraft and a prediction of its position on the next scan.

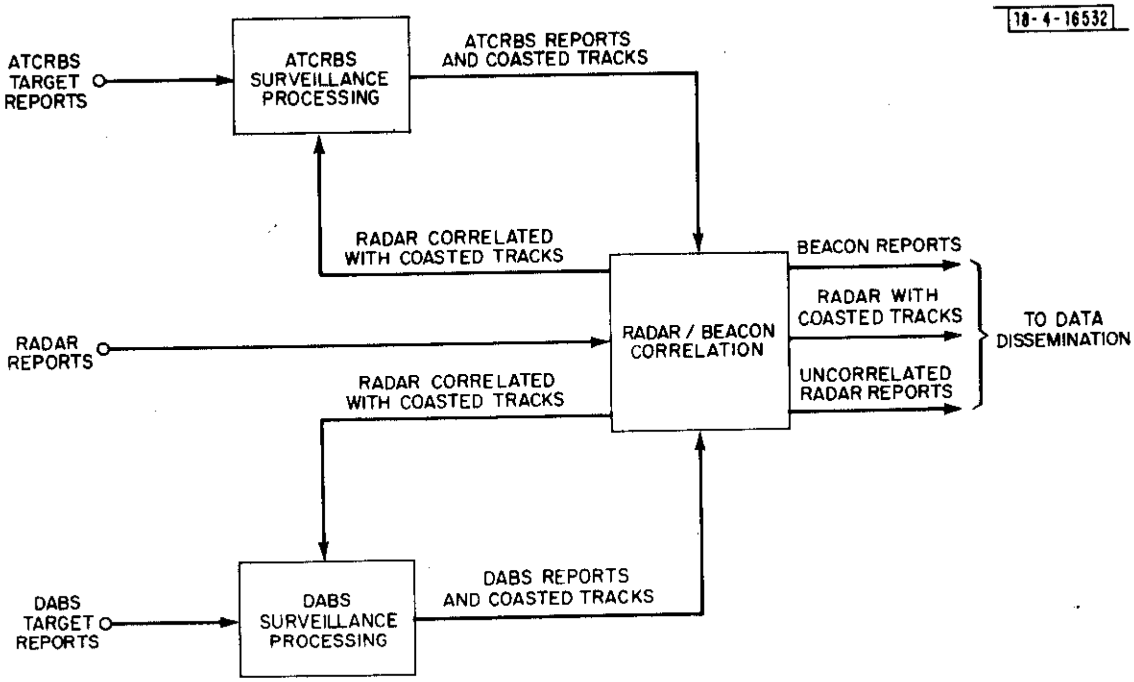

Fig. 3-13. Surveillance Processing

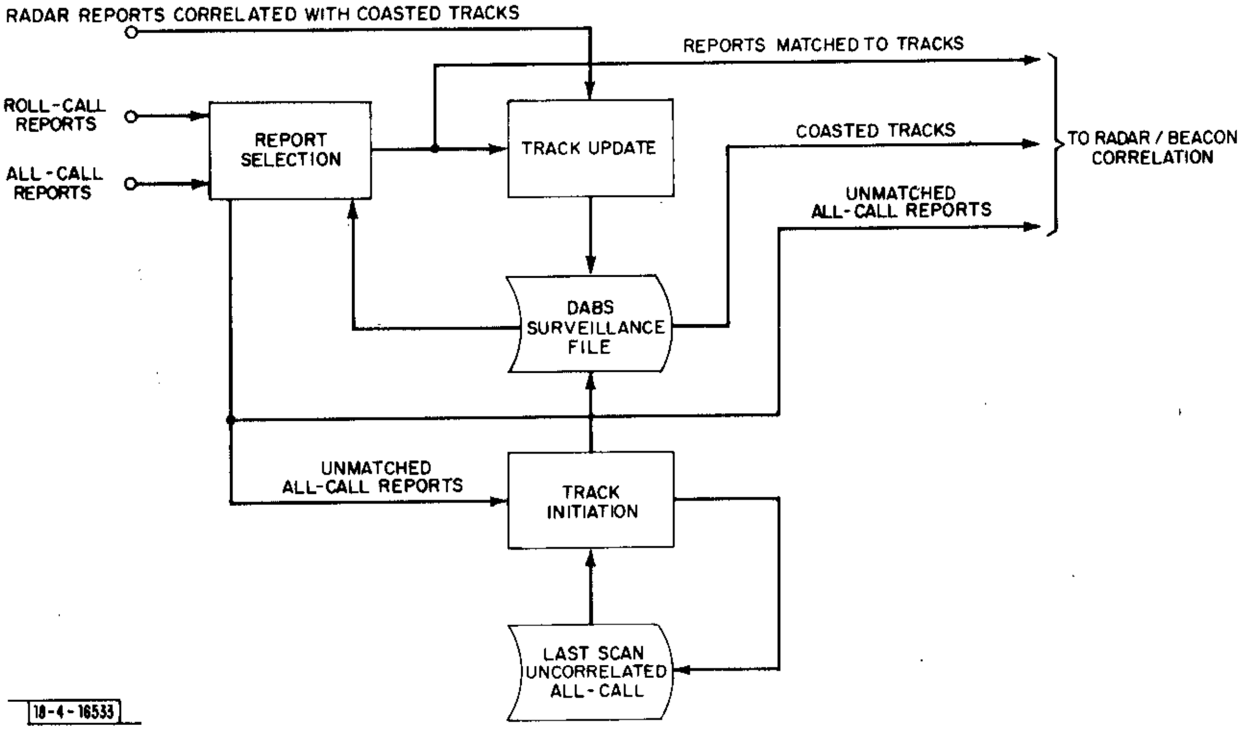

Fig. 3-14. DABS Surveillance Processing

A single DABS report for a given address is selected to represent the surveillance data for each track. Many reports with the same address may be present, either because of multiple roll-calls for data-link activity or because this aircraft is just being acquired and has answered an all-call. The report selection process includes finding the report which is near beam center to maximize azimuthal accuracy, and also finding the report at shortest range to exclude false (reflected) targets.

The DABS all-call reports whose address does not match an existing track are examined in the track initiation process to determine if an address match can be made with uncorrelated reports held over from the previous scan. When a match is found, a test for false track due to reflection is made; if the test is negative, a newly-initiated track is entered into the surveillance file. The still-unmatched reports are saved for one scan and are also used in radar correlation.

Finally, all DABS reports that match with tracks, and radar reports that correlate with coasted tracks, (i.e., tracks that were not matched to a DABS report this scan), are used to update and project the DABS track ahead one scan. This new projection is used by channel management to determine when to schedule the next roll-call interrogation to the aircraft.

ATCRBS Surveillance Processing

ATCRBS surveillance processing (Fig. 3-15) edits, and corrects as necessary, ATCRBS target reports by comparing reports received on the current scan with target tracks derived from reports received on previous scans. Editing includes eliminating residual fruit replies which may have been passed by the ATCRBS reply processor, and flagging reports suspected of being due to reflections, i.e., false targets. When target reports correlate with an existing track, missing or low-confidence code bits may be corrected by insertion of the corresponding bits from the track file.

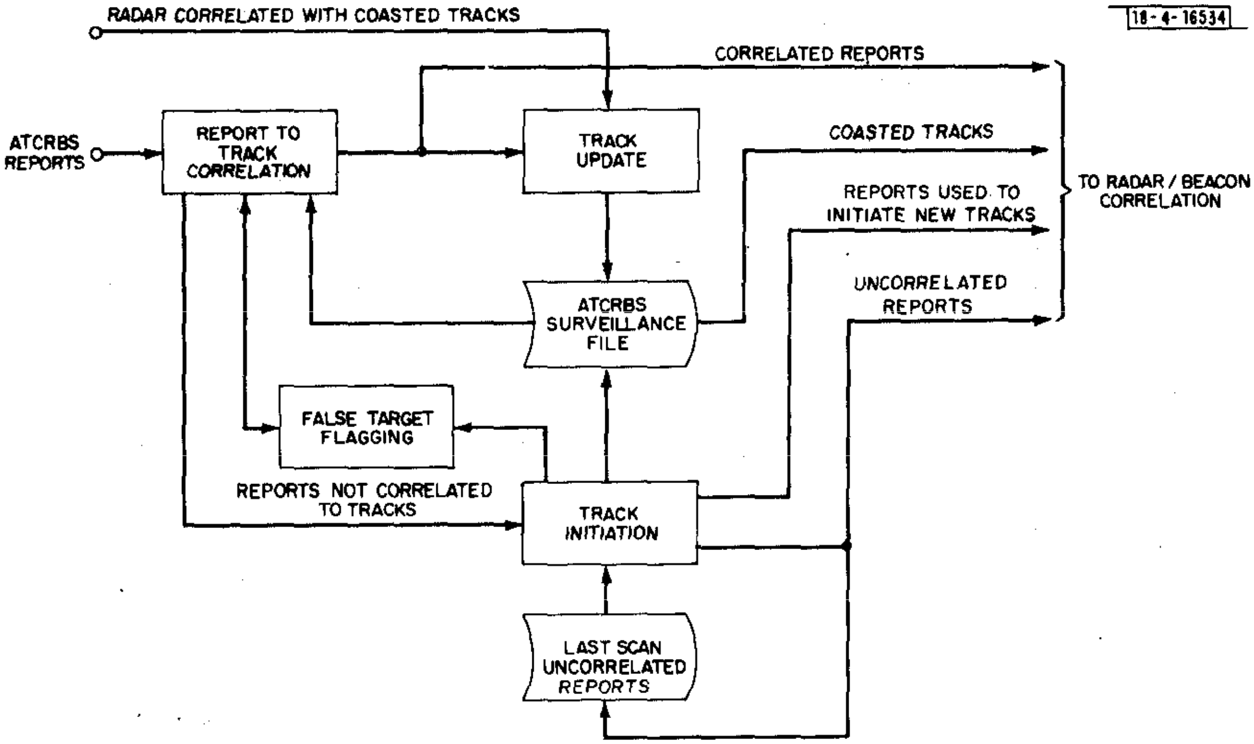

Fig. 3-15. ATCRBS Surveillance Processing

The lack of a unique identity code as part of each ATCRBS reply (as opposed to DABS replies) makes necessary a report-to-track correlation function as the first step in ATCRBS surveillance processing. Report-to-track correlation is based upon the several attributes of the report. A report is said to be associated with a track if it falls within a specified range, azimuth, altitude association interval. Then, if only one ATCRBS report associates with a single track, that report/track pair is declared correlated. For those cases where more than one report associates with a track, or more than one track associates with a report, or both, report and track correlations are based upon the following factors:

(a) code match
(b) number of replies in the report
(c) altitude match
(d) track maturity
(e) distance parameter.

In the final phase of report-to-track correlation, two special situations are sensed. If the mode A code of the report does not match the code of the track, it is assumed that a code change has been made in the aircraft and a transition situation is noted. After three scans of consistent new code, the track file code is updated.

ATCRBS fruit are discarded by rejection of all reports that do not correlate with a track and which are comprised of a single mode A reply, a single mode C reply, or two replies - one mode A and one mode C.

The test for determining whether a report is false (i. e. , due to a reflection) is initiated by comparing the ATCRBS report azimuth with a stored table of reflections zones. If the report is in one of the reflection zones, then an image location is calculated and compared against known tracks. If a known track with matching altitude and mode A code could have caused the report, the report and any track started from it will be tagged as potentially false. Each scan thereafter, the false track is examined to see if it continues to satisfy the "false track" criteria.

Radar/Beacon Correlation

The last step in surveillance processing prior to data dissemination is the comparison of radar reports from a collocated radar with the result of DABS and ATCRBS report processing.

A radar report correlates with a beacon report or track if it satisfies certain distance criteria. When a radar report and a beacon report correlate, the beacon report is said to be radar reinforced.

When a radar report correlates with a track for which no beacon report was received during the current scan, the track is updated using the radar report. However, no tracks are initiated on the basis of radar reports alone.

Surveillance Data Output

At the completion of surveillance processing there are several classes of reports to be disseminated. These are:

(a) beacon, radar reinforced;
(b) beacon, not radar reinforced;
(c) radar correlated with coasted beacon tracks; and
(d) uncorrelated radar.

DATA-LINK PROCESSING

Data-link processing regulates the flow of messages on the air-ground link. This is accomplished through the maintenance of a file, called the active message list, which contains a record of all of the pending communications activities. Entries in this file are organized by DABS address and are used by channel management to determine the number and type of interrogations and replies to schedule for an aircraft when it is available in the antenna mainbeam.

As shown in Fig. 3-16, the two major subfunctions of data-link processing operate to update the active message list. Input processing handles messages

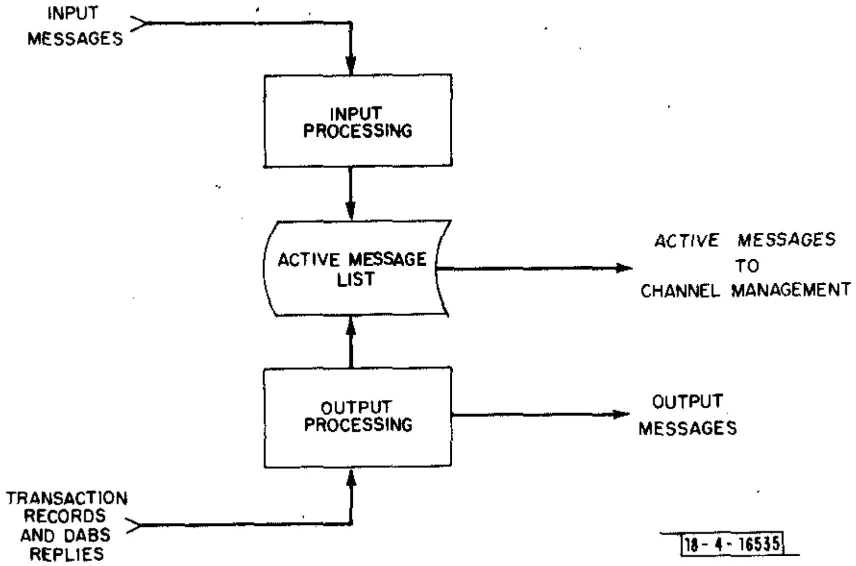

Fig. 3-16. Data-Link Processing

received from ground users of DABS and in general is involved with additions of ground-to-air messages to the active message list. Output processing examines the transaction record prepared by channel management. The transaction record together with reply message contents indicate which communication activities are complete and which, if any, transponders are requesting an air-to-ground message transfer.

Input Processing (Fig. 3-17)

Communication messages[5] are received from both the ATC interface and the IPC functions at the local and adjacent sites. A test is made to determine the status of the addressed DABS aircraft in the local surveillance file. If the DABS aircraft is not contained in the file, an immediate message reject notice is generated. If the DABS aircraft is in the file but in a fade condition, requests for uplink delivery will be accepted but the sender will be issued a message delay notice. The message type is detected and the active message list is updated according to user-defined priority.

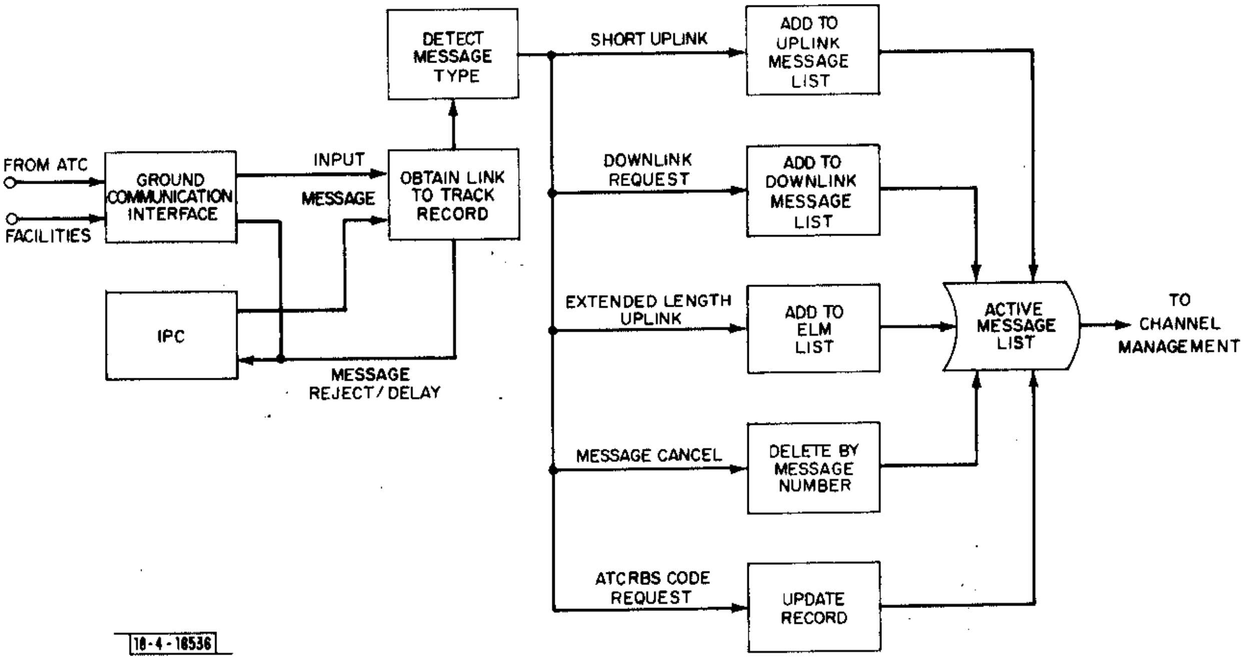

Fig. 3-17. Input Message Processing

Output Processing (Fig. 3-18)

DABS replies from the current scan are checked for indication of successful uplink message delivery and for requests for new air-to-ground message transfers. Downlink messages included in the replies are detected, flagged as complete, and routed to intended recipients as indicated by information stored in the active message list (for ground-initiated messages), or to all connected ATC facilities (for pilot-initiated messages). The final task involves updating the list to reflect additions and completions this scan, and the generation of delivery notices.

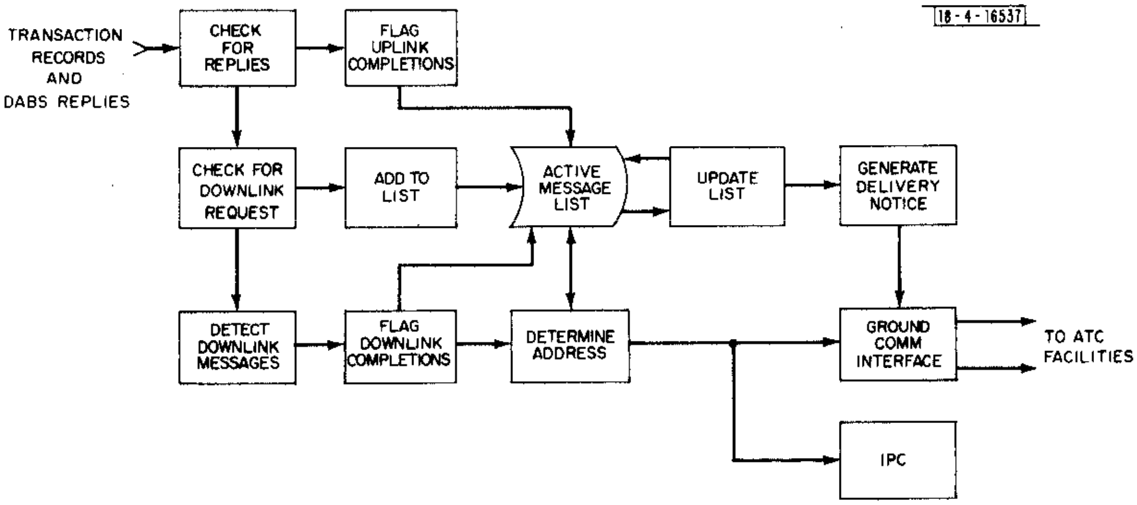

Fig. 3-18. Output Message Processing.

NETWORK MANAGEMENT

DABS sensors exchange surveillance data to hand off targets between sensors and to maintain surveillance continuity and rapid target reacquisition in the event of a temporary link interruption. This multisensor coordination is directed by the network management function, operating under the control of the sensor coverage map.

An overall block diagram of the network management function is presented in Fig. 3-19. Once each scan, each DABS track is processed by coverage coordination to determine if a boundary crossing or a track state change has occurred. Either of these events will cause control message handling to initiate a sequence of messages. The former results in a flow of track data to the sensor whose boundary was crossed; the latter results in a request, or cancellation of a previous request, for surveillance data to fill in during a link interruption. Control message handling also processes network control messages from adjacent sensors and retrieves or stores data in the surveillance file as required.

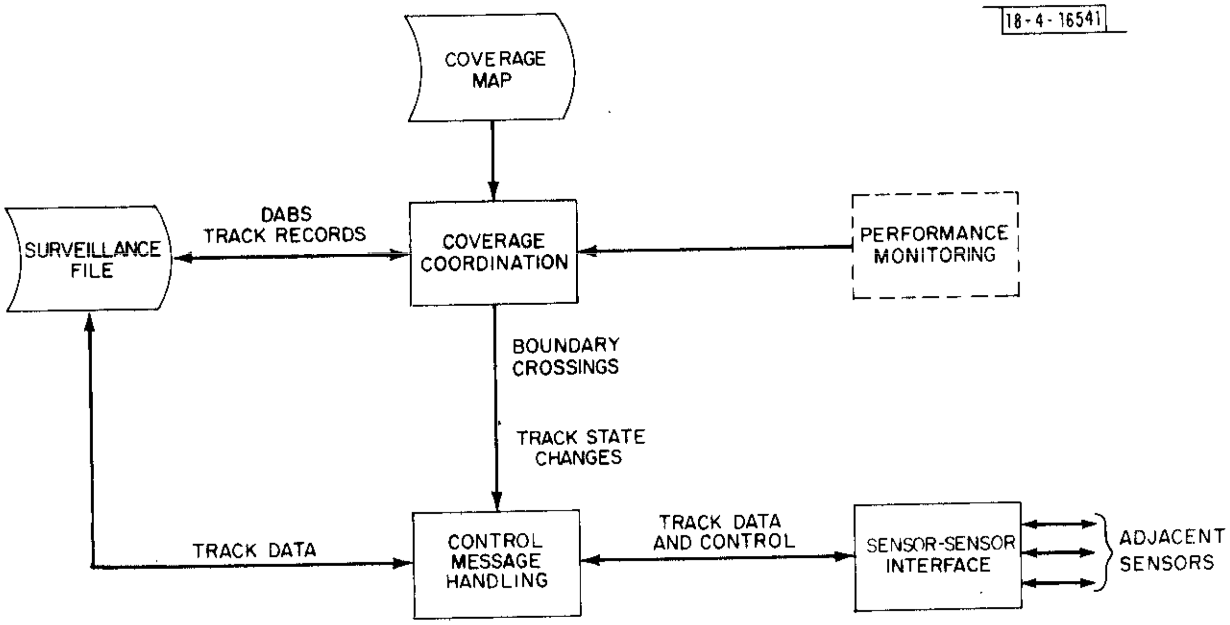

Fig. 3-19. Network Management.

The Coverage Map

The extent and type of coverage to be provided by each sensor is controlled by a data file known as the sensor coverage map. In general, two major boundaries are defined by this map;

(a) the maximum range at which the sensor is to provide surveillance coverage, and

(b) the area where the sensor is assigned primary responsibility.

The coverage map is implemented in a ρ - θ grid as shown in Fig. 3-20.

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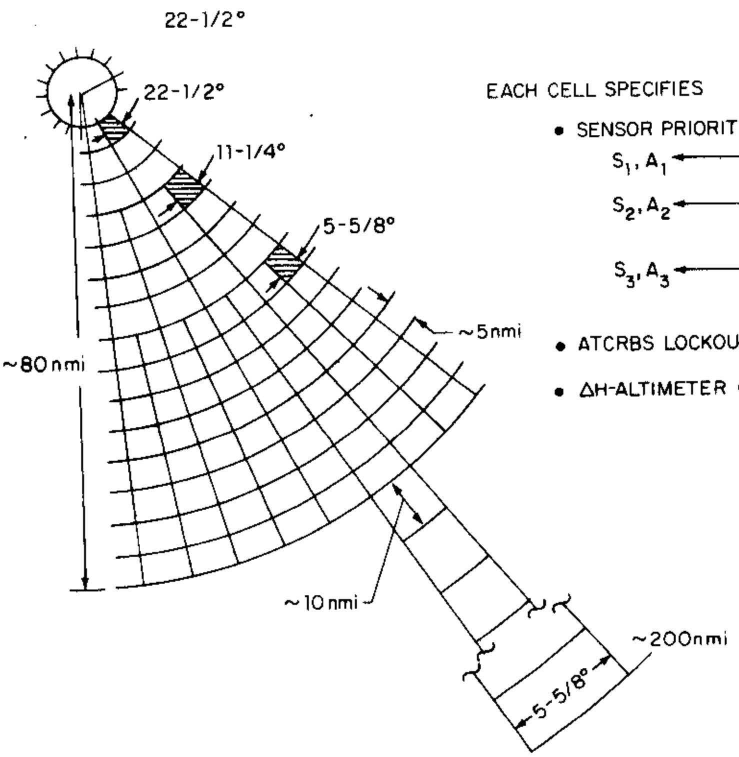

EACH CELL SPECIFIES

- SENSOR PRIORITY AND ALTITUDE CUTOFF

S_1, A_1 ← PRIMARY SENSOR

S_2, A_2 ← NORMAL SURVEILLANCE

S_3, A_3 ← BACKUP COVERAGE

- ATCRBS LOCKOUT STATE
- ΔH-ALTIMETER CORRECTION FOR ALEC

Fig. 3-20. Coverage Map Grid Structure.

For each element of the grid, termed a cell, a sensor prioirty list is specified, with a lower altitude cutoff defined for each sensor. The position of a sensor in the list specifies its surveillance function in that cell: primary, secondary, or backup. Sensor coverage boundaries are thus defined by a change in sensor ordering between adjacent cells.

Also stored for each cell are other geographically-defined data, such as ATCRBS lockout state and the altimeter correction (ΔH) to be used in generating altitude echos.

In the event of a sensor failure, that sensor is flagged as inactive, effectively deleting it from the sensor priority list. In this way the primary and secondary coverage areas of active sensors are automatically enlarged to take over the area formerly serviced by the failed sensor.

Coverage Coordination

Figure 3-21 illustrates the elements of the coverage coordination subfunction. The current position of the track is used to determined the present cell index. If the cell index has not changed since the last scan, and no failure/recovery of an adjacent sensor has occurred, no further action on coverage assignment is done. Otherwise, the sensor priority list for this cell is retrieved from the coverage map, deleting those sensors that the performance monitoring function has declared to be in a failed state. The resulting sensor assignment is compared to the previous assignment (stored as part of the track record) to detect the occurrence of a boundary crossing. If one is detected, an indication is passed to control message handling to initiate the appropriate sequence of messages.

The present track state is then compared to the previous state to detect the beginning or end of the link interruption. Again, an indication is passed to control message handling to begin or terminate the flow of adjacent sensor data. An additional check is made to determine if the track was just initiated as a result of the local sensor's all-call interrogations. If so, surveillance data on this track is disseminated to the other assigned sensor(s) in the cell by control message handling, using the same message sequence as for a surveillance boundary crossing.

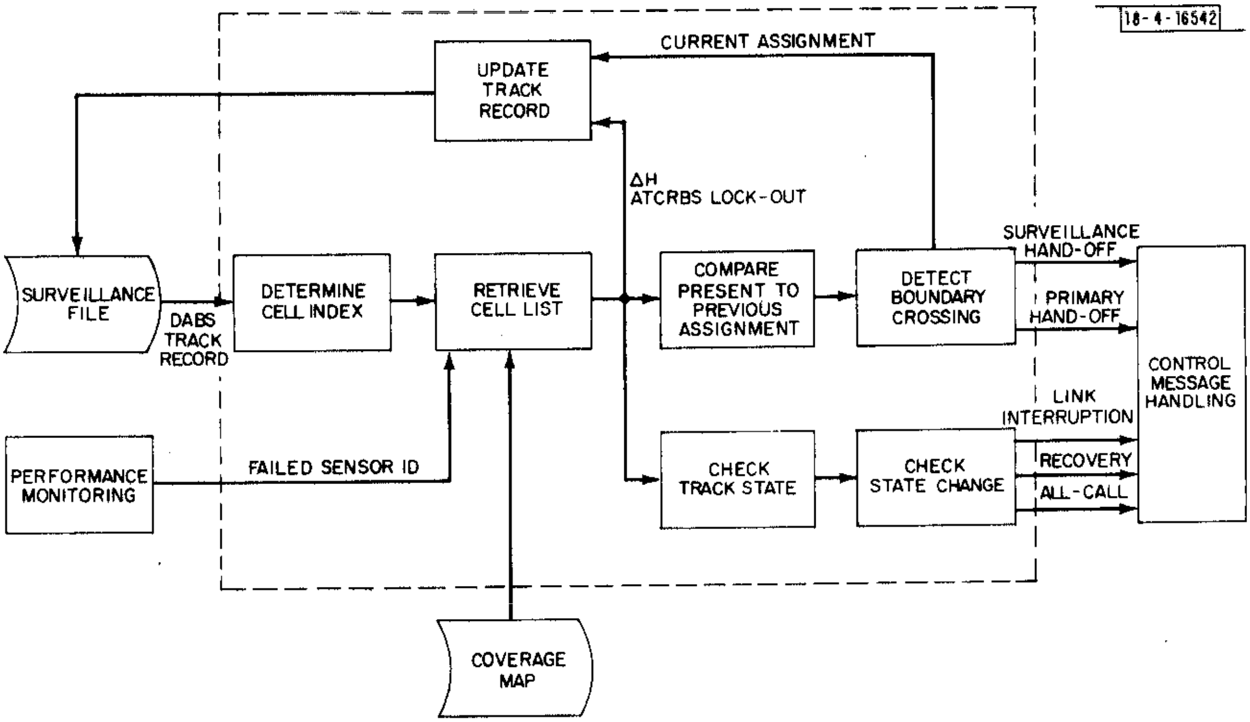

Fig. 3-21. Coverage Coordination.

Storage in the track record of the current sensor assignment and the ΔH and ATCRBS lockout data completes the cycle of activity.

Control Message Handling for DABS

Certain events cause a sequence of messages to be exchanged between DABS sensors. The principal such events, and the resulting messages, are listed in Table 3-1.

TABLE 3-1 CONTROL MESSAGE HANDLING

Event	Message Sequence	To/From
Surveillance Handoff	Send Data Start to Send Track Data to Receive Cancel Request from Send Data Stop to	The New Active Sensor in the Cell
Track State Change	Send Data Request to Receive Data Start from Receive Track Data from Send Cancel Request to Receive Data Stop from	The Other Active Sensor in the Cell
All-Call Acquisition	Send Data Start to Send Track Data to Receive Cancel Request from Send Data Stop to	The Other Active Sensor in the Cell
Primary/Secondary Handoff	Send Primary Assignment to Receive Handoff Accept from	The Sensor Assigned Primary in the Cell

Control Message Handling for ATCRBS

Messages on ATCRBS targets are limited to an exchange of track data on request. The sequence of ATCRBS control messages used to establish this exchange is similar to that shown in Table 3-1 for the DABS track state change event.

INTERMITTENT POSITIVE CONTROL (IPC)

Each sensor includes an IPC function to provide PWI and IPC commands to prevent conflicts between aircraft. This function utilizes the surveillance data to generate its own aircraft track file and position predictions. From these, predictions of potential conflict situations are made, and PWI and conflict resolution messages are sent to the aircraft involved. The IPC function utilizes the ground-to-air data link of the local sensor for these messages. In addition, it may call upon an adjacent sensor to deliver critical messages in parallel to ensure rapid delivery.

The IPC function notifies the ATC facilities of potential conflicts involving IFR aircraft as well as any commands sent to such aircraft. The IPC function communicates directly with adjacent IPC sites for control handover and exchange of track data on aircraft in conflict. The IPC function is described in detail in FAA-EM-74-4. "Multi-Site Intermittent Positive Congrol Algorithms for the Discrete Address Beacon System".[6]

PERFORMANCE MONITORING

The ability of the sensor to perform its surveillance and communication tasks is continuously checked by the performance monitoring function (Fig. 3-22).

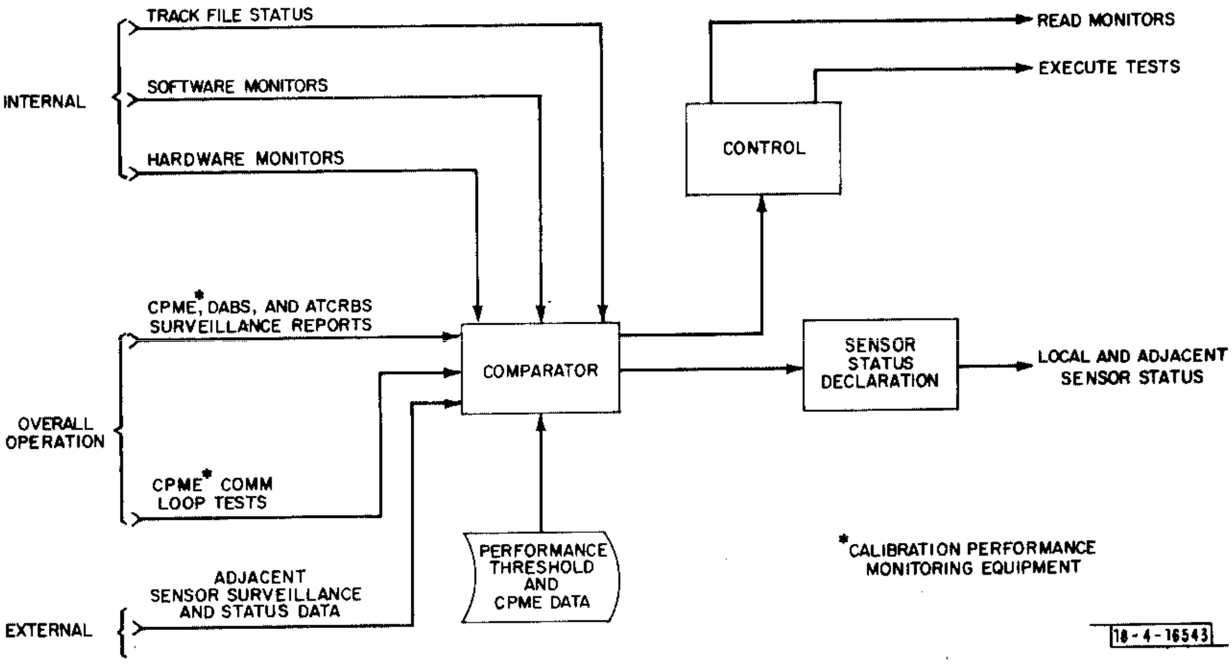

Fig. 3-22. Performance Monitoring.

Three categories of checks are performed:

(a) Overall checks for proper surveillance and data-link operation

(b) Internal checks on the status of the sensor hardware and software.

(c) External checks on the status of adjacent sensors and their ability to provide the local sensor with correct surveillance data.

The output of this function is a sensor status message once per scan which is sent to the ATC interface and to adjacent sensors.

Calibration Performance Monitoring Equipment (CPME)

The CPME is a transponder-like device, several of which are deployed in close proximity to each sensor, as shown in Fig. 3-23.

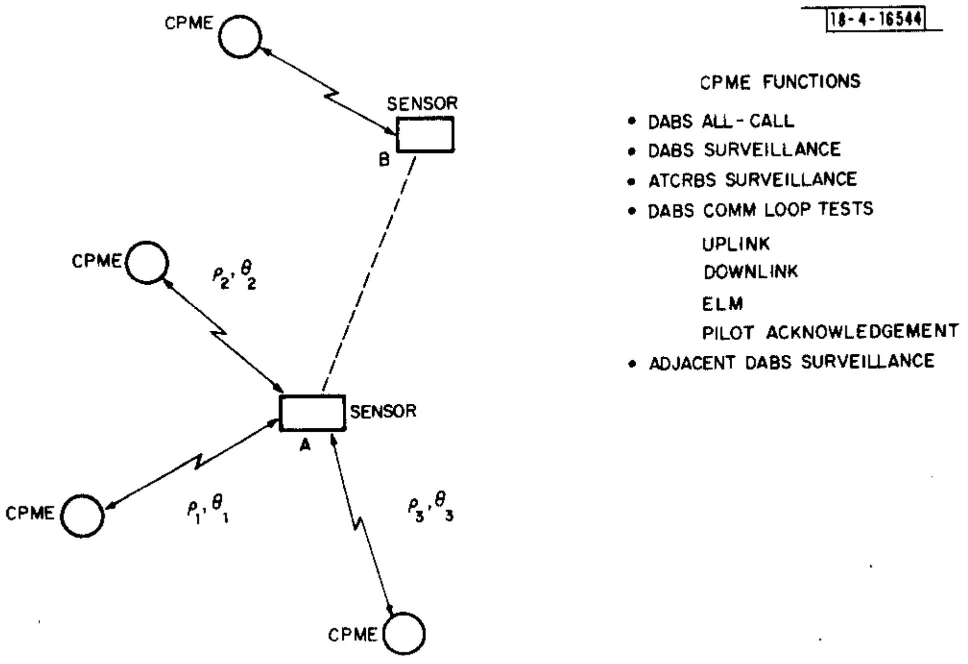

Fig. 3-23. Calibration and Performance Monitoring Equipment (CPME).

CPME's serve as the basis for the overall operational surveillance checks by providing replies from a "target" with a known identification and position (range, azimuth, altitude). Overall operational communication checks are performed by loop tests with the CPME. In these tests an uplink test message delivered to the CPME causes it to initiate a downlink message with the same text as contained in the uplink message.

The ability to obtain surveillance data from an adjacent sensor is also checked using the CPME. In this case, the local sensor requests data on the CPME of an adjacent sensor. Data received in response to the request are checked against the stored data to verify correct delivery.

CHAPTER 4

AVIONICS

The avionics components of DABS are the transponder and the associated data-link message display and input devices. A wide variety of data-link devices have been considered; three have been defined in detail, and are described in this chapter: the IPC/PWI display; the ATC message display; and the call-sign input device.

THE DABS TRANSPONDER

The transponder is the principal avionics component of DABS. It performs all necessary surveillance functions, requiring only, as in the case of an ATCRBS transponder, inputs from an encoding altimeter for altitude reporting. It receives and decodes ATCRBS and DABS interrogations, recognizing discretely-addressed interrogations whose address field corresponds to the address preset into the transponder*. Based upon the type of interrogation, and the contents of the control field in the case of a DABS interrogation, the transponder formats and transmits the appropriate ATCRBS or DABS reply.

For data-link transactions, both standard and ELM, the transponder acts as a modem. Uplink messages, once verified**, are passed on to external display devices. Downlink messages are accepted from external message input devices, encoded by the addition of parity check bits, and transmitted. The transponder does not interpret or modify in any way the contents of such messages.

By keeping most data-link functions external to the transponder, the complexity and cost of the basic transponder have been kept at the minimum required for its surveillance functions. The additional costs associated with the data-link functions are incurred only by users desiring that service.

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* Each DABS transponder must be able to recognize two addresses: the discrete address set into it, corresponding to the aircraft's registration number; and the "all-zeros" address, used in DABS-only all-call interrogations and certain one-way, broadcast transmissions.

** Recognition of its address is implicit verification that the contents of the interrogation were correctly decoded.

All DABS transponders are equipped with the standard message interface, providing outputs to the IPC/PWI display and other standard message input/output devices. Only transponders used in more complex installations, e.g., air carrier aircraft, will have the additional logic and control functions required for accepting and transmitting extended-length messages.

The Pilot Interface - Controls and Indicators

Figure 4-1 depicts the controls and indicators of a DABS transponder as they might be arranged on the front panel of a general aviation transponder. (The same functions would be provided for an air carrier transponder, but as part of a remotely-mounted control head.) All normal ATCRBS controls and indicators are retained, including:

4096 code selector
Ident button
ATCRBS reply indicator
Power switch

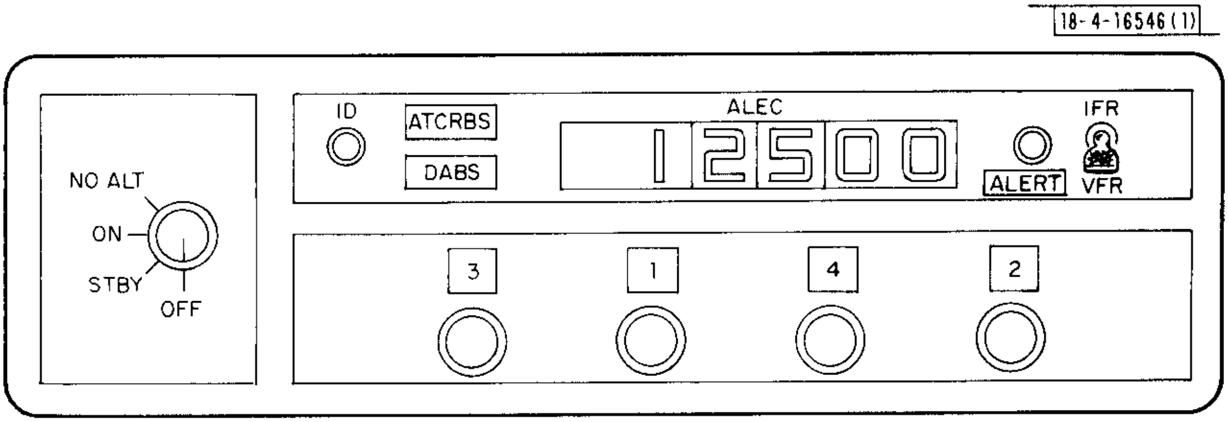


Fig. 4-1. Transponder Panel

In the normal, or "ON", position of the power switch, altitude reports are included in mode C and DABS replies. A "NO ALT" position is included to inhibit altitude reporting in the event of an altitude encoder failure.

The additional controls and indicators included for DABS are:

DABS indicator
ALERT button and indicator
IFR/VFR switch
ALEC display.

The DABS indicator is illuminated whenever the transponder has been discretely interrogated within a fixed time (nominally 16 seconds, corresponding to the period of a few scans of an interrogator antenna), thus indicating that the tranponder is currently on the roll-call of a DABS interrogator.

The ALERT button sets a bit in the next DABS reply which requests the interrogator to read out in a subsequent DABS reply the transponder's 4096 code setting in place of the altitude code. This allows the 4096 code setting to be used for limited air-to-ground communication. The ALERT bit is automatically set whenever the pilot sets a normal emergency code (7600 or 7700) into the 4096 code selector switches.

The ALERT indicator is activated as long as the ALERT bit remains set in the downlink transmissions. Except in the case of a 7600 or 7700 code, the bit is reset and the indicator turned off when the interrogator reads out the 4096 code.

The IFR/VFR switch is set by the pilot to indicate whether the aircraft is operating under instrument or visual flight rules. This information is used by the IPC algorithm in the generation and transmission of conflict resolution commands.

The ALEC (altitude echo) display provides the pilot with a verification of the correctness of the altitude report. For aircraft operating below 18,000 feet the reported altitude is adjusted for local barometric pressure before retransmission to the aircraft, so that the displayed altitude should agree with that indicated by the pilot's altimeter.

Performance Characteristics

The performance characteristics of a DABS transponder are similar to those of an ATCRBS transponder designed for the same class of service. In fact, when operating in the ATCRBS mode (receiving and replying to ATCRBS interrogations), the DABS transponder must conform to all requirements of the relevant ATCRBS transponder TSO. Power output and sensitivity requirements for DABS transponders are as follows:

	General Aviation	Air Carrier	
Power Output	25.5 ± 3	27 ± 3	dBw
Minimum Sensitivity	-72.5	-74	dBm

The 1.5 dB difference between transponders designed for general aviation and air carrier service is in recognition of the greater cableloss in air carrier installations due to generally longer runs between antenna and transponder. It is intended that both types meet the same nominal requirements as measured at the antenna.

Two important performance characteristics peculiar to the DABS transponder are:

(a) The DABS reply delay (the time between the sync phase reversal in the DABS interrogation and the beginning of the reply) is 128 μs. This provides sufficient time for the transfer of the message contents of the interrogation to an external display device before beginning transmission of the reply.

(b) In order to enhance DABS link reliability in the presence of interference from ATCRBS interrogators, the DABS transponder is required to recover its sensitivity rapidly following the receipt of an ATCRBS interrogation to which it does not reply, and to decode DABS interrogations in the presence of interfering pulses whose amplitudes are at least 6 dB below that of the DABS interrogation.

Block Diagram

The principal elements of the DABS transponder, and their interconnection, are depicted in Fig. 4-2. Many elements are similar or identical to the corresponding elements of an ATCRBS transponder. In particular, the RF units, comprising the receiver, transmitter, and modulator, are essentially identical to the corresponding ATCRBS units.

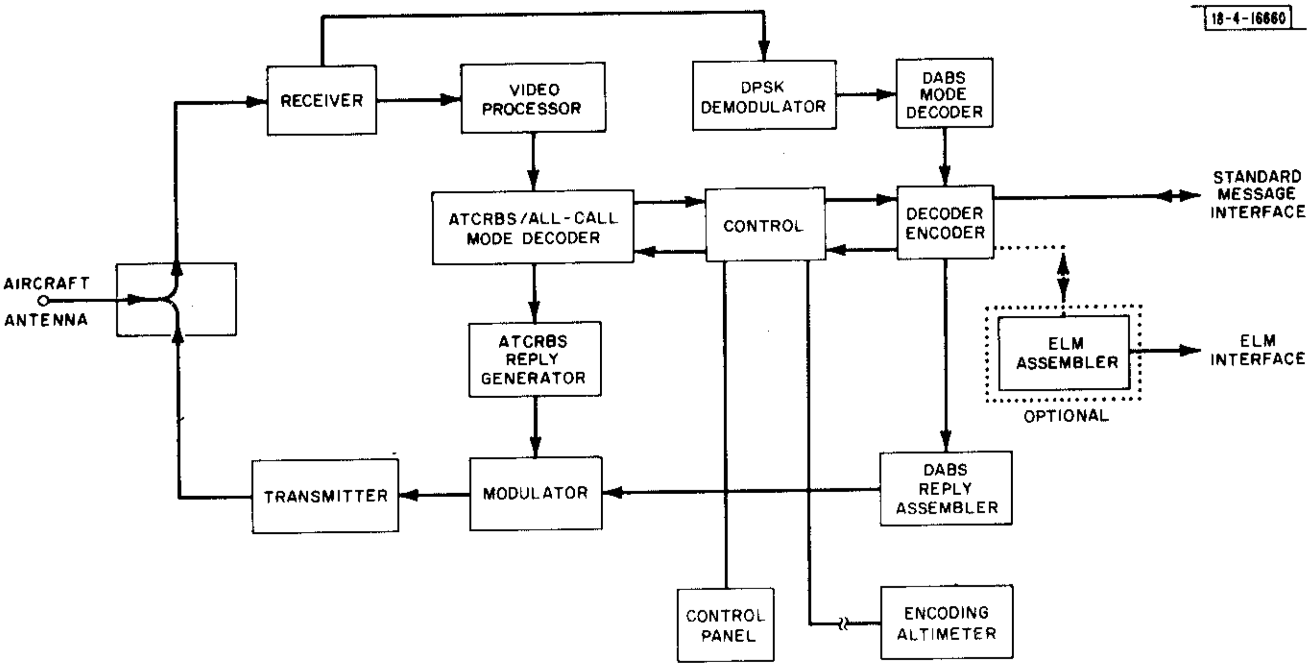


Fig. 4-2. DABS Transponder

Diversity

Many aircraft types exhibit deep nulls in their transponder antenna patterns due to airframe shielding. While these nulls are generally confined to angles above the horizon when the aircraft is in straight and level flight, and thus do not affect the interrogator/transponder link, they can cause serious degradation of the link during other flight attitudes. The effects are particularly severe on large aircraft.

In order to maintain adequate link reliability during aircraft maneuvers, large aircraft (and small aircraft as needed) will be equipped with a diversity transponder. Two antennas located so that at least one is visible in any normal flight attitude, are connected to the transponder. The diversity transponder contains two receivers, selection logic, and a switch to connect the transmitter to either antenna (Fig. 4-3). The selection logic examines the interrogation as received on each antenna, selects the preferred antenna as indicated in Fig. 4-4 and switches the transmission to the preferred antenna for the reply.

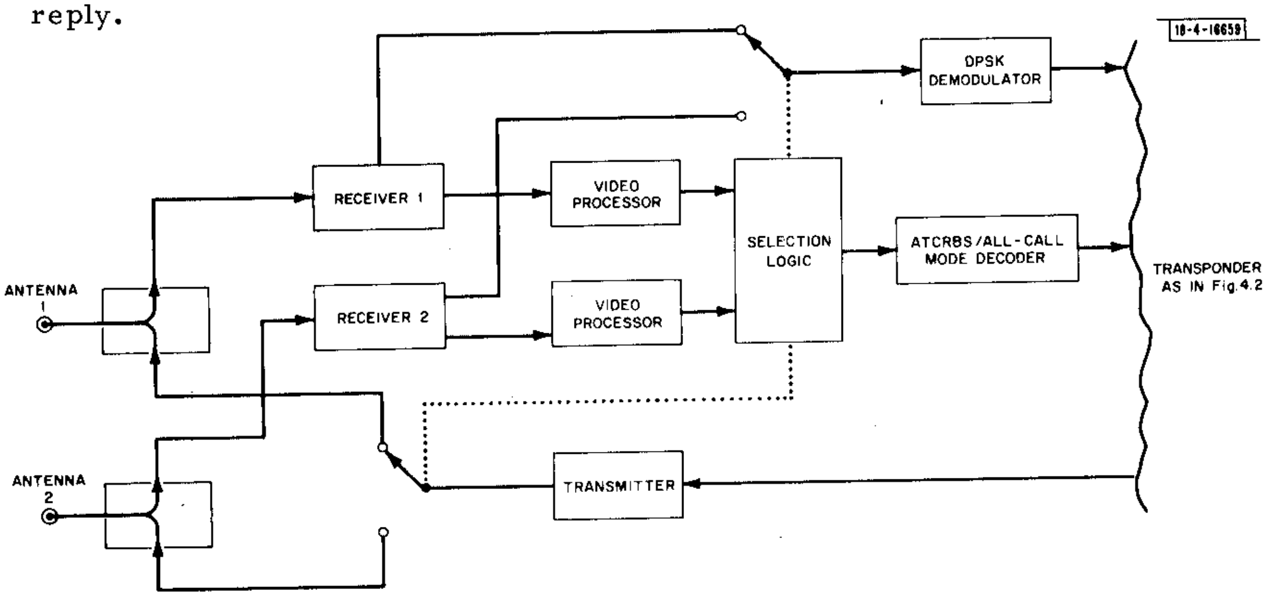


Fig. 4-3. Diversity Transponder

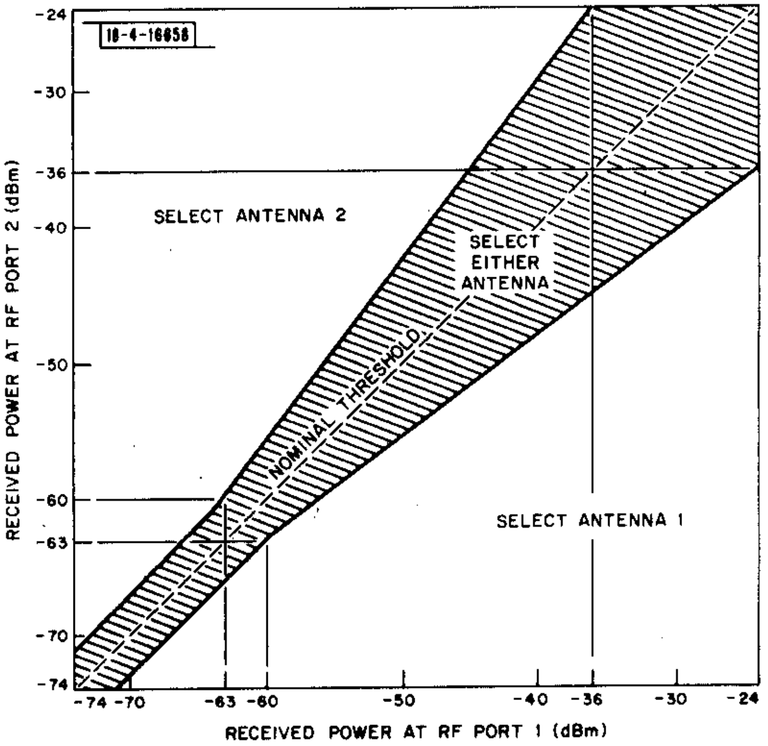


Fig. 4-4.
Diversity Switching Threshold

Data-Link Interfaces

All DABS transponders have the standard message (SM) interface. Higher capability transponders have, in addition, an independent extended-length message (ELM) interface.

The standard message interface consists of a unidirectional clock line and a bidirectional data line (similar to the two-way serial bus used in conventional computer interfaces). The data rate in either direction is 1 Mbps. The data line is a differential, 3-state line, allowing bidirectional party-line operation. Any one of the devices attached to the data line (including the transponder) may drive the line at the appropriate time. The clock line, which is a two-state line since it is driven only by the transponder, allows I/O devices to time their operations so that they extract data from the data line at the proper time and so that they may merge data into the reply data stream at the appropriate time.

Figure 4-5 is a timing diagram for the standard message interface. After the uplink transmission has been verified, the entire uplink message block, including all control fields but excluding the parity field, is transferred out over the interface. This allows flexibility for expansion to additional display and readout functions. Data to be transferred into the interface is synchronized so that it can be merged into the downlink transmission without buffering.

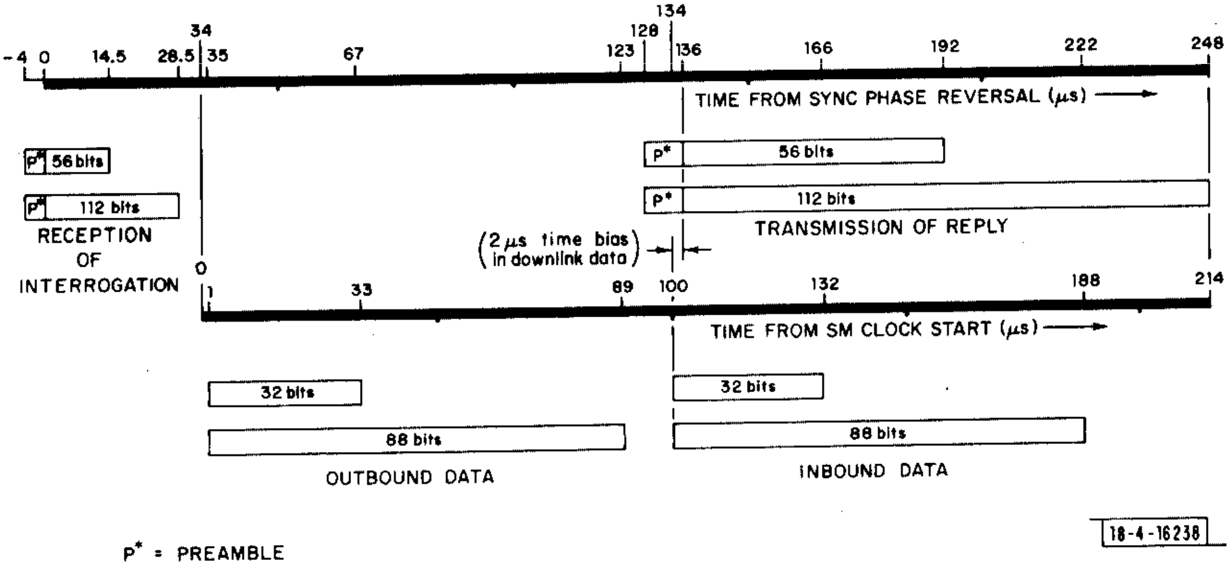


Fig. 4-5. Standard Message Interface Timing Diagram

Extended-Length Message Interface: A transponder equipped for extended-length message operation will be capable of receiving, verifying, storing and acknowledging an uplink ELM transmission. Following receipt of all segments of the ELM (as determined by the protocol described in FAA-RD-74-62[3]), the transponder transfers the entire ELM to an I/O device connected to the ELM interface. This transfer employs an uplink transfer clock line and an uplink data line to shift out serial binary data.

The I/O device also assembles downlink messages for transfer to the transponder. When a message is ready for transmission, the I/O device requests permission to transfer the data to the transponder. As soon as the transponder can accept the data it signals the I/O device and the downlink message is transferred across the interface into the transponder. This transfer is done in a serial manner by means of downlink transfer clock and data lines. The subsequent transfer of the message from the transponder to the interrogator (including partitioning into 80-bit segments for transmission) proceeds without further interaction with the I/O device.

The electrical characteristics of the ELM interface are in accord with EIA Standards[7].

THE IPC/PWI DISPLAY

The IPC/PWI display is used to display to the pilot collision-avoidance information generated by the IPC processor. It consists of three elements: the PWI display, the IPC display, and the acknowledgment and test buttons. A typical display face configuration is illustrated in Fig. 4-6.

The PWI and IPC displays are symbolic indicators. The 36 PWI lights are used to denote high, low, or co-altitude traffic at each of the twelve clock positions. The IPC display includes five X's, denoting "Don't" commands, and four Arrows for "Do" commands. Three pushbuttons permit the pilot to acknowledge or refuse the command, and to request a test transmission. An audible alarm is activated each time the displayed information is changed.

A more elaborate form, the IPC/PWI/ATC display illustrated in Fig. 4-7, includes an ATC section comprising four numeric displays indicating heading, altitude, airspeed, and frequency. These numeric displays would be driven by transmissions originating from air traffic control, and would replace or supplement voice transmissions of the same information.

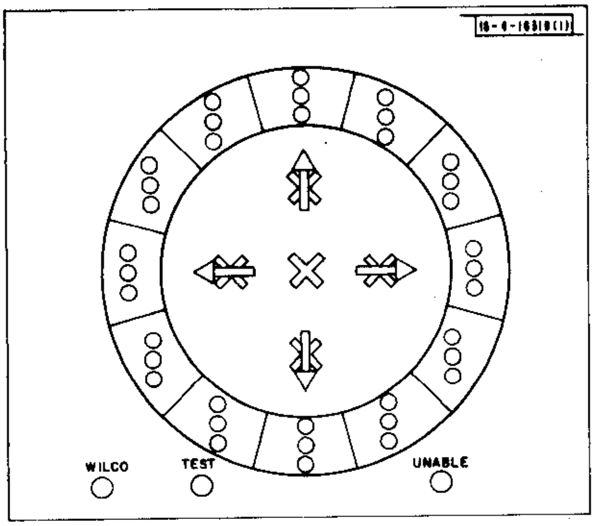


Fig. 4-6. IPC/PWI Display

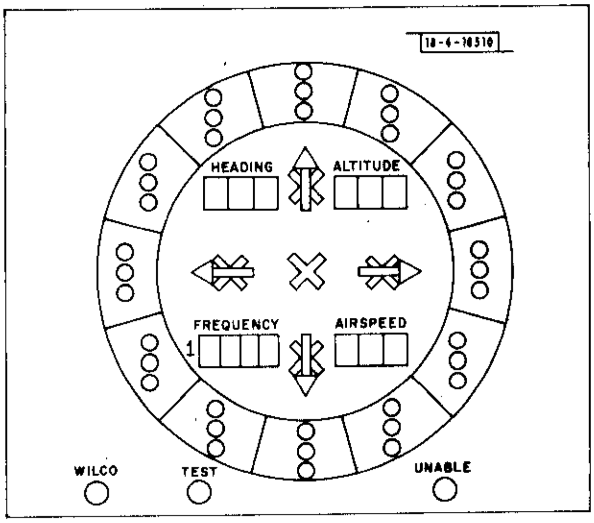


Fig. 4-7. IPC/PWI/ATC Display

THE ATC MESSAGE DISPLAY

The ATC message display, Fig. 4-8, is used to display ATC-generated alphanumeric information to the pilot. It consists of a general-purpose 16-character alphanumeric display and three dedicated numerical display fields (identical in function to three of the fields of the IPC/PWI/ATC display). Also included are acknowledgment buttons, a DISPLAY-CLEAR button, and a DABS contact indicator.

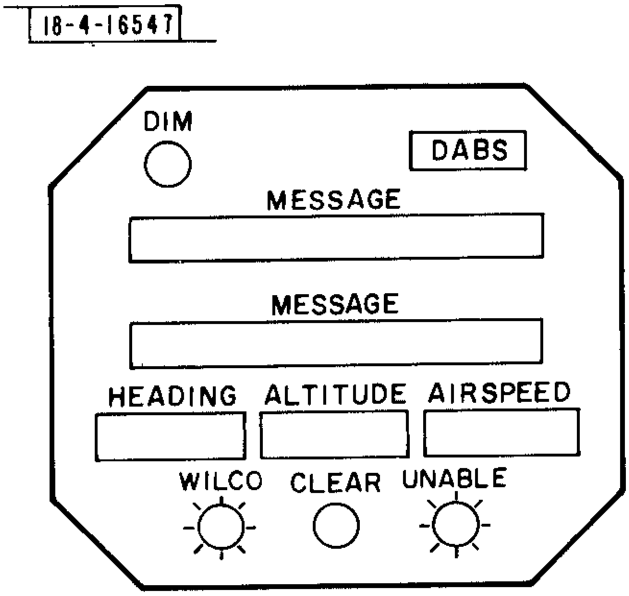


Fig. 4-8.

ATC Message Display

CALL-SIGN INPUT DEVICE

Air carrier and military flights utilize ATC call signs different from the aircraft registration number. For example, air carrier flights use the airline flight number, e.g., TW301. The call-sign input device provides for the transmission of a seven-alphanumeric-character identifier (42 bits). It is set at the beginning of a flight operation, and thereafter can automatically identify the flight to ATC with the same designator used in voice communication.

The presence of the call-sign input device is indicated to the DABS interrogator by a bit set in the capability field of an all-call reply. Upon receipt of that bit, the interrogator reads out the call sign on a subsequent interrogation, and transmits to ATC the association between that call sign and the aircraft's discrete beacon code.

OTHER I/O DEVICES

The SM interface has the capacity to handle a large number of input or output devices. If desired, duplicate displays may be driven by the interface. In addition to the IPC/PWI and ATC message displays described above, other displays are possible, including, for example, an area navigation display showing deviation from course and distance to waypoint. Possible input devices include encoders for air-derived data such as heading and airspeed or MLS input.

The ELM interface is designed to interface only to a single external terminal. If more than one input terminal is to be accommodated by the ELM port, or if multiple independent output devices are to be driven, an external control and multiplex unit must be used to route incoming and outgoing messages to the proper destinations and to handle queues and priorities. Figure 4-9 is an artist's conception of an air carrier transponder with a possible complement of I/O devices on the SM line and a teletype terminal on the ELM line.

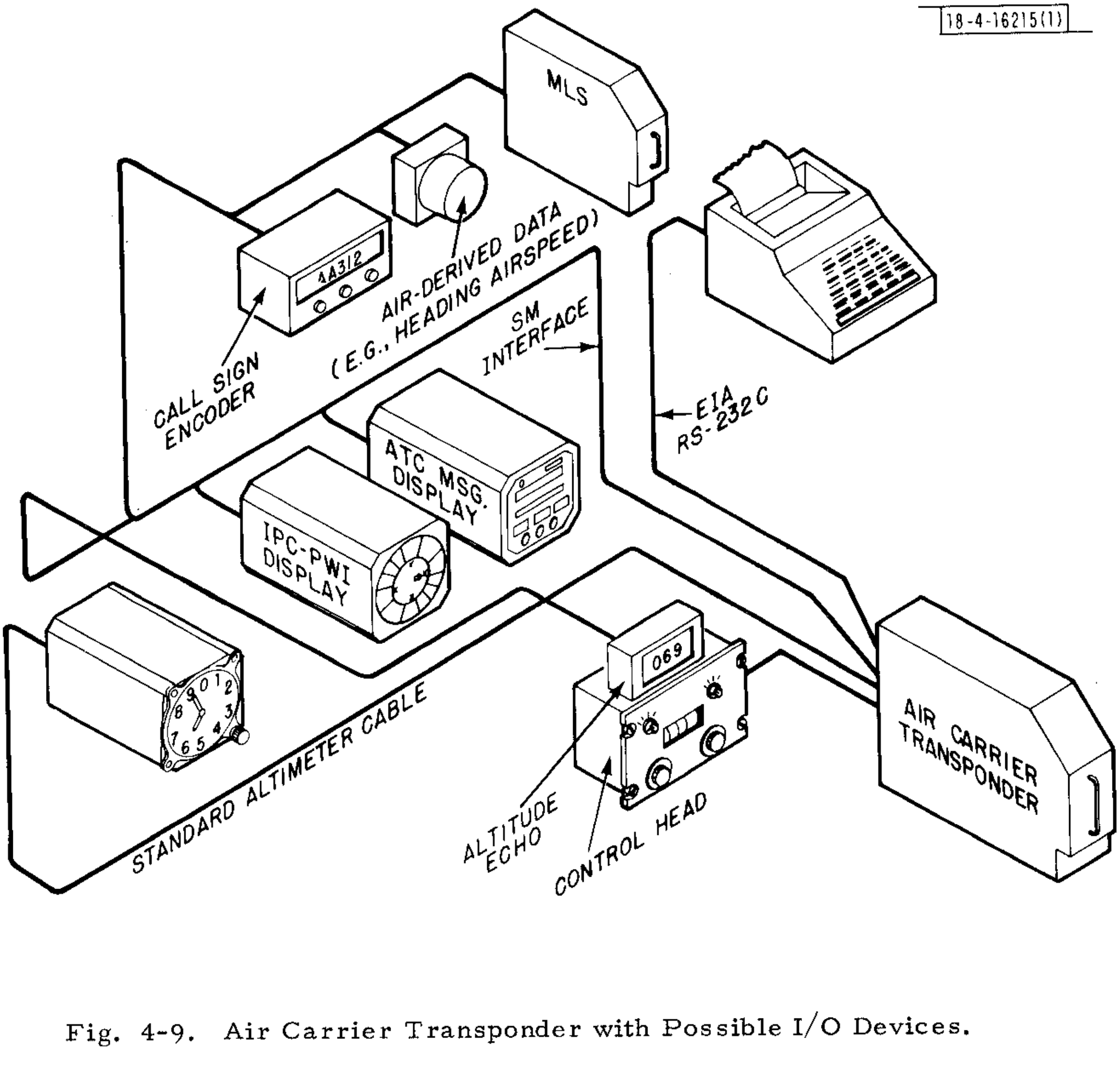


Fig. 4-9. Air Carrier Transponder with Possible I/O Devices.

CHAPTER 5

PERFORMANCE

To adequately support an increasingly automated air traffic control system, DABS must provide reliable and accurate surveillance and data-link communication for large numbers of aircraft. This chapter summarizes results on three particularly important aspects of DABS performance: link reliability in the presence of interference and fading; the azimuth measurement accuracy achievable with off-boresight monopulse; and the target capacity of a sensor using roll-call interrogation.

LINK RELIABILITY

The term link reliability is used to denote the probability of a successful link transaction such as a surveillance update or delivery of a data-link message. Limitations on link reliability are primarily due to interference and fading. This section summarizes these effects, illustrating the link reliability achievable under various typical conditions.

Link Power Budget

Table 5-1 gives DABS link power budgets for an aircraft at 50 nmi range and 0.5° elevation angle, and using a typical interrogator antenna (an ASR with integral beacon feed). Two uplink power modes are shown. Most interrogations are transmitted at low power to minimize uplink interference. In the high power mode the uplink and downlink have equal fade allowance.

TABLE 5-1. DABS LINK POWER BUDGET

PARAMETER		UPLINK		DOWNLINK
		HIGH POWER MODE	LOW POWER MODE	
Transmitter Power		800 W	100 W	500 W
Coupling Loss, Sensor to Antenna		-1.5 dB		
Coupling Loss, Transponder to Antenna		-3 dB		
Ground Antenna Gain	Peak	26 dB		
	Elevation Factor	-5 dB		
Aircraft Antenna Gain (nom)		0 dB		
Path Loss		-132.5 dB		
Received Power		-57 dBm	-66 dBm	-59 dBm
Required Received Power		-77 dBm	-77 dBm	-79 dBm
Fade Allowance		20 dB	11 dB	20 dB

Interrogator Antenna Lobing

The character and magnitude of ground-reflection-induced vertical lobing for interrogator antennas having different rates of lower-edge cutoff are illustrated in Fig. 5-1. Vertical lobing depends on, among other things, the extent of flat ground in the vicinity of the antenna; the case represented in Fig. 5-1 is moderately severe in this respect, although not unusual. Oscillatory behavior of the pattern is evident, with the worst fades occurring at about 1° in elevation. Moderate changes in antenna height will shift the frequency of this oscillation within approximately the same envelope. The smaller null-depth of an antenna having a vertical pattern with sharp lower-edge cutoff is evident[8, 12].

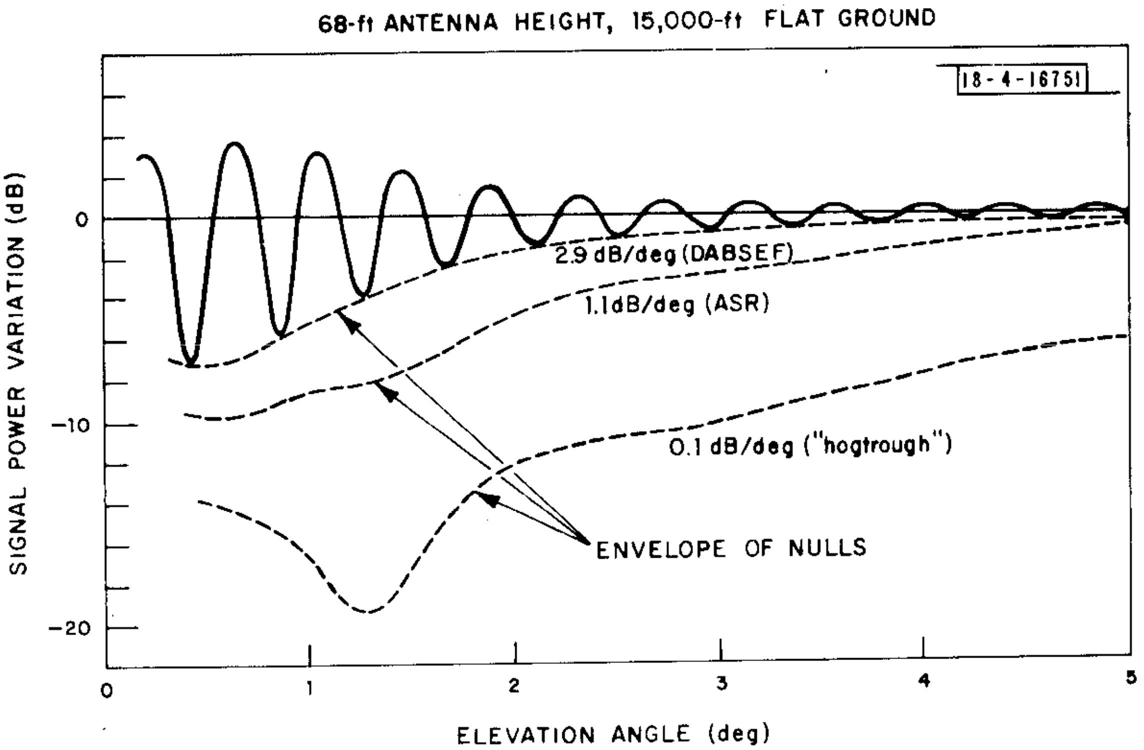


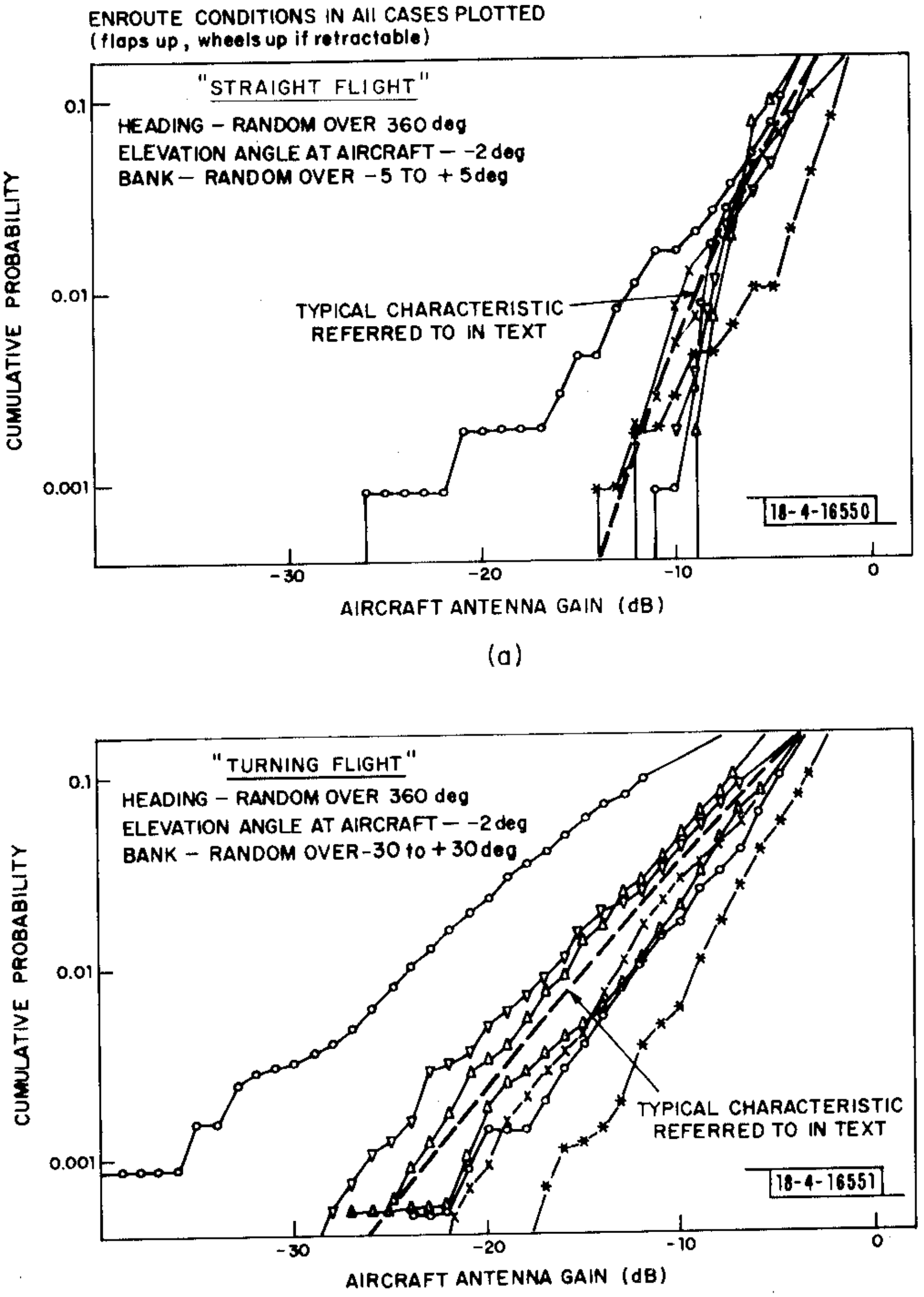
Fig. 5-1 Vertical Lobing

Aircraft Antenna Fading

Aircraft antenna fading is illustrated in Fig. 5-2, based on scale model measurements[9]. Each curve shows the probability of fade greater than a given magnitude for a particular type aircraft in straight and level flight (Fig. 5-2a), and in turning flight (Fig. 5-2b). It is evident that: (1) there are substantial differences between various aircraft types, and (2), if one is interested in events which occur as rarely as 1% of the time for turning aircraft, then aircraft antenna fades as deep as 24 dB must be considered. (These results, of course, are without aircraft antenna diversity.)

Interference Effects

Interference effects on link reliability are illustrated in Fig. 5-3, which shows miss probability versus received signal power level with and



(a)

(b)

Fig. 5-2. Aircraft Antenna Fading.

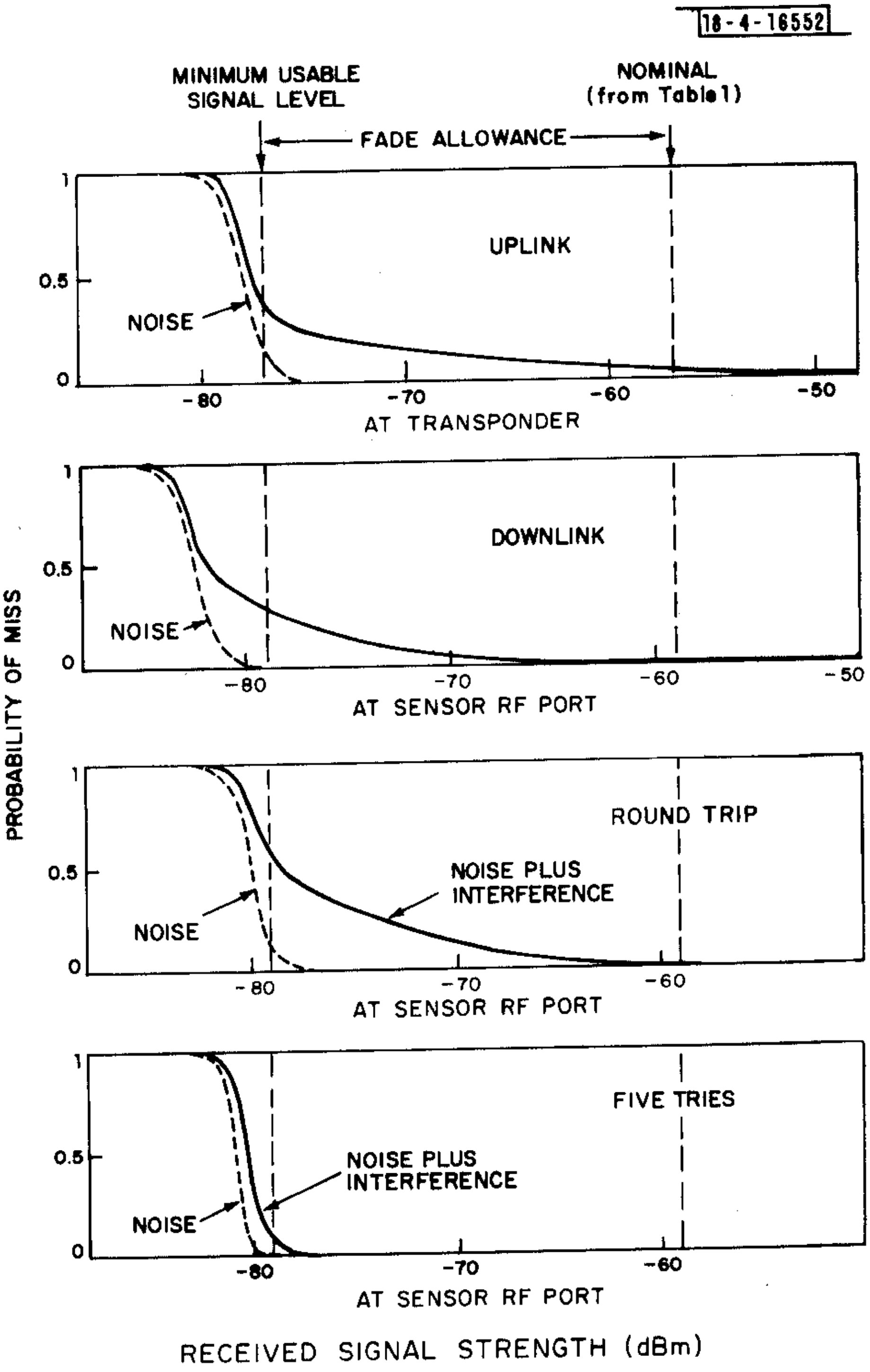


Fig. 5-3. Miss Probability.

without interference. A heavy ATCRBS interference environment is assumed, representative of the interrogator and traffic densities predicted for the Northeast Corridor in the 1980-1985 time period.

At nominal received power levels, the round-trip miss probability due to interference is a few percent. However, link fades, when they occur, cause power to drop and miss probability to rise substantially, For example, when received power drops to a few dB above the "minimum usable signal level", roundtrip miss probability increases to about 40% (the bulk of this increase being due to the large amount of interference which exceeds a signal of this amplitude).

Since to a good approximation the occurrence of interference is independent from one try to the next, the ability to make multiple attempts in the event of a miss (adaptive reinterrogation) can substantially reduce its effect. The residual miss probability for a maximum of five tries is shown in Fig. 5-3. The miss probability with interference is now approximately the same as without, i.e., with noise alone. With adaptive reinterrogation, therefore, link reliability is determined by fade statistics rather than interference statistics; to a good approximation, the link reliability is the probability that fading is no worse than the link margin[10, 11].

Net Link Reliability

Combining fade statistics with the available link margin leads to an estimate of link reliability in various cases. For example, allowing 5 dB of the 20 dB link margin given in Table 5-1 for interrogator antenna effects, the "typical" aircraft antenna characteristics of Fig. 5-2 result in a link reliability of:

>0.999 for straight flight, and
0.99 for turning flight.

Extending these results to other points in the airspace leads to the performance contours plotted in Fig. 5-4. Obviously, performance degrades at longer ranges, but a useful level is maintained out to 200 nmi. It is also clear that link reliability is significantly worse for turning than for straight-flying aircraft.

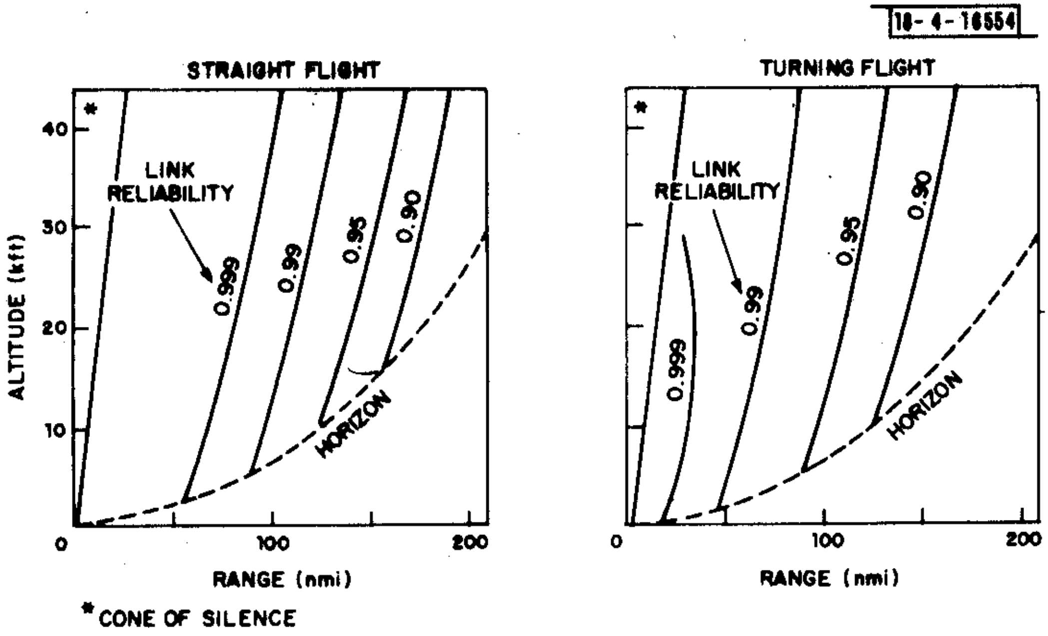


Fig. 5-4 Link Reliability Contours

In summary, reliable link operation is possible in a severe interference environment--the level of reliability being set primarily by fade statistics. The resulting performance depends on the location of the aircraft and on whether or not the aircraft is maneuvering.

MONOPULSE PERFORMANCE

As described in Chapter 3, the monopulse receiver-processor makes an estimate of the off-boresight angle for each received pulse of the ATCRBS or DABS reply, and then combines the individual measurements to provide a single estimate for the whole reply.

The four major sources of error in the monopulse estimate are:

(a) receiver noise,
(b) processor inaccuracy,
(c) variation with elevation angle, and
(d) multipath and interference.

Receiver Noise

The effect of receiver noise on rms azimuth error is illustrated in Fig. 5-5 for an interrogator antenna having a Δ/Σ beamwidth of 4°, i.e., $\Delta/\Sigma = 1$ at $\pm 2^{\circ}$ off-boresight. For pulse signal-to-noise ratio (SNR) as low as 20 dB, a few dB above the operating threshold of the interrogator receiver, the rms azimuth error on each pulse is less than 0.2°. Averaging over N pulses in a DABS reply, or in one or more ATCRBS replies from the same target, will reduce the noise-induced rms error of the overall measurement by $\sqrt{N}$. Note that the azimuth error for a given signal-to-noise ratio increases relatively slowly with off-boresight angle out to $\Delta/\Sigma = 1$, more rapidly for larger off-boresight angles.

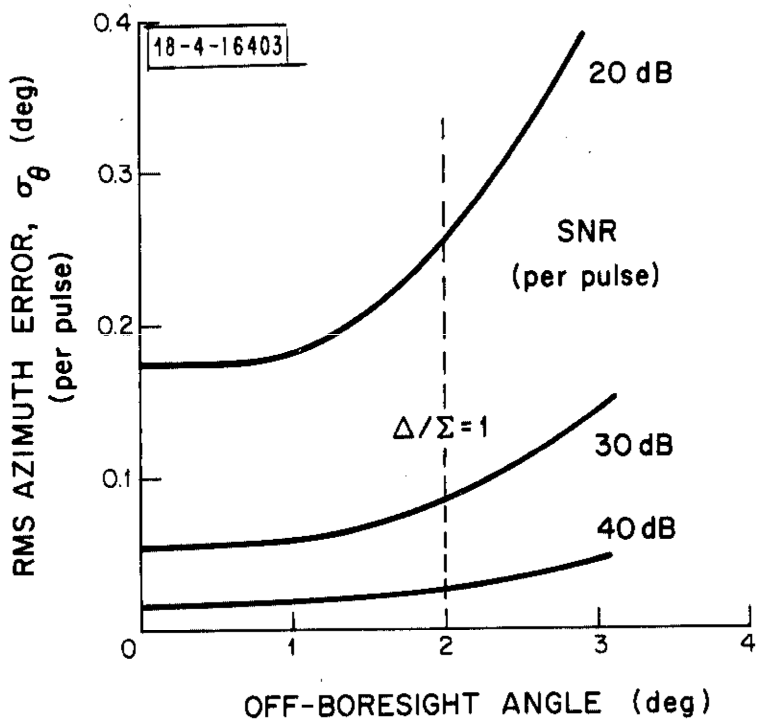


Fig. 5-5.
Noise Induced
Monopulse Error

Processor Inaccuracy

The monopulse receiver-processor must operate over approximately a 60-dB input signal range and must accommodate a ± 3 MHz variation in the center frequency of replies. While the processor can be precisely calibrated, and this calibration maintained by closed-loop techniques, for any one operating point (signal amplitude and frequency), some variation in off-boresight estimate will occur as the parameters of the received signals deviate from this calibration point. As in the case of receiver noise, the errors due to these effects increase with off-boresight angle, gradually out to $\Delta/\Sigma = 1$, and more rapidly thereafter. With careful design, practical monopulse processors can be realized which exhibit processor-induced errors substantially less than 1/40 beamwidth (0.1° for a 4° beamwidth) averaged over the range of expected received signal amplitude and frequency.

Variation with Elevation Angle

The monopulse receiver-processor measure Δ/Σ and translates this into an estimate of the off-boresight angle according to a prestored calibration curve for the antenna. The calibration curve is strictly valid only at the elevation angle at which it was measured, typically one or two degrees above the horizon. For targets at relatively high elevation angles (15° and above), a change in the slope of Δ/Σ versus off-boresight angle can cause significant errors in the off-boresight angle measurement for targets near the beam edge. However, since such high elevation angles can occur only for relatively short-range targets, the resulting cross-range error is small. Thus, it does not appear necessary to compensate measurements on such targets for the measurement error resulting from their high elevation angle.

Multipath and Interference

Interfering signals overlaying the pulses in the desired reply can cause significant error in the monopulse estimate even if their amplitude is substantially less than that of the reply. Such interference may arise from replies, generated by other transponders, which are received in the mainlobe or sidelobes of the interrogator antenna, or from the desired signal arriving by one or more alternate paths.

The most important multipath effect is reflections from the terrain between the interrogator and transponder. If this terrain is essentially flat, it will not affect the apparent angle-of-arrival of the signal but can affect its amplitude. A reduction in received amplitude due to an apparent null can lead to an increased error in the monopulse estimate due to other causes -- for example, receiver noise.

If the terrain causing the reflection is tilted, the composite signal arriving at the interrogator antenna will appear to come from a different direction than the actual target azimuth. In this case, the azimuth estimate will depend on the relative amplitude and phase of the multipath signal, as shown in Fig. 5-6 for the case of a target on-boresight and the reflector (interference) a half beamwidth off-boresight. For a given amplitude of interference, the error is largest when the reflected (interference) signal is out-of-phase with the direct signal. For this worst case of out-of-phase interference, the error as a function of the relative azimuth of the interference is shown in Fig. 5-7 for an interference/target amplitude ratio of 0.5. Errors from multipath are minimized by narrowing the azimuth beamwidth of the interrogator antenna and sharpening the lower edge of the antenna beam, thereby minimizing the amplitude of the signals received from the terrain reflections.

The magnitude and frequency of occurrence of reflection-induced errors are highly site-dependent. Particularly troublesome sites may require resiting of the antenna and/or special antenna configurations to provide adequate performance. (Note that the magnitude of reflection-induced errors using monopulse direction finding is comparable to those of the sliding-window detector/estimator used in current ATCRBS interrogators.[13])

Overlapping signals from other transponders (fruit) produce single-pulse azimuth errors similar to those caused by multipath. Large interfering signals will cause correspondingly large errors in the azimuth estimate. However, unlike multipath interference, fruit interference will be incoherent from pulse-to-pulse, and in general will not affect all pulses of a reply. The main protection against such interference is to sense its presence (the confidence flag) and eliminate that particular measurement from the computation of the azimuth estimate for the reply. The relatively small errors caused by weak interference can be treated as additional receiver noise, and averaged out over a sequence of received pulses.

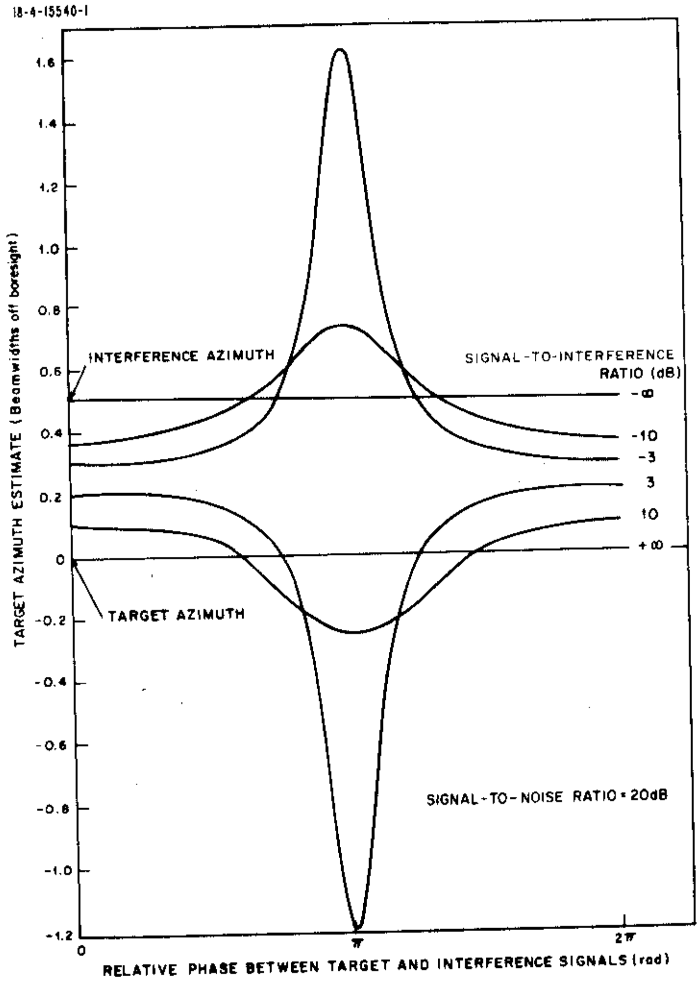


Fig. 5-6.

Monopulse Estimate
With Interference.

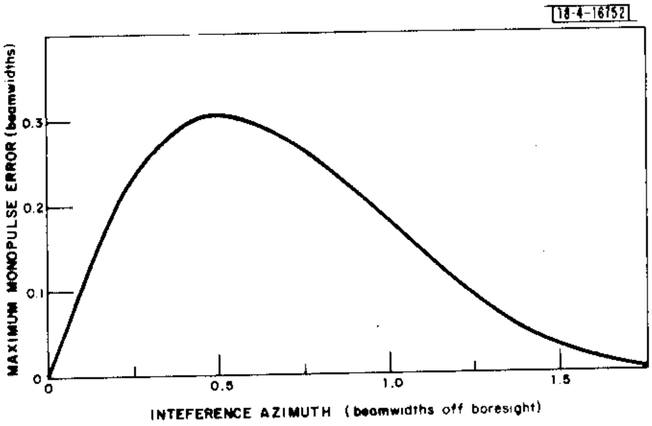


Fig. 5-7.

Maximum Monopulse Error
With Target On Boresight.

CAPACITY

The capacity of a DABS sensor is most generally defined as the number of aircraft to which a sensor can provide discrete-address surveillance and data-link service. With this broad definition, capacity depends not only on the sensor operating characteristics, but also on the number of interrogations needed for each aircraft and the azimuth distribution, or bunching, of aircraft around the sensor.

A simpler definition of capacity, and one providing a more easily interpreted point of reference, is the number of transactions (interrogation/reply pairs) a sensor can make per degree of azimuth. Using this definition, analysis and simulation of the DABS interrogation scheduling algorithm have led to the following expression for capacity in terms of the sensor operating parameters:

$$n \approx 18.5 \left[T - 360 \frac{N_a}{\theta} (2R/c + t_a) \right]$$

where:

n = number of transactions per degree
R = operating range
T = interrogator antenna scan period
θ = interrogator antenna beamwidth
N_a = number of ATCRBS interrogations per beamwidth
t_a = ATCRBS listening period
c = speed of light

Figure 5-8 presents plots of capacity vs interrogator antenna beamwidth for various values of operating range. Typical values are used for scan time (4 seconds) and ATCRBS interrogations per beamwidth (four). Except on the longest (200 mi) range, the ATCRBS listening interval was set at 2 ms to allow time for ATCRBS replies from distant targets (outside the operating range) to ring out before the beginning of the DABS period.

The very large capacity of the DABS sensor is evident from these curves. For anticipated interrogator antenna beamwidths (2.4° - 4°) and operating range, the channel can accommodate more than 40 calls per degree, a number fully sufficient to accommodate expected sensor loading, including effects of azimuth bunching and multiple interrogations to each aircraft.

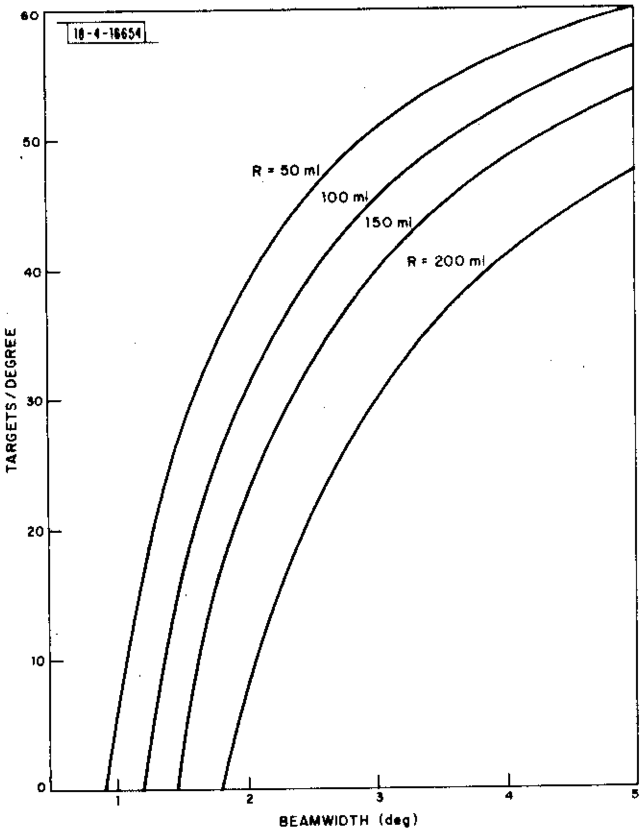


Fig. 5-8. Capacity plots.

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[12] Ibid, pp. 5-9

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DOCUMENTATION

LIST OF DABS DOCUMENTS ISSUED BY LINCOLN LABORATORY

(Available from National Technical Information Service, Springfield, Virginia 22151)

Quarterly Technical Summaries

FAA-RD-72-44	QTS 1	1 April 1972	Development of a Discrete Address Beacon System
FAA-RD-72-76	QTS 2	1 July 1972	Development of a Discrete Address Beacon System
FAA-RD-72-117	QTS 3	1 October 1972	Development of a Discrete Address Beacon System
FAA-RD-73-48	QTS 4	1 April 1973	Development of a Discrete Address Beacon System
FAA-RD-73-101	QTS 6	1 July 1973	Development of a Discrete Address Beacon System
FAA-RD-73-165	QTS 7	1 October 1973	Development of a Discrete Address Beacon System
FAA-RD-74-8	QTS 8	1 January 1974	Development of a Discrete Address Beacon System
FAA-RD-74-85	QTS 9	1 April 1974	Development of a Discrete Address Beacon System
FAA-RD-74-136	QTS 10	1 July 1974	Development of a Discrete Address Beacon System
FAA-RD-74-167	QTS 11	1 October 1974	Development of a Discrete Address Beacon System

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FAA-RD-72-7	ATC-8	24 January 1972	Interrogation Scheduling for the Discrete Address Beacon System	E. J. Kelly
FAA-RD-72-30	ATC-9	12 April 1972	Final Report, Transponder Test Program	G. V. Colby E. A. Crocker
FAA-RD-72-84	ATC-12	14 August 1972	A Comparison of Immunity to Garbling for Three Candidate Modulation Schemes for DABS	D. A. Shnidman
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FAA-RD-73-126	ATC-19	17 October 1973	Interrogation Scheduling Algorithms for a Discrete Address Beacon System	A. Spiridon A. D. Kaminsky
FAA-RD-74-4	ATC-20	28 January 1974	The Effects of ATCRBS P_2 Pulses on DABS Reliability	W. A. Harman D. A. Shnidman
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FAA-RD-74-5	ATC-31	13 February 1974	Report on DABS/ATCRBS Field Testing Program	J. R. Samson, Jr. E. A. Crocker
FAA-RD-74-21	ATC-32	4 February 1974	The Effect of Phase Error on the DPSK Receiver Performance	D. A. Shnidman
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FAA-RD-74-144	ATC-37	To be published.	An Analysis of Airborne L-Band Beacon Antenna Patterns	G. J. Schlieckert
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FAA-RD-74-186	ATC-41	To be published.	DABS Single-Sensor Link	G. J. Schlieckert
FAA-RD-74-197	ATC-43	To be published.	DABS Channel Management	E. J. Kelly

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1973-7	9 February 1973	A Maximum-Likelihood Multiple-Hypothesis Testing Algorithm, with an Application to Monopulse Data Editing	E. J. Kelly
1973-48	26 September 1973	An Optimum Interference Detector for DABS Monopulse Data Editing	R. J. McAulay T. P. McGarty
1973-44	18 December 1973	Azimuth-Elevation Estimation Performance of a Spatially Dispersive Channel	T. P. McGarty

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1974-12	12 March 1974	False Target Elimination at Albuquerque Using ARTS-III Software	A. G. Cameron