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THE FAA CONCEPT FOR A BEACON COLLISION AVOIDANCE SYSTEM (BCAS).--ETC(U)
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CONCEPT DESCRIPTION

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16. Abstract

A unique airborne aircraft collision avoidance system concept is presented which assures adequate separation from the largest possible percentage of potential collision threats. The concept operates in all airspace as a compatible backup to the present and evolving ATC system, and is acceptable to the pilot and the user community. The system concept capitalizes on the aviation community's large existing investment in ATCRBS transponders and on the ground based beacon surveillance system network for the basic sources of the collision avoidance information.

The report is contained in three volumes; an Executive Summary (I), Concept Description (II) and Appendices (III).

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1. INTRODUCTION

The major function of any Beacon Collision Avoidance System (BCAS) is to provide adequate protection against aircraft colisions. Collision statistics show that roughly 33% of collisions occur within radar coverage, 29% of which are in terminal airspace and the remaining 4% in enroute airspace. 57% occur outside of radar coverage, with 54% at uncontrolled airports and 3% in enroute airspace. The remaining 10% are considered unpreventable since they involve intentional close proximity flying. These statistics clearly illustrate that BCAS must perform everywhere. It must perform in high and low density terminal and enroute airspace both in and out of radar coverage. In addition, it must provide protection against the largest percentage of aircraft feasible.

One of the major operational requirements for any CAS is that it must be compatible with the present and evolving ATC system. Safe operation of the Air Traffic Control (ATC) system cannot be compromised and no significant technical or operational interference to ATC can be tolerated. Based on this requirement, it becomes clear that BCAS must:

o Be compatible with

Air Traffic Control Radar Beacon System (ATCRBS)

Discrete Address Beacon System (DABS)

Automatic Traffic Advisory & Resolution Service (ATARS)

Air Traffic Control (ATC)

o Function during transition from

ATCRBS to DABS

o Interface and coordinate with

ATC

ATARS

A final constraint on BCAS is that it must be acceptable to the pilot as well as compatible with ATC. This means that BCAS must be capable of providing safe separation while maintaining a false alarm rate which is equivalent to or lower than ATARS and conflict alert.

Given these major requirements, it will be shown that no simple CAS system can satisfy all requirements simultaneously.

1.1 CONTENT OF THE REPORT

This report presents a BCAS concept which, although not simple, will satisfy the major system requirements and design constraints presented.

Rationale supporting the major design decisions is presented where appropriate. The level of design detail presented is considered adequate to guide the development of an engineering model of a BCAS which will satisfy the system and performance requirements. The supporting analyses which have led to the design presented herein are included as appendices to this report including simulation data and program listings. Performance characteristics of the BCAS concept have been qualified and operating modes of BCAS are described as a function of the operational environment.

This report is divided into two volumes. Volume I presents a description of the concept. Section 2 of Volume I presents the system requirements that BCAS must meet. How BCAS works is the subject of Section 3 while the elements of the BCAS Avionics are detailed in Section 4. The design of the ground-based radar beacon transponder is provided in Section 5. Section 6 discusses the BCAS air-to-air data link and Section 7 presents a summary of the BCAS environment and performance characteristics.

Although a great deal of work has been accomplished, there still is work required to complete an analytic proof-of-concept. A description of such work is given in Section 8. The last Section of Volume I is a listing of the references.

Volume II provides the appendices which document the analyses that have been performed to support the development of the BCAS concept.

2. SYSTEM REQUIREMENTS

2.1 Performance Requirements

BCAS performance can be measured by its ability to provide adequate separation from collision threats while maintaining a low false alarm rate. It must provide this capability against the largest percentage of aircraft possible. As a result, it is required that BCAS provide PWI protection against all aircraft including aircraft equipped with Mode A only, and, in addition, provide threat detection and resolution against all altitude encoding transponder equipped aircraft and future DABS equipped aircraft, including other aircraft equipped with BCAS.

2.1.1 Minimum Allowable Separation Criteria

It is required that BCAS provide adequate warning time and a resolution maneuver to the pilot which it executed by the pilot, will result in separation from the threat aircraft of at least 1000 ft. horizontally and $\pm$ 200 ft. vertically. This separation must be achieved even under conditions of maximum error in surveillance. PWI information must be provided to assist the pilot in sighting the threatening aircraft. It is of particular importance in the case of turning encounters where it becomes the only means for providing the desired level of protection.

The criteria of 1000 ft. horizontal separation and 200 ft. vertical are based on the extensive flight tests of IPC (9) and on extensive simulations (10) of IPC performance. These criteria have been used as the basis for the various BCAS modes developed for the concept. The details of mode selection are presented in Appendix B. The accuracy analysis used to evaluate the modes of BCAS operation is presented in Appendix E.

2.1.2 Missed Alarms

Any CAS which does not detect collision threats violates the requirement to provide adequate separation. Many conditions however may cause missed alarms. Among these are antenna shielding, garble and fruit. These factors significantly affect the the ability of BCAS to track aircraft which is critical to performing the threat detection function. Flight tests has shown that even with top and bottom antennas on a BCAS aircraft, roughly 25% of the targets will be undetected by BCAS primarily due to antenna shielding by the other aircraft. Garble and fruit also seriously affect the ability to track aircraft in high aircraft density environments. Current technology has demonstrated the feasibility of degarbling up to 8 overlapping replies but garble studies have indicated that substantially higher garble levels exist in high density airspace. Such BCAS features as directional antennas, whisper/shout and passive tracking help to solve this problem but there exists the probability of garble saturation in high density airspace under certain conditions. Details of the garble problems are discussed in Appendix A.

Another major problem associated with missed alarms occurs when an unequipped aircraft turns from a close proximity parallel path into an equipped aircraft. Simulations show that any CAS will fail to provide adequate separation in more than 90% of these cases. As a result, the only possible protection which can be provided in this case is a PWI alert.

The requirements concerning missed alarm can be summarized as follows:

No missed alarms shall be allowed when a BCAS has established track on an intruder aircraft. Resolution commands shall be provided in adequate time to provide the required separation against each tracked target equipped with altitude encoders and ATCRBS or DABS transponders. PWI shall be provided against all targets which are equipped with a transponder, even though it has no altitude encoding provisions. The pilot display will show three flashing lights in the correct 30° sector for a Mode A target. Additionally, it will show one of these three lights in the 30° sector for a Mode C altitude encoded target, indicating to the pilot whether the target is above, below or at the same altitude as the BCAS aircraft.

In the case of a close proximity parallel turn to collision, flashing PWI shall be the minimum protection provided since there is no tracker that can react quickly enough to a target's turn when he has been flying parallel and close. Note that PWI in this design includes bearing information.

The BCAS shall establish and maintain track on all potential threat aircraft having at least an ATCRBA transponder if the signal levels from the transponder are usable (not shielded). The system is to operate satifactorily in the 1985 Lax garble environment 90% of the time. BCAS will not see 20 to 25% of the targets because of target antenna shielding problems. These problems arise when targets fly below a BCAS aircraft so that the target's airframe shilds it's bottom mounted ATCRBS antenna.

2.2 Operational Constraints

2.2.1 Compatibility

BCAS must have the capability of operating in an all ATCRBS environment, an all DABS environment and a mixed

DABS/ATCRBS environment. This includes compatibility with both ground and air environments. Further, BCAS shall not significantly interfere technically or operationally with the ATC system. This means that no significant interference with the existing or planed surveillance or communications systems shall be tolerated and that BCAS must coordinate with ATC its functions, such as conflict alert, when commands are planned or given by BCAS to controlled aircraft and in (the future) ATARS when commands are planned or by BCAS to any aircraft. In areas where ATARS is not implemented and where BCAS operation is shown to significantly interfere with ATC operation, ATC shall have the capability of desensitizing BCAS automatically and BCAS shall display this information to the pilot.

2.2.2 Ground/Aircraft Density

BCAS shall be capable of operating everywhere. The most dense traffic area anticipated is (see Appendix C) the LA Basin traffic model for 1985. The ground radar environment is detailed in Appendix D for CONUS as well as the top 60 hubs. Estimated aircraft densities for these hubs are also presented in Appendix D and it should be noted that density peaking factors of 3 or 4 to 1 are expected at certain locations in these hubs.

BCAS shall also operate in areas where no ground radars are available and shall satisfy the PWI requirements including bearing information under these conditions.

2.2.3 False Alarms

False Alarms are defined as commands which are given to avoid a collision when no collision threat exists. These can arise from issuing commands against phantom (false) tracks or against real targets which pose no threat, i.e., they will clear the BCAS equipped aircraft with sufficient separation. BCAS shall not issue a false alarm against any track which in reality will pass clear of BCAS by 1 nm horizontally or 500 ft. vertically. This is an important requirement for BCAS since it affects the ultimate acceptance of the system by pilots and controllers.

2.2.4 Mutual Interference

One of the basic problems which can degrade passive mode BCAS performance is the inability of BCAS to transmit 1090 uHz replies to 1030 uHz ground interrogations and simultaneously receive or listen for 1090 uHz replies of other aircraft. BCAS should not intentionally suppress 1090 uHz replies to 1030 uHz ground interrogations to alleviate or overcome this problem.

2.2.5 Airspace

As previously stated, BCAS should operate in all airspace and should not interfere with the ATC system. To satisfy these requirements, BCAS will operate passively wherever possible but must have the capability of providing semi-active and full active capability where passive operation is not feasible. The details of the operational modes of BCAS are presented in Appendix B.

2.3 Interface and Coordination Requirements

It has been stated that BCAS must interface with ATC and ATARS. In addition, in order to meet functional requirements, BCAS must also interface with air data systems, with the pilot via an appropriate display, and with other BCAS aircraft. These interface requirements are discussed as follows.

2.3.1 ATC

ATC is the primary separation service provided to all controlled aircraft. BCAS is a backup to ATC and shall not interfere with the safe operation of the ATC system (which includes ATARS). In airspace where ATC and atars separation service is not available, BCAS shall be the primary aid to the pilot's mission to see and avoid other aircraft. In order to satisfy these requirements BCAS must be capable of communicating with ATC. The DABS data-link shall provide this communication. In cases where no DBS ground site exists, a radar beacon transponder with DABS data link (RBX) located at ATCRBS sites will provide this communication link. BCAS shall provide adequate warning of an impending avoidance command to the controller for conflict alert integration.

2.3.2 ATARS

ATARS is planned as a ground based collision avoidance backup to the ATC system. In airspace where ATARS service is provided, ATARS will take precedence over BCAS. The one exception is the situation in which a BCAS command is issued for a target transitioning from a non-ATARS coverage region into an ATARS coverage region. For such targets BCAS will take precedence. The details of this logical interface, which is accomplished using the DABS data link, are described in Appendix L.

2.3.3 Pilot Interface

The primary interface with the pilot will be a common BCAS/ATARS display which shall contain the ability to provide the pilot with avoidance commands, PWI information including bearing and altitude, BCAS status (e.g., saturated, unsaturated or desensitized) and service being provided (e.g., BCAS/ATARS or both).

In addition to this common display, provisions to provide information to an air-traffic situation display shall also be made. The primary interface with this display will be through the BCAS track file. BCAS will inhibit access to the track file by any device during track file updates and reads by BCAS.

2.3.4 Air Data

In order to perform its function, BCAS must be capable of interfacing with the aircraft altitude encoder, airspeed and heading indicator and when available a navigator such as RNA or INS which provides ground speed and course. Additional benefits accrue from the interface with airspeed since BCAS, with this additional information, can provide wind speed and direction in certain modes.

2.4 Constraints on Active BCAS

The active mode of BCAS can suppress target aircraft with P_1 P_2 transmissions and the target receivers will be made dead (unable to detect incoming interrogations) when replying to BCAS interrogations. Each time a receiver responds to BCAS or is suppressed by BCAS, it cannot respond to ATCRBS. The BCAS active mode design concept is restricted to 2% reduction of this round reliability of other aircraft and ground surveilance..

3.0 CONCEPT OPERATION

3.1 Introduction and Overview

The basic mode of operation of the BCAS is passive, and active mode will only be used as necessary to supplement the passive in the case of poor geometry conditions (singularity), garble situations, or lack of beacon radar coverage.

The BCAS concept integrates the best of each of the previously tested concepts described in Section 1.3 and eliminates the disadvantages found in each of the previous concepts. However, it is important to discuss the rationale for multiple mode operation, use of a directional antenna, the whisper/shout technique, and the RBX, each of which is a key element of the BCAS concept.

The heart of the BCAS is the mode control logic which determines the mode of operation based on the:

- o number of radar beacon interrogators available
- o types of beacon interrogators
- o relative position of BCAS-equipped aircraft, target(s), and radar(s)
- o range from BCAS aircraft to the radar(s)

- o mode singularities
- o garble interference

A flow diagram indicating the principal elements of the mode control and selection logic is shown in Figure 3-1. There are four major considerations which influence the selection of a particular mode of the BCAS. First, the difference in ATC surveillance coverage, including the number of ground interrogator sites in view as well as capabilities of each of the sites (i.e., ATCRBS, ATCRBS/RBX or DABS). Second, the BCAS is required to provide passive operations whenever possible in order to minimize the impact of BCAS on the ground-based ATC system. The third consideration is effective BCAS performance. One element strongly influencing BCAS performance is the magnitude of the two dimensional position error σ_ρ . As shown in Figure 3-2, if BCAS can achieve a specified σ_ρ of 825 ft., then BCAS performance will be extremely effective. Finally, the BCAS must avoid the geometric singularities, which occasionally occur in certain modes, by changing to a different mode of operation.*

*/A region of singularity is defined to be those regions of airspace around a BCAS aircraft for which the passive solution (either single or dual site) is characterized by having both the shape of the σ_ρ vs. bearing angle graph close to a 90 degree angle and the absolute value of σ_ρ greater than 825 ft. value.

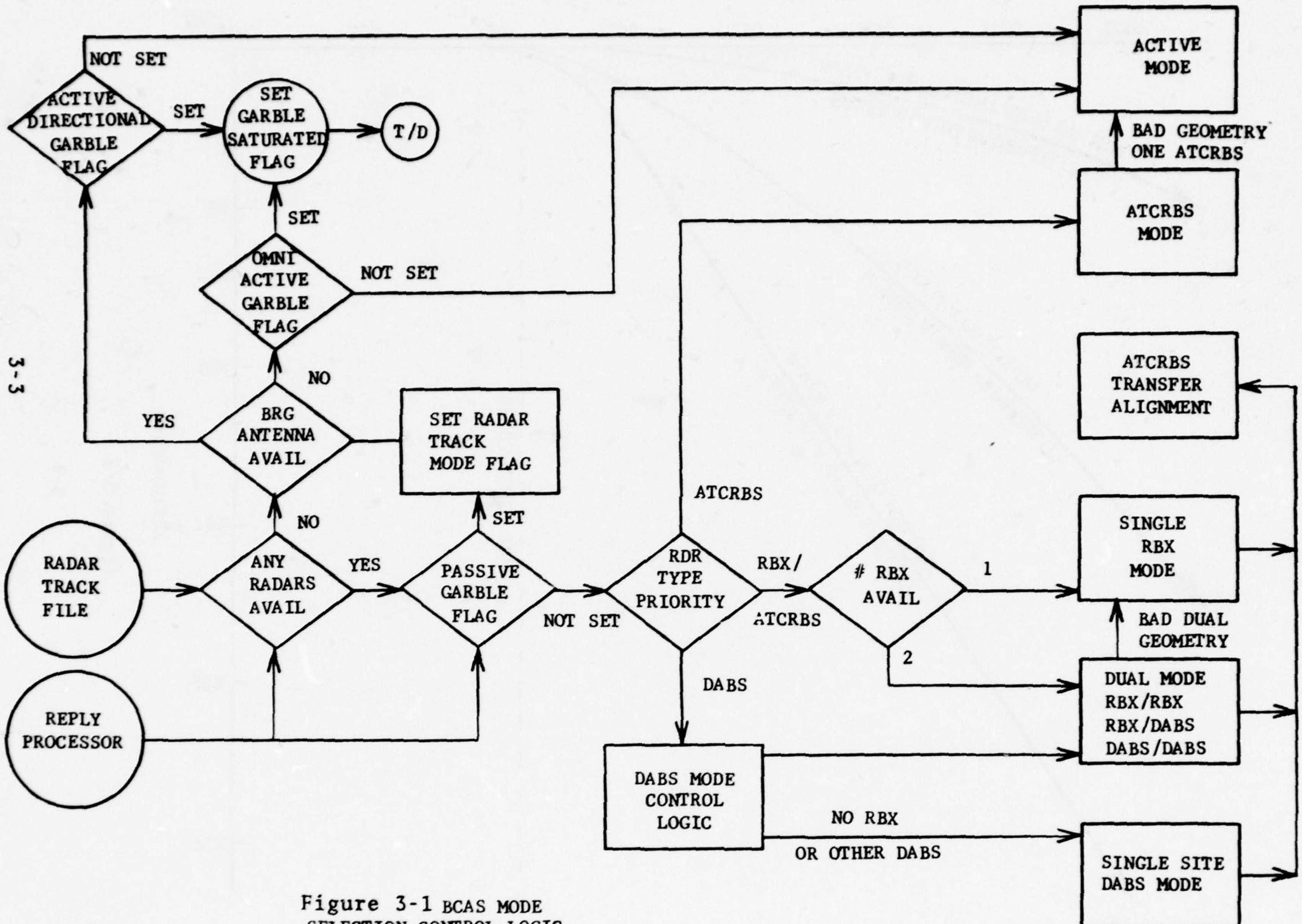


Figure 3-1 BCAS MODE SELECTION CONTROL LOGIC

BCAS PERFORMANCE

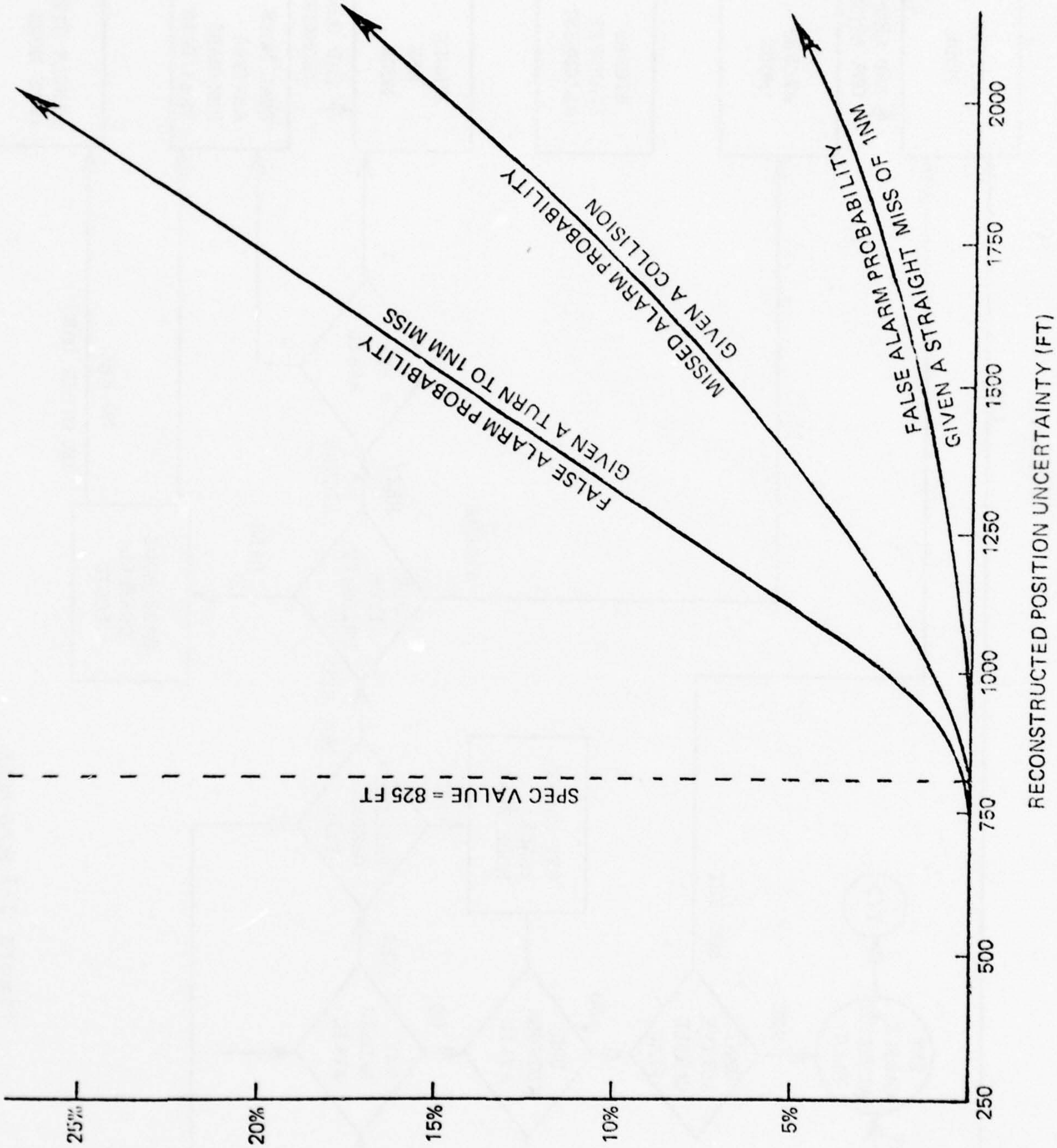


Figure 3-2

BCAS through its multimodal logic selects the mode of operation which minimizes active interrogations consistent with an acceptable level of performance, and maximizes system effectiveness.

Directional Antenna

The BCAS concept was initiated under the premise that it should operate satisfactorily everywhere. In studying BCAS operation in the L.A. Basin, (the airspace of highest aircraft density - see Volume III Appendix A) it was found that passive garble would be excessive for a multi-site passive solution but acceptable for a single site passive solution. The single site passive solution however has a singular region and requires active interrogation of targets in the singularity. The only known way to operate in the singularity was to provide an improved active mode capability utilizing both a directive antenna and the whisper/shout interrogation technique which reduces the active garble problem resulting from high density airspace.

The directional antenna has many other advantages. It provides sufficient bearing information to give PWI for Mode A (only) transponder targets and provides the only known protection against close non-BCAS equipped turning aircraft.

It also helps in reducing "phantom" targets and provides a means for operating in an all-ATCRBS environment without ground system modification. Peripheral advantages include a significant improvement in round reliability of the air-to-air BCAS data link (see Volume II Section 6) and an improved air-to-ground (RBX) data link (see Volume II Section 5).

Whisper/Shout

The whisper/shout interrogation technique is a means for grouping targets according to their detection capabilities, principally determined by receiver sensitivity and antenna gain. Aircraft are initially interrogated at a low power level (the "whisper") which causes those targets to respond which are nearby or equipped with sensitive receivers. Once these targets have replied they are suppressed by subsequent BCAS interrogation pulses and during their suppression period another interrogation is transmitted from the BCAS equipped aircraft at a higher signal level which obtains responses from a new set of targets. This procedure is repeated several times with the last interrogation being of highest power (the "shout") to insure that all targets have been interrogated within the protection and tracking volume of the BCAS aircraft.

Ground Based Radar Beacon Transponder (RBX)

The use of an RBX has several significant advantages. It provides a great deal more information about a site than a North pulse reference and will allow a single site passive solution while a North reference alone cannot. In addition, an RBX provides a BCAS-ATC/ATARS interface through its data link capability which cannot be provided by a North reference-only ground installation.

The operation of the BCAS concept will be described in Section 3.2 first for an all-ATCRBS environment, which represents the initial operational environment for BCAS. Next, the BCAS concept operation in an all-DABS environment will be presented in Section 3.3. The manner in which BCAS evolves from an ATCBRS to an all-DABS environment is the subject of Section 3.4.

3.2 All ATCRBS Environment

An all ATCRBS environment represents an idealized version of today's surveillance environment. In this environment there are only ATCRBS interrogators, and, with the exception of unequipped aircraft, all aircraft have ATCRBS transponders with either Mode A or both Mode A and Mode C. Ground-based radar beacon transponders (RBX's) are eventually to be colocated with many ATCRBS interrogator sites. However, it is not assumed initially that each ATCRBS site is equipped with an RBX. Sites equipped with an RBX will be referred to as ATCRBS/RBX (or simply RBX) sites. Each BCAS aircraft has a modified DABS transponder, a DABS/ATCRBS 1030 MHz interrogator, two 1090 MHz receivers, and two phased array antennas (12" to 18" in diameter).

The information required for proper mode selection is obtained by processing the 1030 MHz radar interrogations, the 1030 MHz RBX squitters, the 1090 MHz aircraft replies, and the 1090 MHz DABS squitters. The directional antenna aids in the signal processing function by reducing the garble interference in high density environments and is also used to supplement the basic 1030 MHz, 1090 MHz signal data with bearing and azimuth data.

Given the basic signal data and BCAS mode, target position relative to BCAS is estimated by solving the appropriate geometry problem for a given mode. Tracking and smoothing is then used to improve this relative position estimate and to estimate target velocity. These data are the essential ingredients of the target track file which is used to drive the threat detection and resolution logic. Threats are detected using both Tau and miss distance criteria and the algorithms are very similar to ATARS. Similarly, the resolution logic provides PWI and positive and negative commands, again using logic similar to ATARS. These data are then displayed to the pilot for execution.

Coordination with ATARS and ATC is achieved via the DABS data link and in certain cases the RBX data link. The system also interfaces with the air data system on board the BCAS aircraft. An additional interface for a future CDTI is also provided. The details of operation of each of the BCAS operating modes are described in the following section.

Any air-derived beacon-based CAS system must be multi-modal to function effectively in a variety of site locations, geometries, and air traffic environments. BCAS utilizes sophisticated on-board computer algorithms to establish target tracks and to determine target threats with acceptably low false alarm rates. These various modes arise because of close correlation between air traffic density and the number of ATCRBS sites in view of the CAS aircraft. Thus, BCAS will utilize a simple interrogation mode over oceans where the air traffic density is minimal and where no ground-based surveillance exists. The complexity of the mode of operation must increase with the traffic and site density. In BCAS, the software portion of this complexity is basically due to the reply processor, which must read reliable tracks through severe synchronous garble environments. Note that the garble problem is more severe for the BCAS aircraft than for the ground beacon because the aircraft antenna, whether used omnidirectionally (as in the passive mode) or directively (passive and active modes), is not as selective as the 4° ATCRBS beam.

The concept for an all-ATCRBS environment will be presented in seven stages corresponding to the seven modes of BCAS shown in Figure 3-3. Each mode carries one or more of the following designations:

Passive:*	Entirely passive operation (no interrogation by BCAS)
Active:	Entirely active operation (no reception of ground interrogated ATCRBS replies by BCAS)
Semi-Active:	Mixed mode in which both passively-obtained and actively-obtained information is used to construct target tracks.

*/We define a mode passive if no target is interrogated by BCAS.

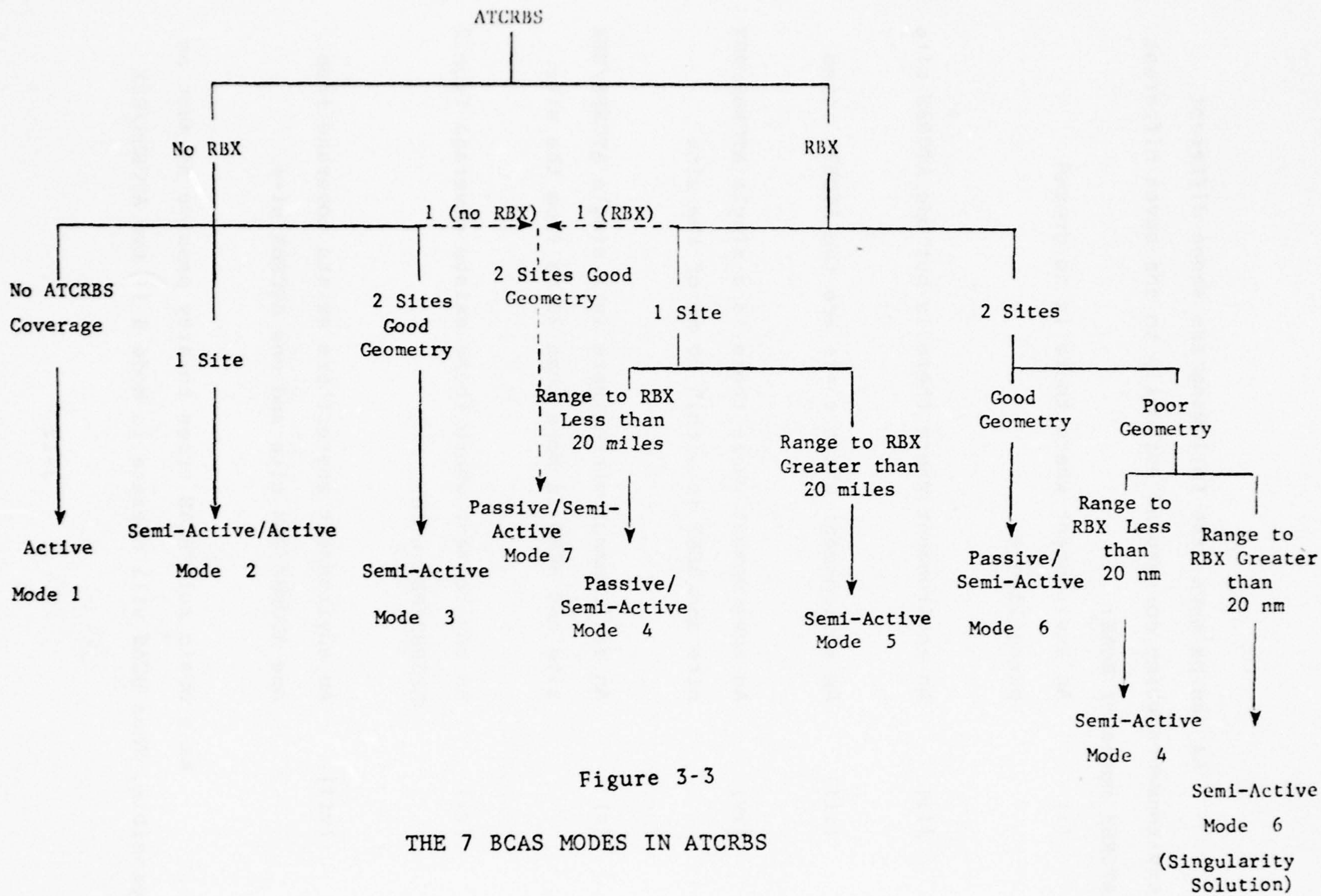


Figure 3-3

THE 7 BCAS MODES IN ATCRBS

As can be seen, the following are seven different environments which correspond basically to the seven different ATCRBS modes of BCAS:

(i) An environment where there is no ground surveillance

(ii) An environment where there is but one ATCRBS site

(iii) An environment where there are two ATCRBS sites

(iv) An environment where there is a single ATCRBS/RBX site and BCAS is within 20 nm of the site

(v) An environment where there is a single ATCRBS/RBX site and BCAS is more than 20 nm from the site

(vi) An environment where there exists coverage from 2 ATCRBS/RBX sites

(vii) An environment where there exists coverage from one ATCRBS/RBX site and one ATCRBS site.

As a basic rule BCAS tries to stay passive as much as possible. Thus BCAS will operate in Mode 6 if two ATCRBS/RBX sites are available. If only one ATCRBS/RBX site is available but there is a second ATCRBS site, BCAS will operate in Mode 7. As will be seen Mode 7 performance is not quite as good as Mode 6 performance. When only one ATCRBS/RBX site is available BCAS will use Mode 5 or 4. Mode 5 is used only when BCAS is close to the ARCTBS/RBX site (within 20 nm). When close, BCAS can stay passive more of the time then when it is far from the site (greater than 20 nm).

If no RBX sites are available but there are ATCRBS sites BCAS will use these sites for passive operation (Mode 3), while if only one ACTRBS site is available (Mode 2) BCAS will use its directional antenna to determine a North reference and will operate in a semi-active mode. Finally if no ground site exists (Mode 1) BCAS goes active.

The collision avoidance capability provided to the BCAS aircraft will vary with the target's ATCRBS equipment and with the BCAS mode of operation as summarized in Table 3-1. The principle that is followed in BCAS is to provide the best collision avoidance capability that target equipment, geometry, and ground equipment will allow. Thus Mode A only targets cannot be tracked in altitude but can be tracked in range and bearing so that a position warning indication (PWI) can be

Target Equipment	BCAS Mode		PWI	Vertical Maneuver	Horizontal Maneuver
			COLLISION AVOIDANCE CAPABILITY		
Mode A	All		✓		
Mode C/A	1		✓	✓	
Mode C/A	2	Region of no singularity	✓	✓	+
		Region of singularity	✓	✓	
Mode C/A	3	Region of no singularity	✓	✓	+ +
		Region of singularity	✓	✓	+ +
Mode C/A	4	Region of no singularity	✓	✓	✓
		Region of singularity	✓	✓	✓
Mode C/A	5	Region of no singularity	✓	✓	✓
		Region of singularity	✓	✓	+
Mode C/A	6	Region of no singularity	✓	✓	✓
		Region of singularity	✓	✓	✓
Mode C/A	7	Region of no singularity	✓	✓	+ +
		Region of singularity	✓	✓	✓

Table 3-1

BCAS COLLISION AVOIDANCE CAPABILITY IN ATCRBS

✓ Everywhere
+ + In many areas
+ In a few areas

given for such targets as illustrated in Figure 3-4*

When in Mode 1, the active mode, an airborne directional antenna with a monopulse detector will be used to provide bearing accuracy to within 5 to 10 degrees. Although such bearing accuracy is sufficient for PWI, it will not be accurate enough to allow horizontal maneuvers for collision avoidance purposes.** The active interrogation mode does provide the necessary accuracy in range and altitude so that vertical collision avoidance maneuvers can be given everywhere.

Mode 2 is semi-active in regions of no singularity and active in its singularity region. Because of the added site and the good geometry, Mode 3 can be semi-active everywhere. Both modes provide PWI and a vertical maneuver capability everywhere. As will be discussed later, BCAS in Mode 3 will, in addition, have a horizontal maneuver option when the BCAS aircraft is within 50 nm of an ATCRBS site. The term

*/ The pilot display does not show range to target. However, the Cockpit Display of Traffic Information (CDTI) can show both bearing and range-to-target information. A study is in process to determine, if Mode A aircraft can be tracked in 3 dimensions when replies are received by BCAS from more than one ATCRBS site.

**/ When discussing collision command maneuvers it is implied that the target has a Mode C capability.

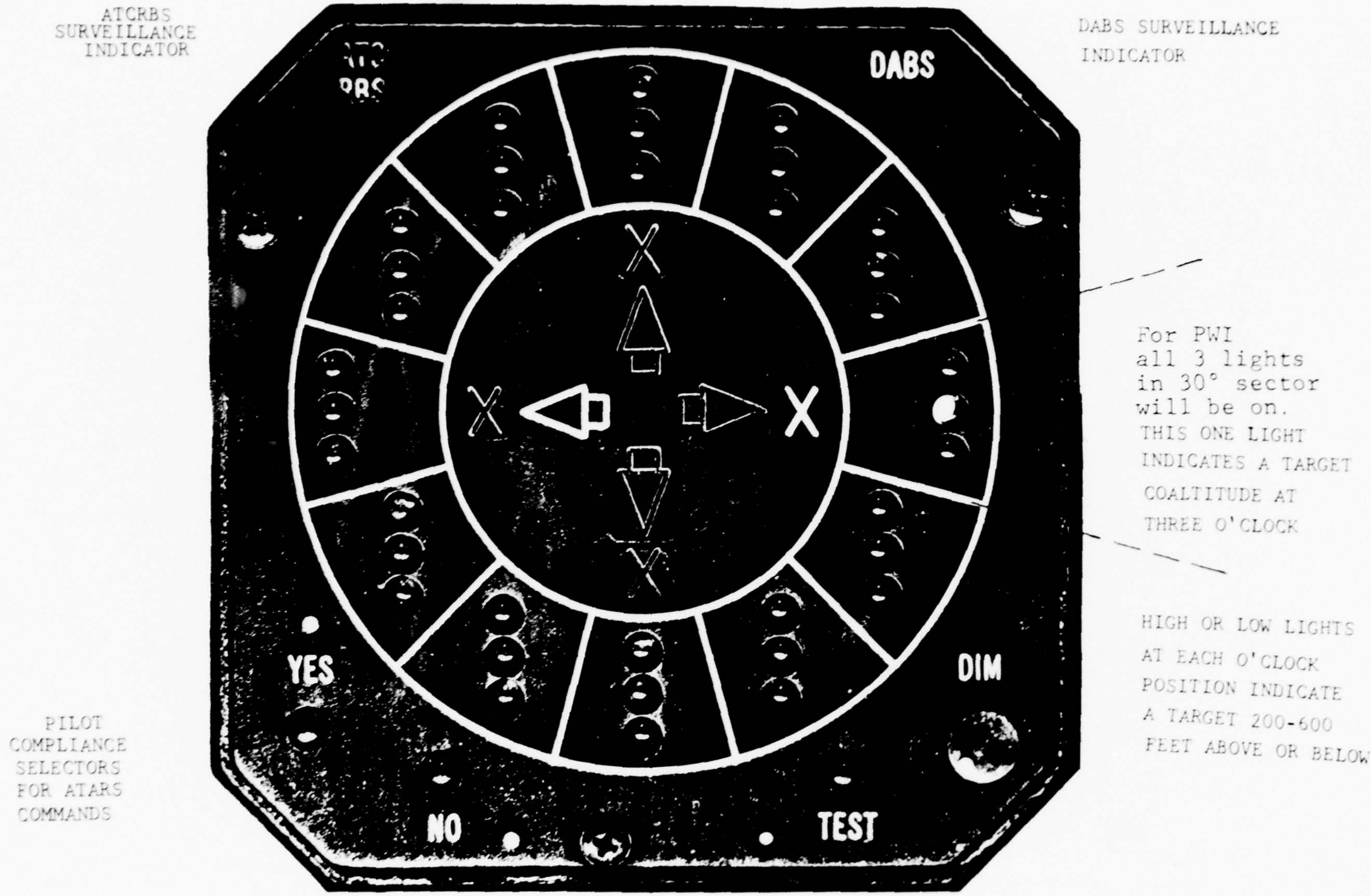


Figure 3-4

PILOT DISPLAY - Positive Turn Left and No Right Turn Displayed "singularity region" relates to the accuracy of the model solution. When the accuracy of any modal solution exceeds a certain limit over a region of air space, the solution is unacceptable and a better technique has to be found to reduce the position error.

When operating passively outside of the singularity regions of Mode 4 or semi-actively within the singularity region, targets can be tracked very accurately in three dimensions, allowing the BCAS aircraft to make the best maneuver whether vertical or horizontal to avoid collision. The Mode 4 solution is also used when there are 2 RBX sites available, but because of poor geometry one is discarded.

In Mode 5, which is semi-active everywhere, BCAS has sufficient accuracy outside the singularity to provide vertical and horizontal maneuvers, while in the singularity horizontal maneuvers cannot be given everywhere.

With good geometry and two ATCRBS/RBX sites (Mode 6), BCAS target tracks are very accurate everywhere, allowing for optimum collision avoidance maneuvers. A somewhat degraded performance is achieved when one of the sites is ATCRBS/RBX with the other being an ATCRBS site (Mode 7).

The remainder of this section will deal in more detail with each of the ATCRBS modes of BCAS.

Section 3.2.1 treats environments in which there is inadequate ground surveillance for passive BCAS (Mode 1). The best of ATCRBS environments is described in Section 3.2.2 for regions in which ATCRBS/RBX surveillance coverage exists (Modes 4, 5 and 6). Single and double site ATCRBS solutions (Modes 2 and 3) are the subject of Section 3.2.3 while Section 3.2.4 discusses the mixed ATCRBS-ATCRBS/RBX mode of operation (Mode 7).

3.2.1 Inadequate Ground Surveillance for Passive BCAS (Mode 1)

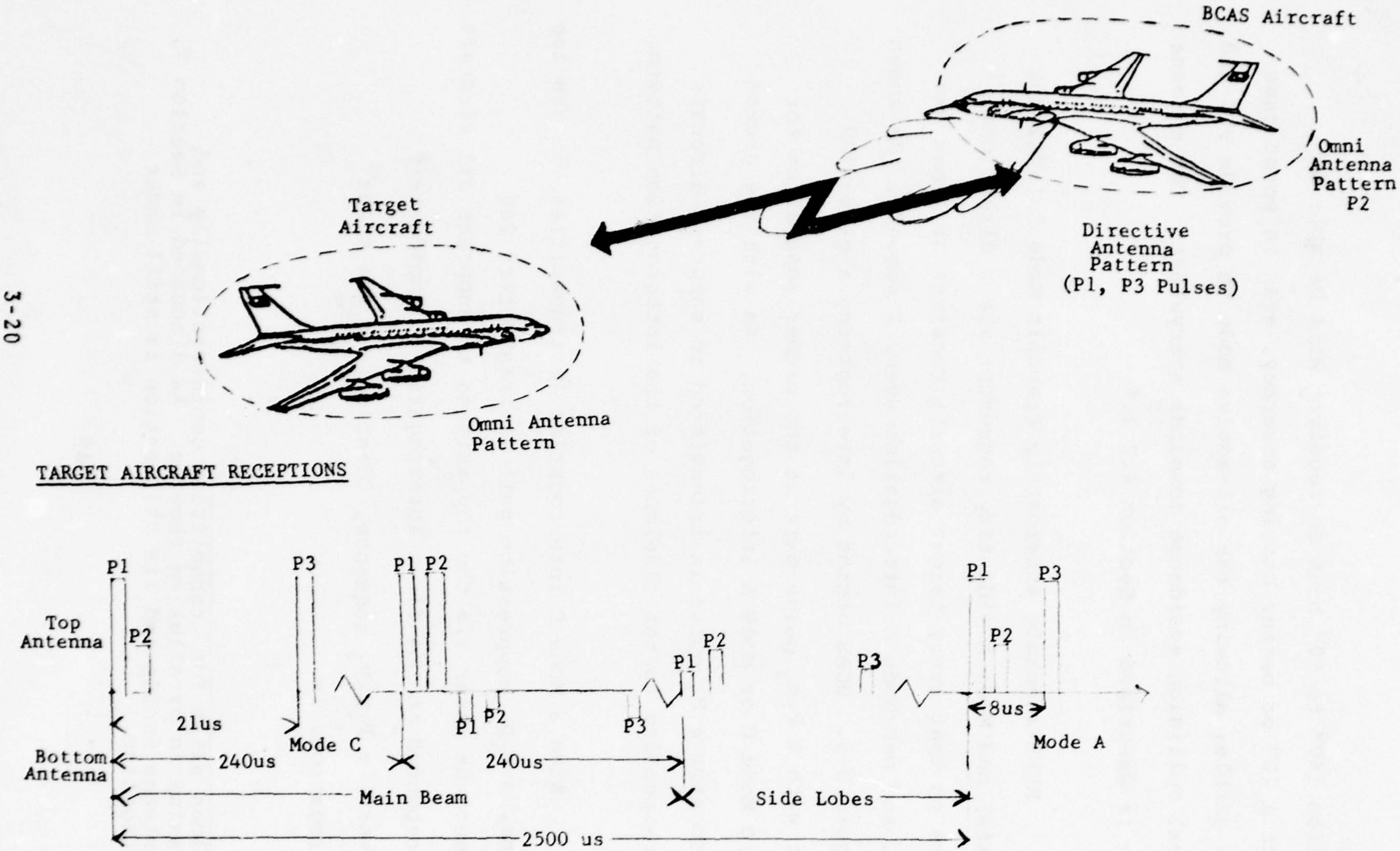
3.2.1.1 Ordinary Targets

In areas with no surveillance, such as over the ocean, BCAS will operate in an all-active mode. In this mode, BCAS will actively interrogate targets with both Mode C and Mode A which provide aircraft identification and tracking data in range and altitude (when available). To obtain bearing information, phased array antennas (6-8 elements, and 12"-18" in diameter), located both on the top and bottom of the aircraft, will be used. Each antenna can effectively form a 20^{o} beam on transmit (see Section 4.2.1), and using monopulse *detection (40° to 50° beam on receive)* will be able to provide a 10° or better bearing accuracy, even in worst case active garble, allowing the all-active mode to provide PWI and vertical collision avoidance commands everywhere. The antenna design is described in Section 4.2.1.*

BCAS aircraft alternately transmit Mode C (altitude requests) and Mode A (identity requests) via a directional antenna so that every target aircraft receives at least one Mode C and one Mode A interrogation every 2 seconds. As shown in Figure 3-5. BCAS begins by interrogating a given 40° sector with a P_1P_3 pulse pair at the proper separation for a valid Mode C or Mode A interrogation. As with the ground interrogator a P_2 pulse is transmitted to suppress aircraft from responding to the sidelobes of the interrogation pattern.

When a Mode C interrogation is transmitted via the top antenna, a P_1P_2 suppression pair is transmitted 240 microseconds later via the top antenna to suppress all aircraft who responded to the first interrogation. Immediately afterward, a $P_1P_2P_3$ sequence, identical to the first interrogation, is

*/Options exist for transmitting omnidirectionally and processing in parallel on receive. As discussed in Section 7, the antenna design and its utilization is still under investigation.



ACTIVE MODE INTERROGATION SEQUENCE

Figure 3-5

transmitted via the bottom antenna. This procedure would be repeated 9 times with the main beam sequenced through 9 positions assuring that all targets have been interrogated at least once. One second from the start of the first interrogation sequence, a Mode A interrogation is transmitted and it too would be sequenced through top and bottom antennas and all 9 azimuthal positions. This completes one 2 second interrogation cycle.

The procedure described above is adequate when the number of target replies per interrogation is sufficiently small so that the reply processor finds and tracks targets reliably. The reply processor's performance is limited by the average number of overlapped replies it sees in a 30 second period. Overlapped replies are defined as the number of targets in a 40^{o} azimuth sector and within a slant range of 1.6 nm of each other. The limit is defined, with respect to a target in worst case garble, to be less than 4 when averaged over 30 seconds. In those sectors where the garbled replies become excessive, BCAS can form 20^{o} interrogation beams and use the whisper/shout interrogation technique to eliminate the problem. The techniques available for forming a narrow beamwidth using a small circular phased array antenna will be discussed in Section 4.2.1.

3.2.1.1.1 Whisper/Shout Interrogation Technique

Whisper/shout is a technique for discriminating among aircraft according to their detection capabilities. This capability is a function of receiver sensitivity and antenna patterns. As illustrated in Figures 3-6 and 3-7, there is a wide variation in an aircraft's transponder detection capability.

Up to eight levels of whisper/shout have been tested (Reference 11) using the active BCAS engineering model. Based on these tests, the whisper/shout technique appears successful.

A BCAS equipped aircraft will interrogate from a top antenna, requesting a Mode C (or A) response from targets in the area. Aircraft in the area that have sufficient receiver sensitivity to hear the request will respond with altitude (or identity). A short time later (700 us), at the same power level as the previous transmission, a P_1P_2 pulse suppression pair is transmitted which suppresses all aircraft that have responded to the first interrogation. Immediately following the P_1P_2 pulse suppression set a second Mode C (or A) request is transmitted at a higher power

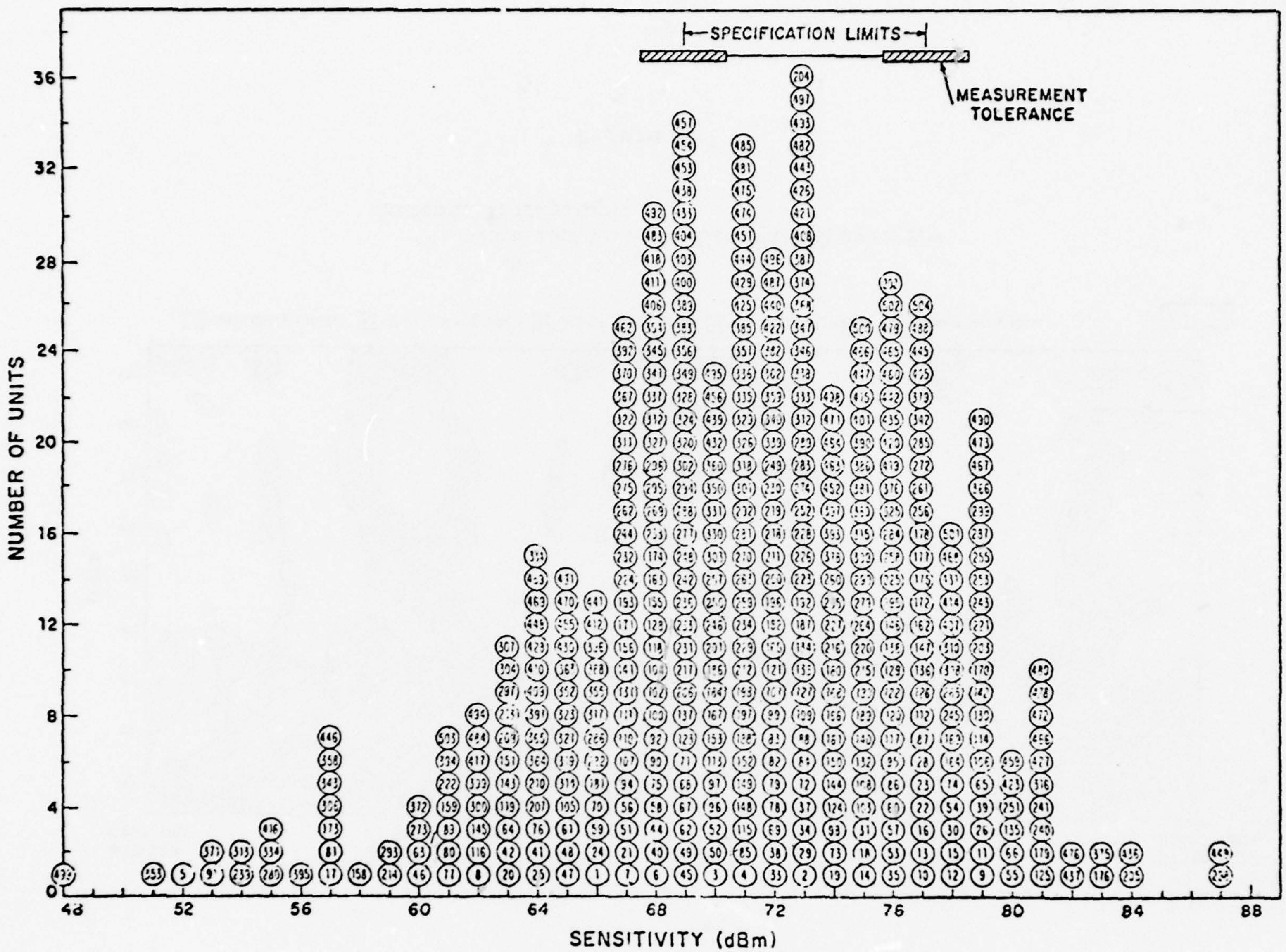
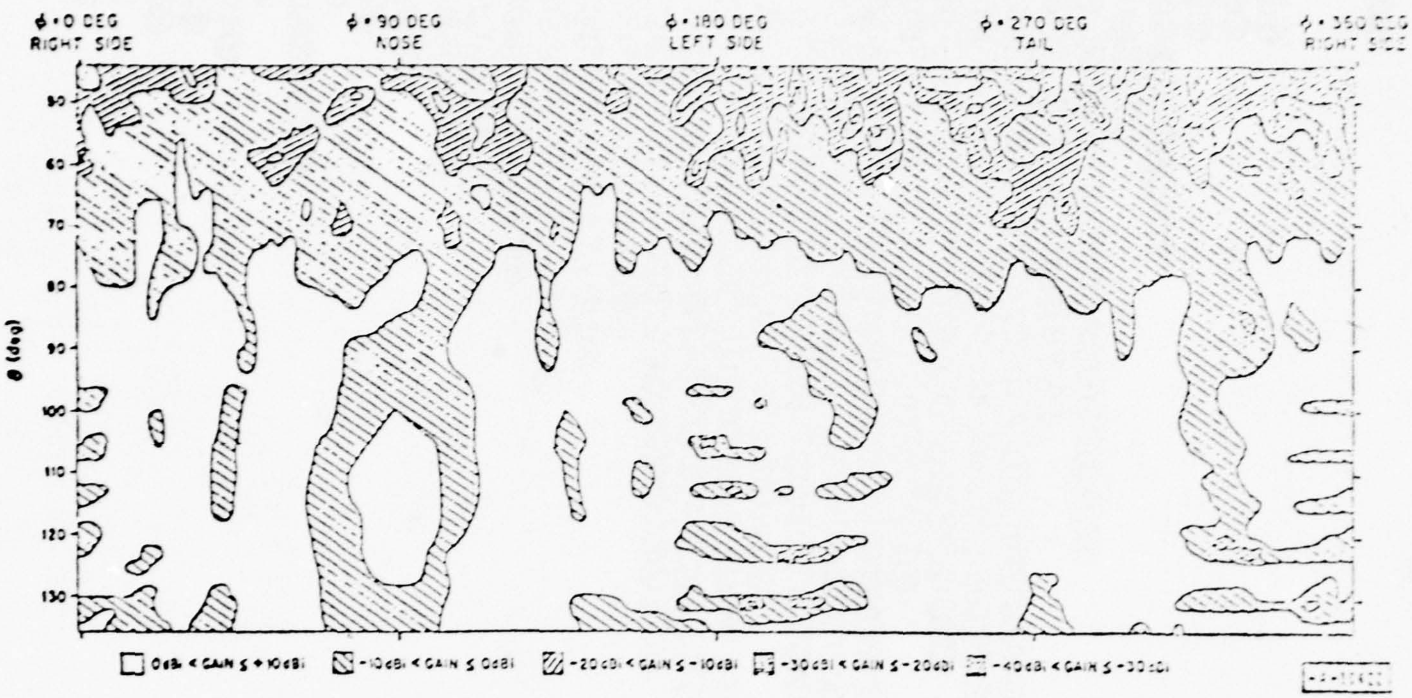


Figure 3-6 Sensitivity - general aviation transponders.



Gain contours for Cessna 150 over θ, φ (antenna 3; flaps up).

Figure 3-7

level. All aircraft not suppressed and which hear this second interrogation will respond. This process of suppressing previously interrogated aircraft and then transmitting at a higher power level is repeated a total of three times so that four different power level interrogations are made per sector from the top mounted antenna as depicted in Figure 3-8.

The four interrogations will elicit responses from all aircraft except those in a narrow vertical volume below the aircraft who will be in a null of the bottom mounted antenna. To ensure that such aircraft are seen by the BCAS, all aircraft who have responded are suppressed by a P_1 P_2 suppression at the next to lowest power level (2nd level) since targets will not be far from the BCAS aircraft. During the suppression period a 2nd power level Mode C (or A) interrogation is transmitted via a bottom mounted antenna. (See Figure 3-8.)

One possible implementation of whisper/shout is shown in Figure 3-9. Here the suppression pulse is transmitted 1/2 dB below the Mode C or A request. This is caused by our uncertainty in knowing if a receiver's threshold level for a Mode C or A request is the same as for a P_2 suppression.

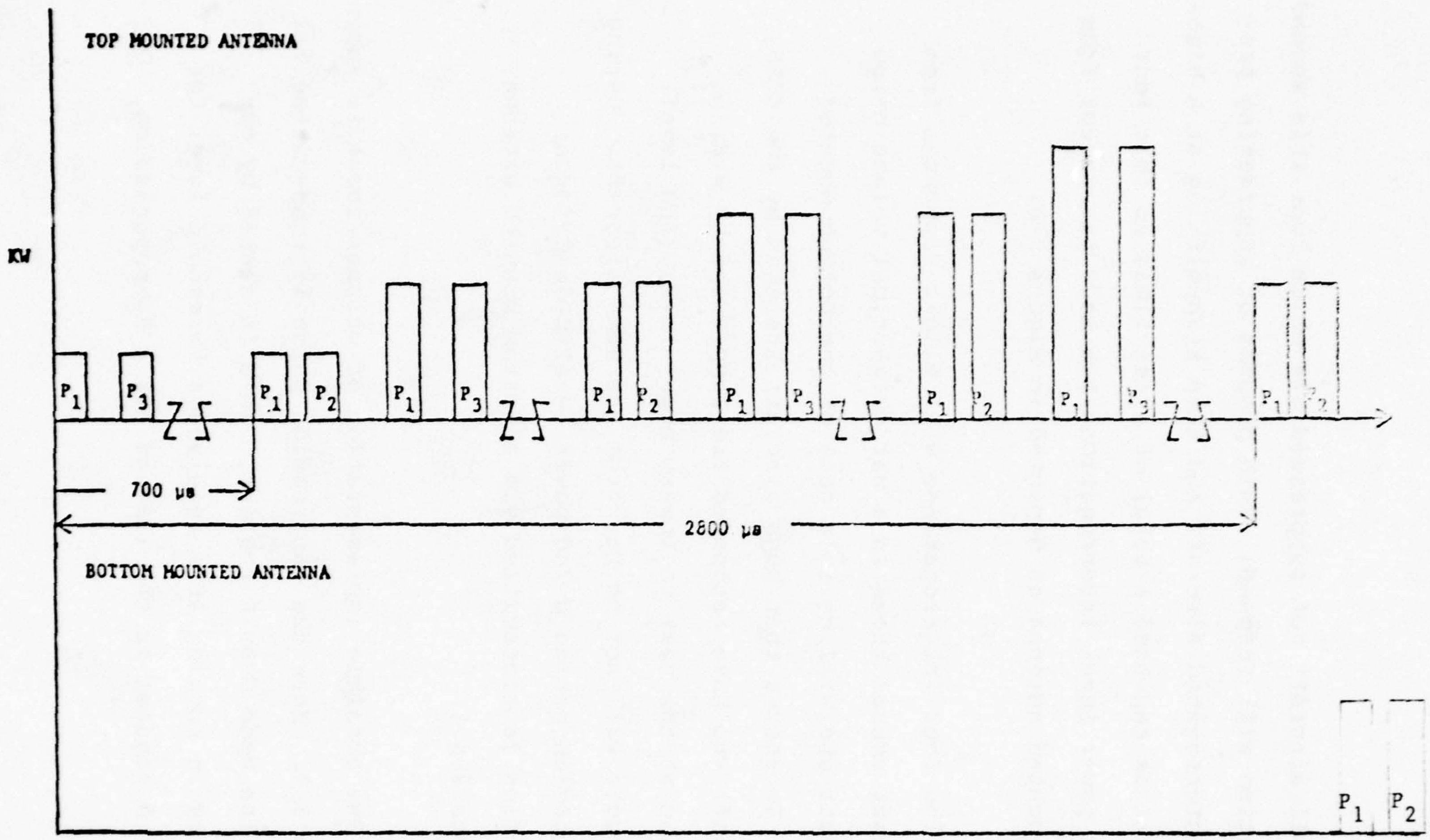


Figure 3-8

BCAS Whisper/shout Interrogation Sequence

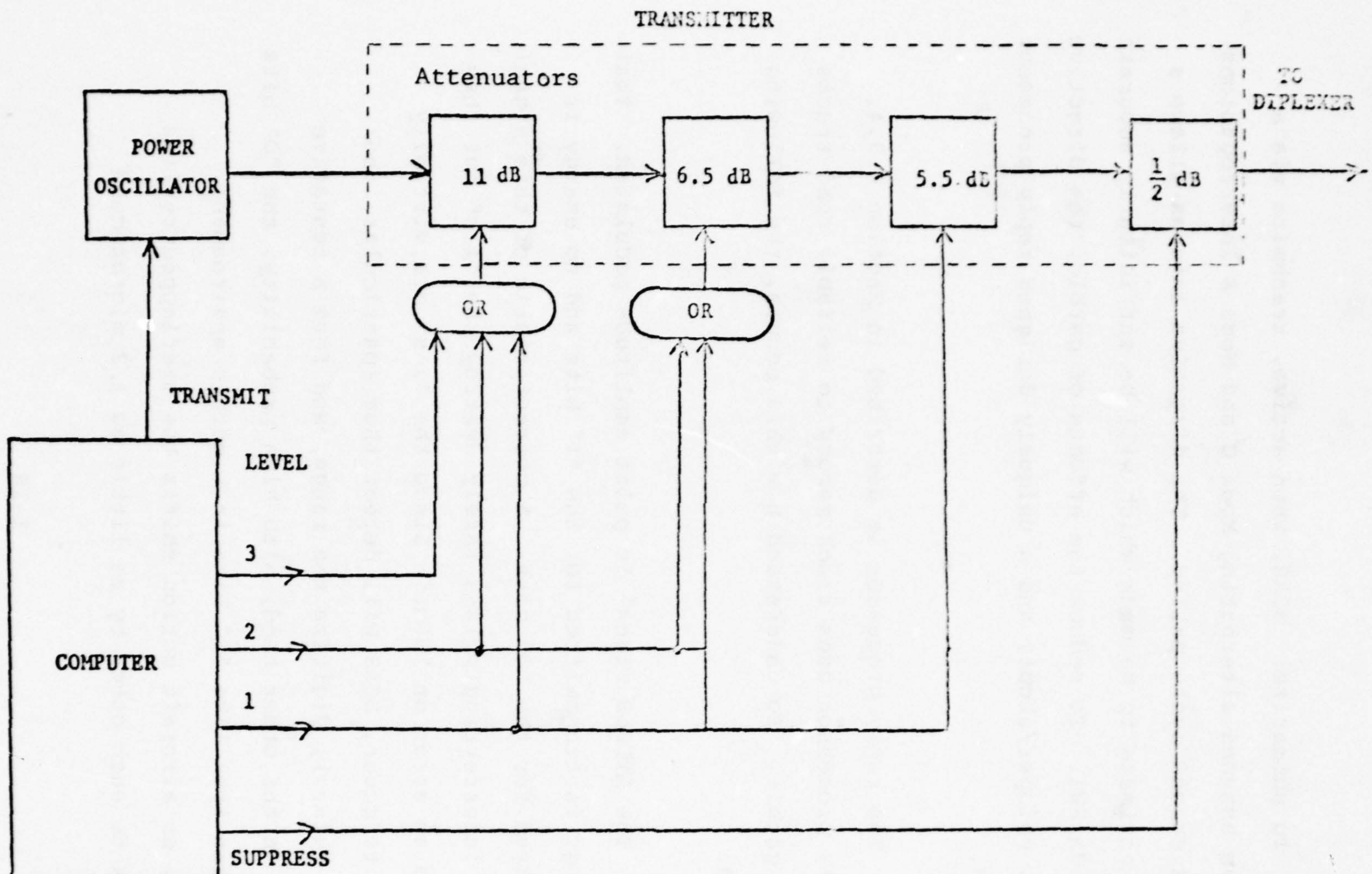


Figure 3-9

Whisper/Shout Implementation

To summarize: BCAS, when active, transmits via a directive antenna alternating Mode C and Mode A interrogations over a 2 second cycle period. The directive antenna allows a bearing estimate to be made which will be sufficiently accurate to provide PWI. To reduce the effects of garble, the directive antenna, whisper/shout, and a uniquely designed reply processor are used.

The reply processor is described in Section 4.3.4. The reply processor uses track memory to reliably read tracks through garble. To understand how this occurs, the following is noted.

The ATCRBS signal is pulse amplitude modulated. That is, energy is transmitted for the "1" bits and no energy is transmitted for the "0" bits. A characteristic of this signal is that interferring pulses rarely destroy the "1's" but they do cause an error on "0's." Since the "1's" are virtually certain to occur, BCAS will detect them (particular, the bracket pulses), digitize the range, and form a tentative track. On the other hand, with high probability, the "0" bits will often look like "1" bits in a garble environment. However, as aircraft motion shifts the overlapped replies relative to each other by as little as 1/2 microsecond

(500 feet), the garble nearly always becomes independent. Therefore, correlating many successive samples of a track will enable the true code to be read. In addition, the RF phase of garbled pulses will vary randomly with time across the antenna aperture (because the pulsed oscillators retain no phase coherence from pulse to pulse), which causes random variations in the monopulse bearing estimate. With time, these errors can be averaged down. Thus, given enough time, one can resolve ambiguities, determine all true tracks and eliminate all phantom tracks (see Section 3.2.1.3 for discussion of phantom targets).

The BCAS tracker acquires aircraft sufficiently far away (20 nm) so that at least 60 seconds are available before a collision hazard could occur. 30 seconds are used to establish track reliability, and 30 seconds are for escape maneuvers. Thus, by allowing sufficient tracking time, BCAS is able to acquire aircraft in garble and to continue tracking through it.

The BCAS all-active mode interrogates Mode A and Mode C and forms reliable target tracks in its vicinity. This information is then used to determine if a target is a collision threat. When such a target is of concern the pilot is given a PWI indication of the bearing of the threat aircraft and, if the target has a Mode C capability, the pilot is given a collision avoidance command. This procedure works in all cases except where the target is another BCAS. In such situations, there is the possibility that both aircraft will receive the same command, which may increase rather than decrease the probability of collision.

In order to avoid such situations, a "tie breaker" means of communication between the two aircraft must be available. This means of communication is provided by the DABS data link. Since each BCAS aircraft is DABS-equipped, an aircraft can transmit his intended maneuver to the DABS-equipped threat aircraft, which will enable coordinated conflict resolution maneuvers by both aircraft (e.g., aircraft A climbs, while aircraft B dives).

In order to utilize this air-to-air data link, the threat DABS ID must be known. This information is obtained from the "squitter" mode of the DABS transponder aboard the threat (Reference 6). BCAS can then interrogate the target. The responses confirm ID and provide range and altitude. Interrogations can be carried out at a low rate until a target is assessed as a threat, at which time the rate is stepped up.

3.2.1.2 Pop-Up Targets

A second situation in which potential collision threats have no ground-based surveillance is referred to as the "pop-up" target. The pop-up is an aircraft which is outside the coverage of the ground site. Typically, such an aircraft is low and near the coverage fringe of the site. If the target gains altitude and comes into coverage, it can usually be tracked by the single site methods given in the following section (3.2.2). The difficult exception is the case in which the BCAS aircraft is flying so low that there is insufficient time to allow for proper threat detection and execution of an avoidance maneuver. Although the pop-up is a special case of the single-site situation, it is treated here because the solution involves active tracking, as in the oceanic environment.

A target out of surveillance of the ATCRBS beacon is not passively detectable inasmuch as it emits no replies. BCAS can in principle avoid the pop-up phenomenon by issuing Mode C and Mode A interrogations, every 2 seconds in each 20° sector determined by its bottom directive antenna and look for new target reports, especially those indicating low flight levels. When such a target is detected and is sufficiently near or has a closing range rate, the interrogation rate can be stepped up for more accurate tracking.

The problem which could occur, however, in a moderately dense environment is that the replies from other nearby aircraft might garble the pop-up return and disguise it. To circumvent a possible garble problem, the interrogation by BCAS can be timed so that it arrives at aircraft near BCAS while they are in suppression from a recent interrogation by the beacon. Those aircraft within ground coverage will not reply; those outside coverage (i.e., pop-ups) will not be suppressed and will issue a reply. Since the number of out-of-coverage craft should be small compared to the in-coverage population, active self-garble among the pop-ups should be negligible. Of course, aircraft within coverage that have not been interrogated recently enough will also respond; the following geometric argument shows that there is nevertheless a clear volume around the BCAS aircraft which is sufficient to permit adequate threat detection of pop-ups.

A detailed analysis of the geometry shows that aircraft within a sphere of radius ½ r_s (where r_s is the "suppression radius," i.e., the distance a signal can travel during the suppression time T_s) will be in suppression when the interrogation from BCAS arrives.* The limits on T_s are defined as 35 ± 10 us. Since all transponders suppress for at least 25 us there is a clear radius of at least 2.37 nm within which no ATCRBS mainbeam targets will reply and garble out-of-coverage targets. Within the spherical shell of inner radius 2.37 nm and outer radius 4.76 nm (45 us), some aircraft in the main beam may reply, depending on the suppression time of their transponders. Unless the traffic density is extremely heavy, their numbers and reply probabilities should keep the main beam active garble to a tolerable level.

If BCAS is at the coverage fringe (100 mi), the ATCRBS beam (4°) will be 7 mi across, showing that all aircraft within the ½ r_s sphere are also in the main beam (when BCAS is at the beam center). When BCAS is closer to the beacon, the main beam is narrower in linear extent, but then the ATCRBS coverage will be lower and correspondingly, there should be less of a pop-up problem.

The timed interrogation technique discussed above offers some protection against pop-up targets, but does not

*/The actual region is a hyperboloid of revolution which contains the sphere of radius ½ r_s.

assure detection of all of them at the range required to establish a full confidence track before declaring a threat.

3.2.1.3 Detection of Phantom Targets Near Airports

A problem which has been reported during the active BCAS experiments is the occurrence of phantom targets near airports. These are false targets created by replies from two or more aircraft on the ground which are stationary and close enough to one another such that synchronous garble of their altitude codes reponding to an active interrogation, results in an apparent target at altitude. A range/altitude system cannot identify phantoms easily. However, the active mode described in this section can do so because bearing and bearing rate are available in the tracker. Two techniques for the detection of these phantoms are described in detail in Appendix I.3 and summarized here. In either case, the basic idea is to determine whether the target is stationary.

One technique is to compute the component of target velocity along the range vector between BCAS and the target. This requires that the BCAS make use of an estimate of its airspeed along with target range rate and bearing. A single observation of this velocity component is insufficient to determine if the target is stationary (zero velocity along the range vector could correspond to a target moving parallel to BCAS). If the component is tracked over a period of time, it is possible to resolve the question of whether the measurements are consistent with a moving or stationary target. Note that neither bearing rate nor range explicitly enter the indicated computation.

In the second method, bearing rate and range are used in addition to derive an instantaneous estimate of the target speed.* If this speed is below a certain threshold (the threshold may be chosen in accordance with the indicated altitude), the track can be assumed to be a phantom and dropped. This method is not really an instantaneous test, as it might appear, because some track build-up time is required to get reliable range rate and bearing rate. It has the advantage that speed is indicated directly, whereas in the former case, speed is essentially inferred from successive observations of one component plus side information.

Inclusion of the directive antenna and bearing information has provided active mode BCAS a means to detect and rapidly eliminate these phantom tracks.

*/Enough information is available to determine the full target velocity vector if desired.

3.2.2 Regions of ATCRBS/RBX Surveillance Coverage (Modes 4, 5, and 6)

BCAS, in its passive mode (with RBX), will utilize no more than two ATCRBS sites. In this section we will first describe the single site ATCRBS/RBX operation which will then be followed by a description of BCAS operating in an environment of two ATCRBS/RBX sites.

3.2.2.1 Single Site ATCRBS/RBX

In order to understand how BCAS works passively, it is necessary to know the passive geometry, the measurements that have been taken, the data available to BCAS, how garble is treated, and the accuracy of the passive solution. As will be described, there are singularities in the BCAS solution which will require BCAS to go semi-active. This section will cover all of the above and in addition will describe how BCAS interfaces with ATCRBS.

3.2.2.1.1 Geometry and the Target Position Measurement Algorithm

The BCAS geometry is described with the help of Figure 3-10. The BCAS aircraft (0), the ATCRBS beacon (A1), and the intruder or target aircraft (T) are shown. It is desired to determine the target range (ρ_{OT}), the bearing angle to the target (β) and the relative altitude of the target (Δh). It will be found that the information available in the observable

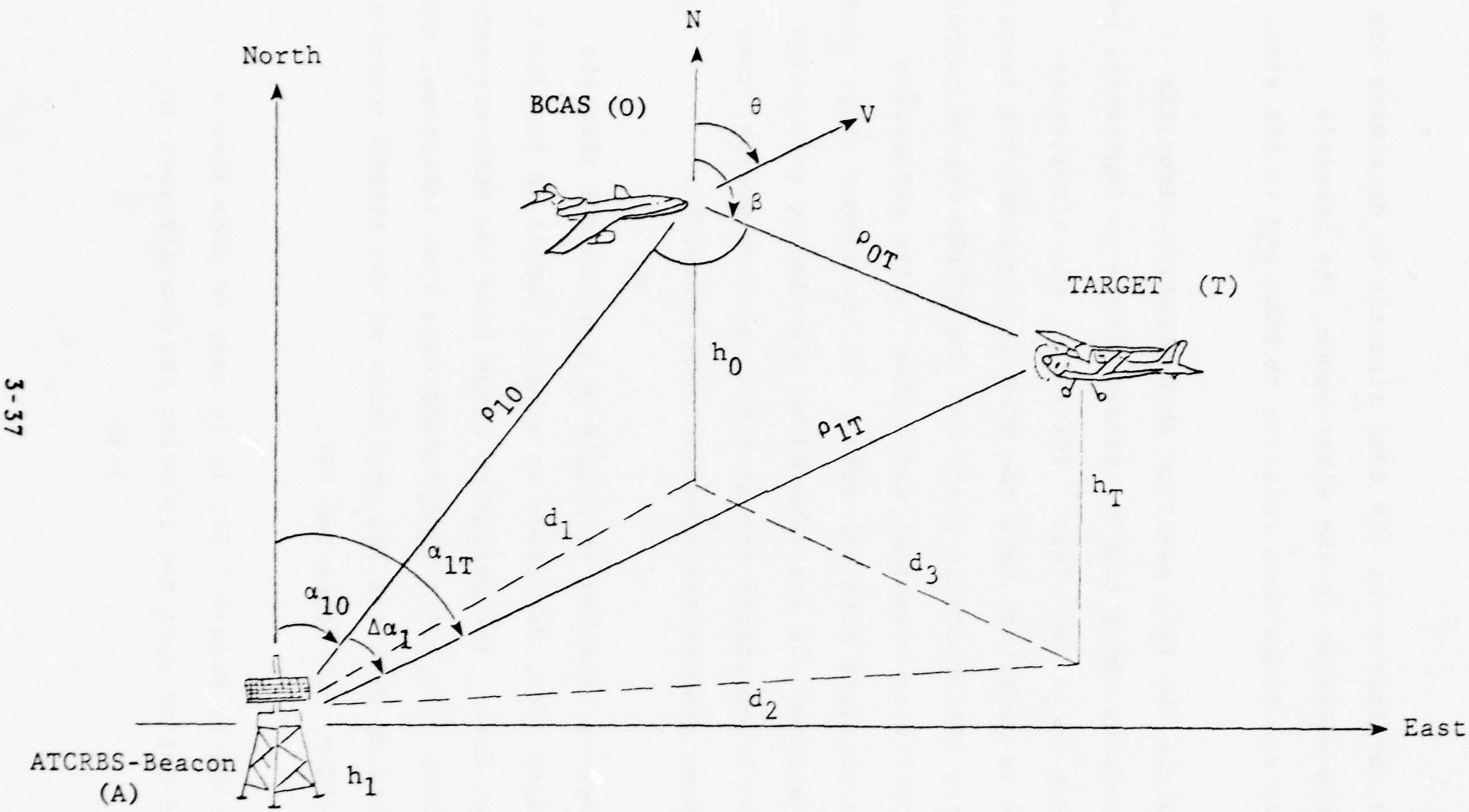


Figure 3-10 : Single Site ATCRBS/RBX Geometry: All-ATCRBS Environment signals is sufficient for the BCAS aircraft to determine its own position relative to the site; hence, the target's coordinates are known both relative to BCAS <u>and</u> to the site.

Since the full position determination algorithm is somewhat complex conceptually, albeit simple to implement, we will explain it in two steps. Initially, the simplifying assumption is made that both the BCAS aircraft and the target aircraft are stationary in space and the ATCRBS beacon mainbeam has essentially no azimuthal width (the latter assumption eliminates multiple hits per scan). In the second step, these idealized assumptions are removed by introducing correction factors which compensate for aircraft relative motion, time lapse between measurements, and antenna beamwidth.

Before starting it should be pointed out that the RBX/BCAS data link, described in greater detail in Section 5, has several uses: (i) measuring range from the BCAS aircraft to the ATCRBS site, (ii) BCAS/ATCRBS data link interface, and (iii) providing data via RBX squitters of the ATCRBS rotation rate, position, ACP count and PRF.

Referring to Figure 3-10, it is easy to show that a sufficient set of data for locating the two aircraft is

ρ_{10}, α_{10}, $\Delta\alpha_1$, ρ_{1T}, and the three altitude h_1, h_T, and h_0. Under the above simplifications, the BCAS aircraft indirectly obtains these parameters in the following ways:

(a) ρ_{10} (Range-BCAS to Beacon)

The round trip time δt_1 from the BCAS aircraft to the ATCRBS beacon is measured by interrogating the RBX once every four seconds. This measurement directly converts to distance ρ_{10} ($\rho_{10} = c \cdot t_1/2$ where c equals the speed of light).

(b) α_{10} (BCAS Azimuth)

The following are measured:

- The time of arrival of the most recently received RBX squitter (t_{oS}), which was transmitted when the mainbeam pointed North, South, East, or West;
- The time of arrival of the ATCRBS main beam interrogation (t_1);
- The beacon antenna pointing angle at the time of squitter (α_B); (decoded directly from the squitter)
- The antenna rotation rate (ω_R) (decoded directly from the squitter).

Then,

$$\alpha_{10} = \alpha_B + \omega_R \cdot (t_1 - t_{oS})$$

(c) α_{1T} (Target Azimuth)

Two methods are available. The first measures α_{1T} directly, the second determines α_1. For either, the receiver measures:

- The time of arrival of the target reply to the main beam interrogation (t_{2+3}).

The direct measurement uses the most recent RBX squitter arrival time t_{oT}, (as defined in b) prior to the reply arrival time t_{2+3} as follows:

$$\alpha_T = \alpha_B + \omega_R \cdot (t_{2+3} - t_{oT})^*$$

The differential measurement is:

$$\Delta\alpha_1 = \omega_R \cdot (t_{2+3} - t_1)^*$$

$$\alpha_{1T} = \alpha_{10} + \Delta\alpha_1$$

The differential method is preferred when BCAS and target reply to the same interrogation. Otherwise, preference is determined according to which is more recent, t_o or t_1.

---

*/This formula neglects the path delay along the portion equal to ATO minus AO (See Figure 3-10), but this is generally insignificant (on the order of 0.01°) due to the slow rotation rate of the antenna, compared to the repetition rate.

(d) ρ_{OT} (Range-BCAS to Target)*

The measured arrival times t_1 and t_{2+3} are required. In addition,

- The interrogator PRF is demodulated from the RBX squitter.

The parameters N_{12} and $_{12}$ are defined as follows:

$$N_{12} + \epsilon_{12} = (t_{2+3} - t_1) . PRF$$

where N_{12} = nearest integer value ($\pm$), and

$$0 < \epsilon_{12} \ll 0.5.$$

Then the target is replying to an interrogation which occurred N_{12} sweeps after the BCAS interrogation ($|N_{12}|$ interrogations before if N_{12} is negative). The fractional part $_{12}$ is proportional to the differential time of arrival TOA which is the time which would elapse between BCAS reply and BCAS receipt of target reply if both were interrogated on the same sweep:

$$\Delta TOA = \epsilon_{12}/PRF$$

Then,

$$\Delta\rho = \rho_{OT} + \rho_{1T} - \rho_{10} = c^* \Delta TOA$$

Note that this method of obtaining TOA does not require detection of the omnidirectional SLS

*/The equations given below apply as given only to a uniform PRP interrogator. Obvious modifications are made if the interrogator uses the jittered or staggered interrogation sequence.

pulse (P_2 pulse correlation). The reason is that using only the available data and onboard clock, interrogation times can be precisely predicted and need not be measured, even for beacons which jitter or stagger their interrogations. No additional sensitivity requirements are imposed on the airborne 1030 MHz receiver by the ACTRBS position measurement algorithm.

To get ρ_{1T}, compute

$$\Delta\alpha = \alpha_{1T} - \alpha_{10}$$

$$\rho_{OT} = \frac{\Delta\rho(\Delta\rho + 2\rho_{10})}{2(\Delta\rho + \rho_{10}(1-\cos\Delta\alpha))}$$

$$\rho_{1T} = \Delta\rho + \rho_{10} - \rho_{OT}$$

(e) h_A (Beacon Altitude)

The altitude of the ATCRBS beacon, h_A, is obtained from the RBX squitter.

(f) h_T (Target Altitude)

The altitude of the target, h_T, is obtained from the target's Mode C reply

(g) h_O (BCAS Altitude)

The altitude of the BCAS aircraft, h_O, is obtained from the BCAS encoding altimeter. Then

$$\Delta h = h_T - h_0$$

(h) (Target Relative Bearing)

First, compute the ground projection of $_{10}$ and $_{OT}$ (d_1 and d_2, respectively):

$$d_1 = (\rho_{10}{}^2 - (h_S - h_B)^2)^{1/2}$$

$$d_2 = (\rho_{OT}{}^2 - (h_T - h_B)^2)^{1/2}$$

In the North/East coordinate system shown in Figure 3-11, the ground-plane coordinates of BCAS and target are:

$$N_0 = d_1 \cos \alpha_{10}$$

$$E_0 = d_1 \sin \alpha_{10}$$

$$N_T = d_2 \cos \alpha_{1T}$$

$$E_T = d_2 \sin \alpha_{1T}$$

Two algebraic signs are computed to denote the sign of the target aircraft's North and East coordinates relative to BCAS:

$$\sigma_N = \text{sgn } (N_T - N_0)$$

$$\sigma_E = \text{sgn } (E_T - E_0)$$

Then the target bearing

$$\beta = \tan^{-1}\left[\frac{E_T - E_O}{N_T - N_O}\right]$$

can be assigned the proper value within

$0^\circ \leq \beta \leq 360^\circ$

by determining the quadrant in which it lies from σ_N and σ_E.

Thus, for the simplified static assumptions given above, the position determination algorithm is complete.

The real world differs from the above model in that the two aircraft are moving and the antenna beam has an effective width of 4° (2.3° at the -3 dB points). Because of the relative motion of the aircraft, measurements which are made at different instants of time have to be referred to a common time base. Therefore, the BCAS and target positions, which are measured every 4 seconds, must be tracked so that accurate estimates of their values can be found at the required reference times. In addition, a main lobe beamwidth of 4° is too wide for obtaining BCAS bearing information without some form of beam splitting. Fortunately, an aircraft will be interrogated with as many as 16 sweeps/scan by the main beam, and estimates of azimuth which are accurate to within 0.25° can be obtained from the resulting hits using a sliding window detector type algorithm. The detector essentially attempts to determine the beam pointing angle (centermark of a set of target hits) (See Reference 17 for a description of the centermark used in the ATCRBS reply processor). A similar averaging is applied to the ΔTOA measurements in finding differential range. If a jittered or staggered interrogation sequence is used by the site (this will be known by the RBX squitter), the BCAS aircraft must monitor sufficiently many sweeps to find the phase of sequence before it can initiate tracking.

The time instant to which all the measurements are referenced is the instant estimated to be the time of passage of the main beam center at the BCAS aircraft. When the interrogations are staggered or jittered, it may be preferable for computational purposes to project the times onto a more nearly uniform grid. The assistance of the tracker is required to provide smoothed estimates of the range and azimuth coordinates and their derivatives. The equations given in Table F-1 of the Appendix F show how the resulting correction factors are incorporated.

The ATCRBS/RBX single site solution has a solution singularity when one takes into account altitude. It has been found that if altitude is accounted for then there exists regions of possible targets which are at a lower altitude than BCAS and between BCAS and the ATCRBS/RBX site, for which 2 solutions exist. That is, both solutions have the same differential arrival times and are at the same azimuth with respect to the ATCRBS/RBX site.

As will be discussed in Section 4 BCAS uses a phased array antenna and will process received replies in parallel in up to 9 (40^{o}) sectors. To resolve the solution ambiguity parallel processing combined with monopulse detection will be used to obtain an independent bearing measurement (to within 1^{o} accuracy) of target positions. Once this bearing estimate is compared with the RBX target track solutions the true solution will be identified. Note that this monopulse detection does not have to be repeated on a continuous basis since once the true solution is ascertained an unambiguous target track can be maintained.

In summary then, the dynamics of the aircraft movement and the use of a multiple hit/scan interrogation rate requires the BCAS computer to take measurements made sequentially in time and reference them to a given instant of time. The BCAS computer can do this with great accuracy since it tracks its range to the beacon, centermarks for accurate azimuth determination and accounts for target aircraft dynamics by tracking both its own position and that of the target with a second order $\alpha \cdot \beta$ tracker. The method of position determination outlined in the above table is also flow-charted in Figure 3-11.

3.2.2.1.2 BCAS Passive Reply Processing With a Single ATCRBS/RBX Site

The previous section described the measurements that have to be made in order to obtain a passive single site ATCRBS/RBX solution. What was not described was how garble affects the accuracy of the measurement. This section describes the general principles of garble reduction which characterize the design of the BCAS reply processor. The reply processor is treated in greater detail in Section 4.2.4.

By way of comparison, in the active mode a directive antenna, whisper/shout, and reply processing are used to reduce active mode garble. In the passive mode a directive antenna is of little help, whisper/shout cannot be used, and the update rate is but once every 4 seconds as opposed to once per second. However, the passive mode has less garble and the

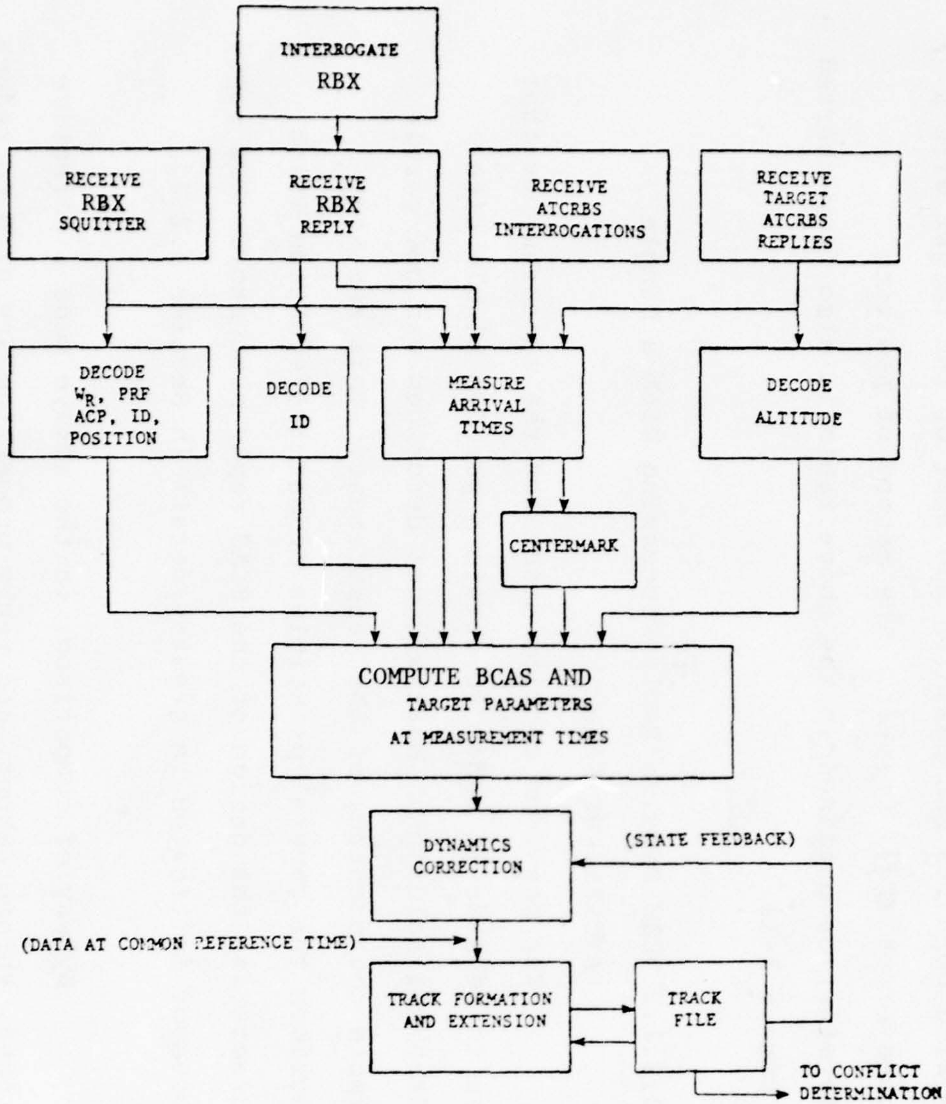
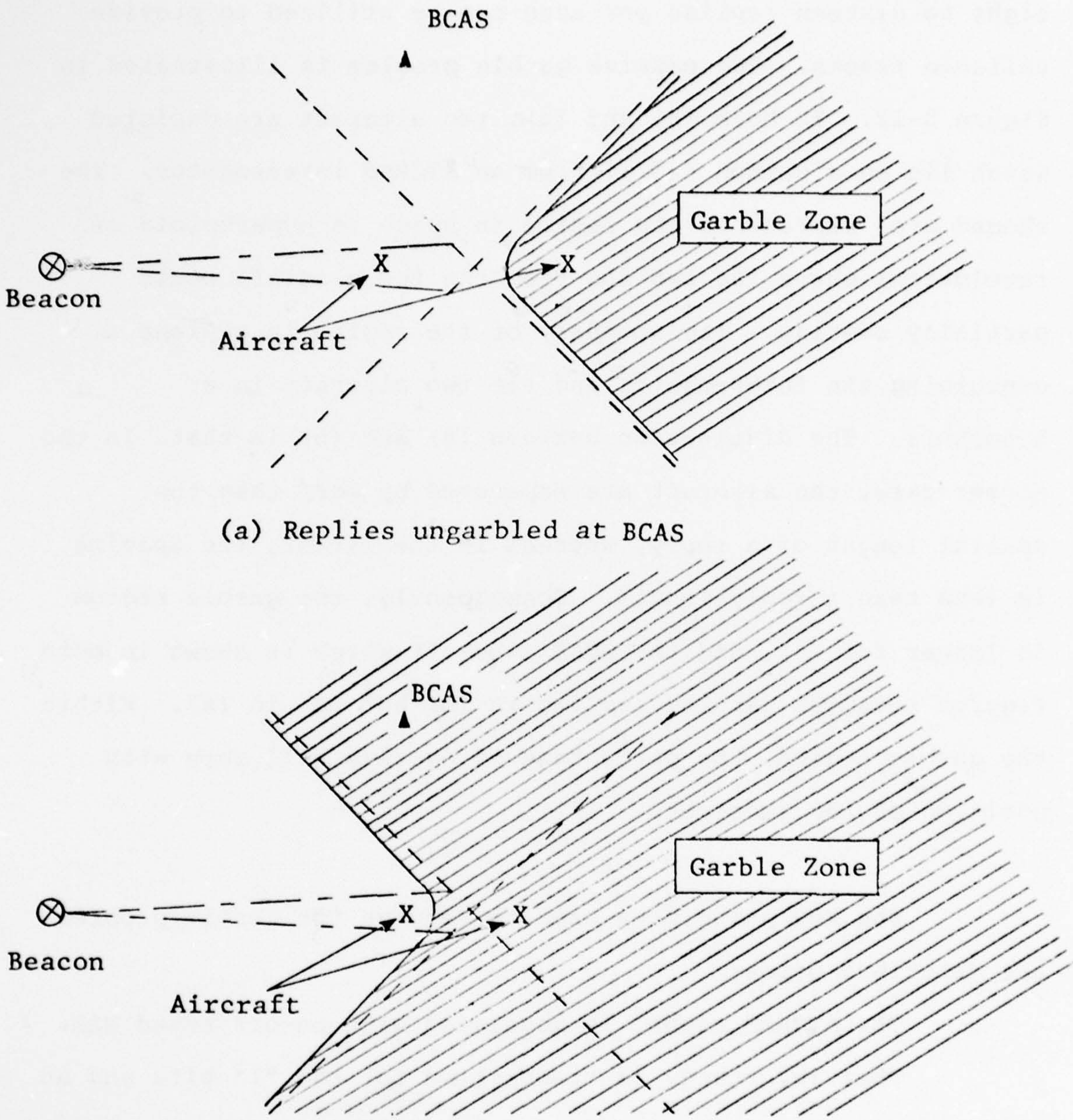


Figure 3-11 : Flow Chart of Position Determination Algorithm for Passive Mode ATCRBS/RBX Single Site eight to sixteen replies per scan can be utilized to provide reliable tracks. The passive garble problem is illustrated in Figure 3-12. In both (a) and (b), two aircraft are depicted which lie on a common radial from an ATCRBS interrogator. The shaded area represents the region in space (a hyperboloid of revolution) where the replies from the two aircraft would partially overlap. The boundary of the region in a plane containing the interrogator and the two aircraft is a hyperbola. The distinction between (a) and (b) is that, in the former case, the aircraft are separated by more than the spatial length of a reply, whereas in the latter, the spacing is less than a reply length. Consequently, the garble region is larger for (b), and the BCAS aircraft which is shown in both figures receives garbled replies in (b) but not in (a). Within the garble region, the percentage of overlap will vary with position of the receiver.

The key principles used to resolve the garble problem are described below:

- The ATCRBS signal is modulated with on-off keyed PAM. That is, energy is transmitted for the "1" bits and no energy is transmitted for the "0" bits. A characteristic of this signaling is that interfering replies rarely destroy the "1" bits in a reply, but



(a) Replies ungarbled at BCAS

(b) Replies garbled at BCAS

Figure 3-12 : ATCRBS Passive Synchronous Garble they may cause an error on "O's." Since the "1's" are virtually certain to occur, BCAS will detect them.

- On the other hand, with high probability, the "O" bits will often be detected as "1" bits in a garble environment. However, as aircraft motion shifts the overlapped replies relative to one another by as little as 0.5 us (500 ft change in differential range), successive samples of a track will greatly increase the probability that a true code can be read. Thus, given enough time, one can hope to resolve ambiguities, eliminate all phantom tracks and determine all true tracks.

- Targets with overlapping interrogation replies at the BCAS aircraft are nearly always separable in azimuth since no two targets will garble at the BCAS aircraft on all of each other's ATCRBS replies per scan unless their positions in space are identical except for altitude. Thus, with a high probability, azimuthal "end effects" will provide some clear altitude and ID target replies, even when most of the replies per scan per target are overlapped, allowing azimuthal centermarking of targets.

The end effect is illustrated in Figure 3-13. There a two-dimensional array is shown in which the ordinate is the differential time of arrival and the abscissa is the interrogation sweep number per scan. A given row then represents a constant value of TOA. In the top row shown, replies occur without overlap between aircraft interrogations 3 and 18 inclusive. The centermarking of this aircraft is then a trivial problem. In the second row two overlapping reply runs are shown. However, thanks to end effects, it is easy to determine aircraft identity, altitude and azimuth centermark of each. This is the case since "1's" are rarely destroyed and overlaps merely "fill in" "O's." Thus, with very high probability, returns 4 through 17 will have no "O" for all ID and altitude replies which is not in each of the ungarbled aircraft 1 and aircraft 2 replies.

The third row describes a case of a three aircraft overlap. Clear end effects exist for aircraft 1c and 3c, but the aircraft 2c reply run is completely garbled. However, a study of the bit patterns of each of the replies could allow a clear azimuth centermarking for aircraft 2c.

A four-garble situation is illustrated in row d, and even though aircraft 3d and 2d have no clear end effects,

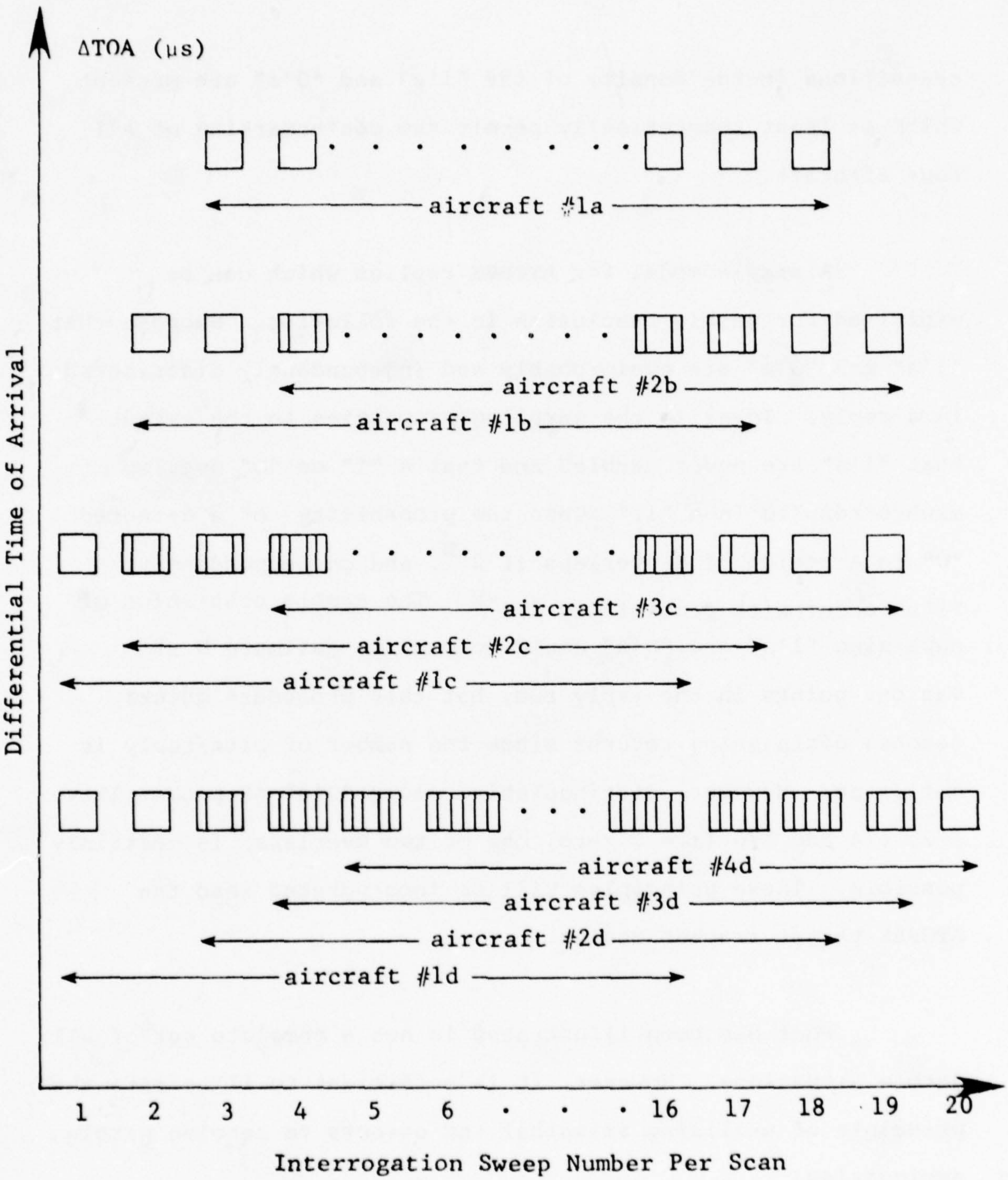


Figure 3-13 Obtaining Track Information from Garbled Replies

transitions in the density of the "l's" and "O's" are present which at least theoretically permit the centermarking of all four aircraft.

A simple model for ATCRBS replies which can be exploited for garble resolution is the following. Suppose that "l's" and "O's" are equiprobably and independently distributed in a reply. Idealize the garbling properties to the extent that "l's" are never garbled and that a "l" on "O" overlap always results in a "l." Then the probability of a detected "O" in a region of N overlaps if 2^{-N}, and correspondingly, "l's" occur with probability $1-2^{-N}$. The sample statistics of supersing "l's" and "O's" could be used to estimate N at various points in the reply run, but this procedure quickly reaches diminishing returns since the number of bits/reply is not large. However, distinguishing among "O's" of probability 1/2, 1/4 and 1/8 (i.e., zero, one or two overlaps) is certainly possible. These principles will be incorporated into the ATCRBS target tracker design.

What has been illustrated is not a complete set of all garble situations. However, it is sufficient to illustrate the principle of utilizing azimuthal end effects to resolve garble ambiguities.

Most passive garble problems originate with aircraft at differing ranges from BCAS. Figure 3-14 helps illustrate the point. In this figure, the passive garble geometry is depicted from a different point of view than that of Figure 3-10. Here, the interrogator and BCAS positions are fixed, and the locus of garbling aircraft is varied. The ellipse shown is a locus for aircraft, all of whose replies would arrive at BCAS with the same delay relative to the interrogation time. The beacon and the BCAS aircraft are the foci of the ellipse. Since ATCRBS interrogations are highly directional, not all positions on the ellipse correspond to aircraft which would actually respond to one interrogation.

In the figure, aircraft T_2 and T_3 are shown within an ATCRBS beamwidth and would have fully overlapping replies at BCAS in response to an ATCRBS interrogation. Note that their ranges from BCAS, ρ_{32} and ρ_{33}, are not equal, however. Thus, if T_2 and T_3 were interrogated by BCAS, a new garble environment would occur. In general, if an active mode omnidirectional interrogation is used by BCAS following passive garble detection, new garble resolution information can be obtained. This information can, in some geometries, enhance garble resolution of existing tracks, especially in moderate traffic density areas.

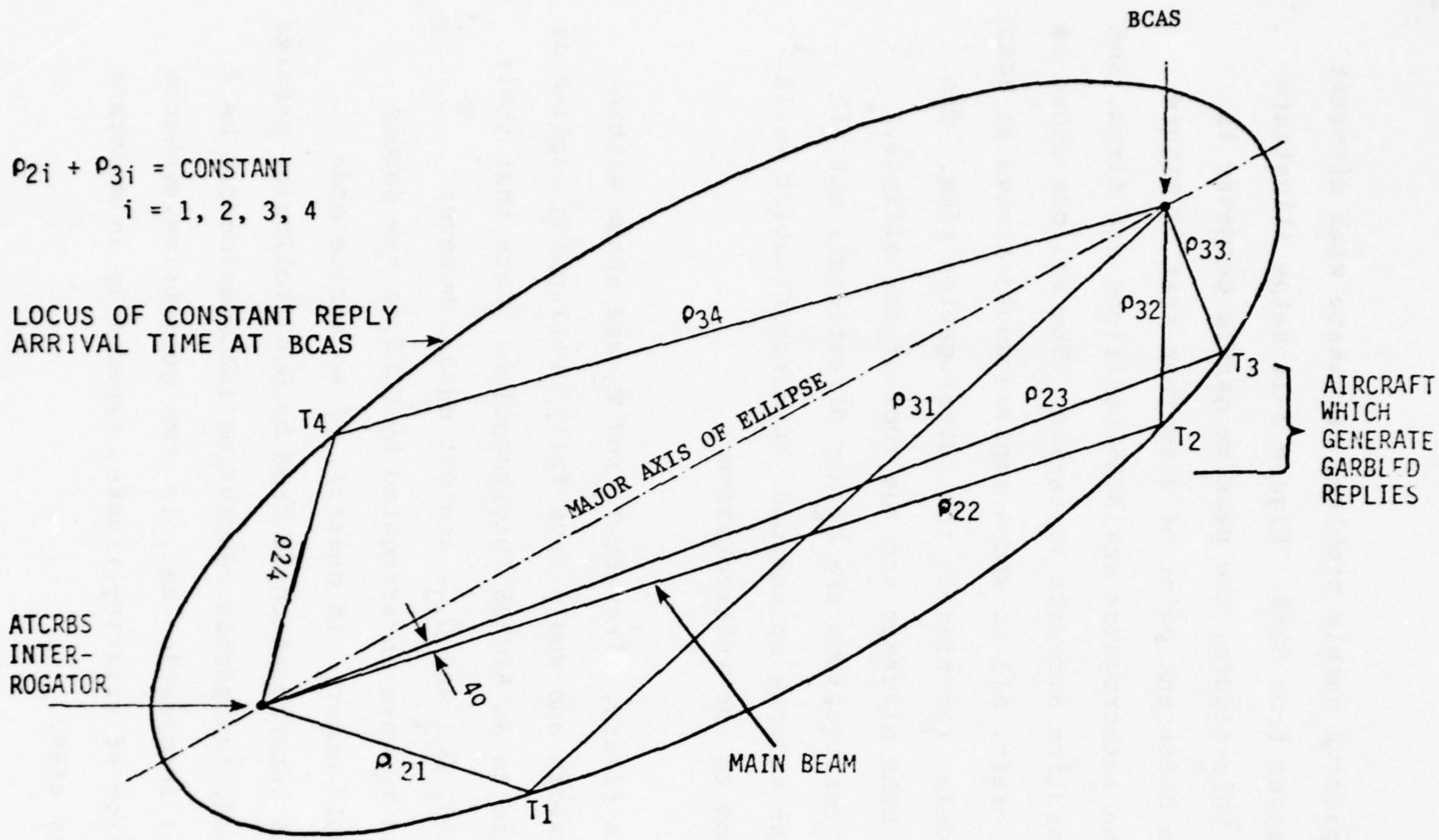


Figure 3-14 : Geometry of Passive Synchronous Garble for Fixed Interrogator, Fixed Receiver

Using all the principles discussed thus far, the BCAS reply processor can acquire aircraft sufficiently far away that at least 60 seconds are available before a collision hazard could occur -- 30 seconds are used to establish track reliability and 30 seconds are for escape maneuvers. Thus, by allowing sufficient tracking time, BCAS is able to acquire aircraft in garble and to continue tracking through it.

A block diagram description of the reply processor is given in Figure 3-15. After reception of a declared time of arrival (a bracket pair spread 20.3 us apart) the ΔTOA is computed and the value of ΔTOA is passed to the centermarker ($\Delta\alpha$), altitude, and ID estimates. In this subroutine a two-dimensional array, as described in Figure 3-13, is generated, and for each row of the array (constant TOA) clusters of replies corresponding to a sequence of replies from at least one aircraft are seen. For each cluster that it finds, the bit pattern of each reply is studied to determine the reply which has the greatest number of zeros. Starting with this reply, it then proceeds to make an estimate of the azimuth (centermark), the altitude, and the ID for each aircraft it determines to be part of the cluster. In addition, it associates with each centermark, altitude, and ID a confidence factor which is a function of the continuity of the cluster, or the percentage of zeros in the "best" reply, which

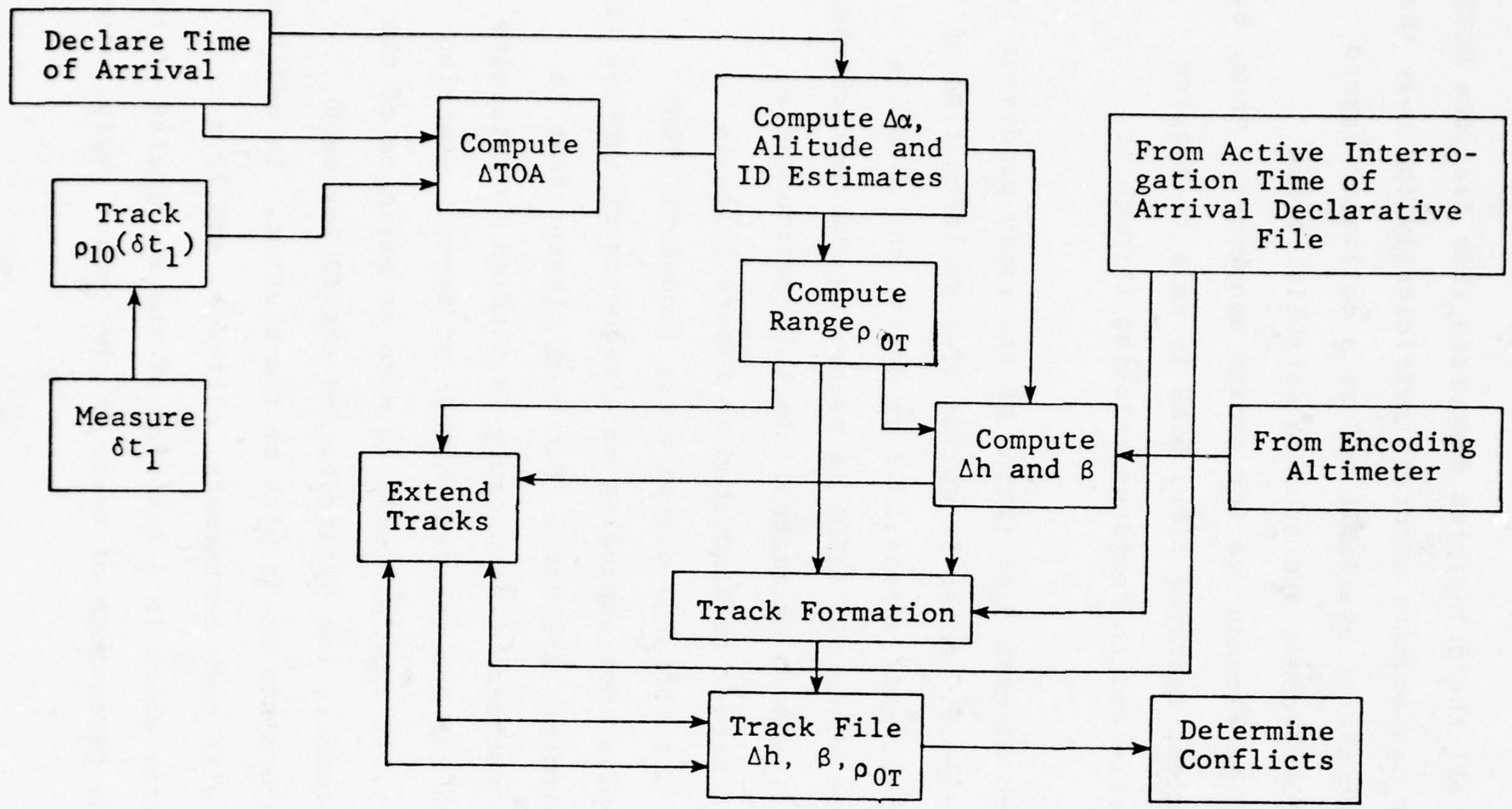


Figure 3-15: REPLY PROCESSOR

in turn is directly related to the reply rate probability for ATCRBS and the "end effect" properties observed in the cluster. Once these estimates are made the range $_{OT}$ can be computed. The range ρ_{OT}, altitude estimate, $\Delta\alpha$ estimate, and ID estimate are then passed on to the *relative altitude and* bearing computer subroutines.

The computed values of ρ_{OT}, Δh and β, along with confidence factor for the computation, are sent on to the extended track file where previously formed tracks are correlated with the latest scan target estimates. Those replies which correlate highly are then used to extend existing tracks, while the remaining target estimates are sent to the track formation routine.

In track formation, tracks are formed by straight line estimates over a 3-scan period. Taking into consideration aircraft dynamics, a single target (Δh, ρ_{OT} and β) estimate per scan can be used in the formation of more than one track. This comes about since we do not have perfect information and want to ensure against losing true tracks. False tracks (or phantom tracks) will be eliminated in track extension when with time the true "O's" of a target reply become evident.

With time, aircraft dynamics will allow the tracker to see the true "O's", and the confidence in ρ_{OT}, Δh, and β will improve on real tracks, while phantom target tracks are eventually purged from the track file before the target ever comes within range of being considered a potential threat.

3.2.2.1.3 Passive Single Site ATCRBS/RBX Singularities

The accuracy of the passive solution is geometrically dependent upon the range of the BCAS aircraft to the ATCRBS/RBX site and the relative orientation of the target with respect to both BCAS and the ATCRBS/RBX site. To illustrate this, the two dimensional rms position error σ_ρ (ρ_{1T}, β) is plotted as a function of β in Figure 3-17 to Figure 3-20.* These figures were derived for the geometry shown in Figure 3-16.

In Figure 3-16 the target is described to be on a circular track a distance r from the BCAS aircraft while the BCAS aircraft is seen to be a distance ρ_{10} from the radar. The performance figures show how σ_ρ varies with ρ_{10} and β.

As can be seen the rms position error σ_ρ increases with range. However, for values of ρ_{10} less than 20 nm, and

*/ Assumptions and equations used in obtaining these results are given in Appendix E. It should be noted that the effects of garble were not included in this analysis.

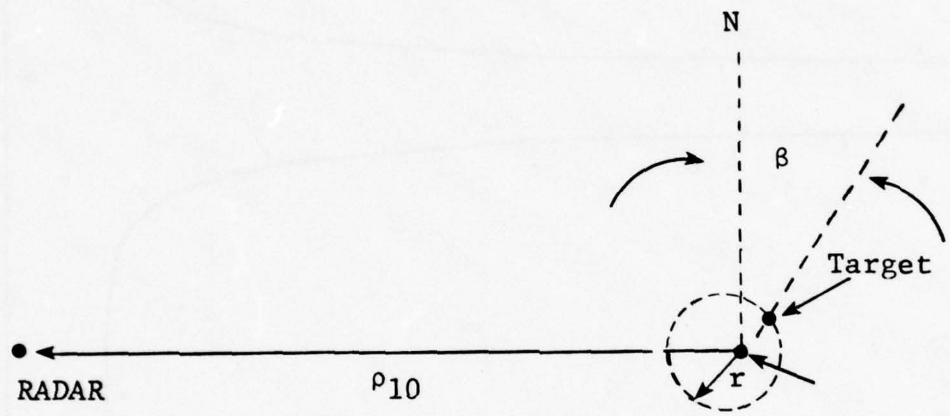


Figure 3-16

Geometry for σ_ρ Analysis - ATCRBS/RBX Site

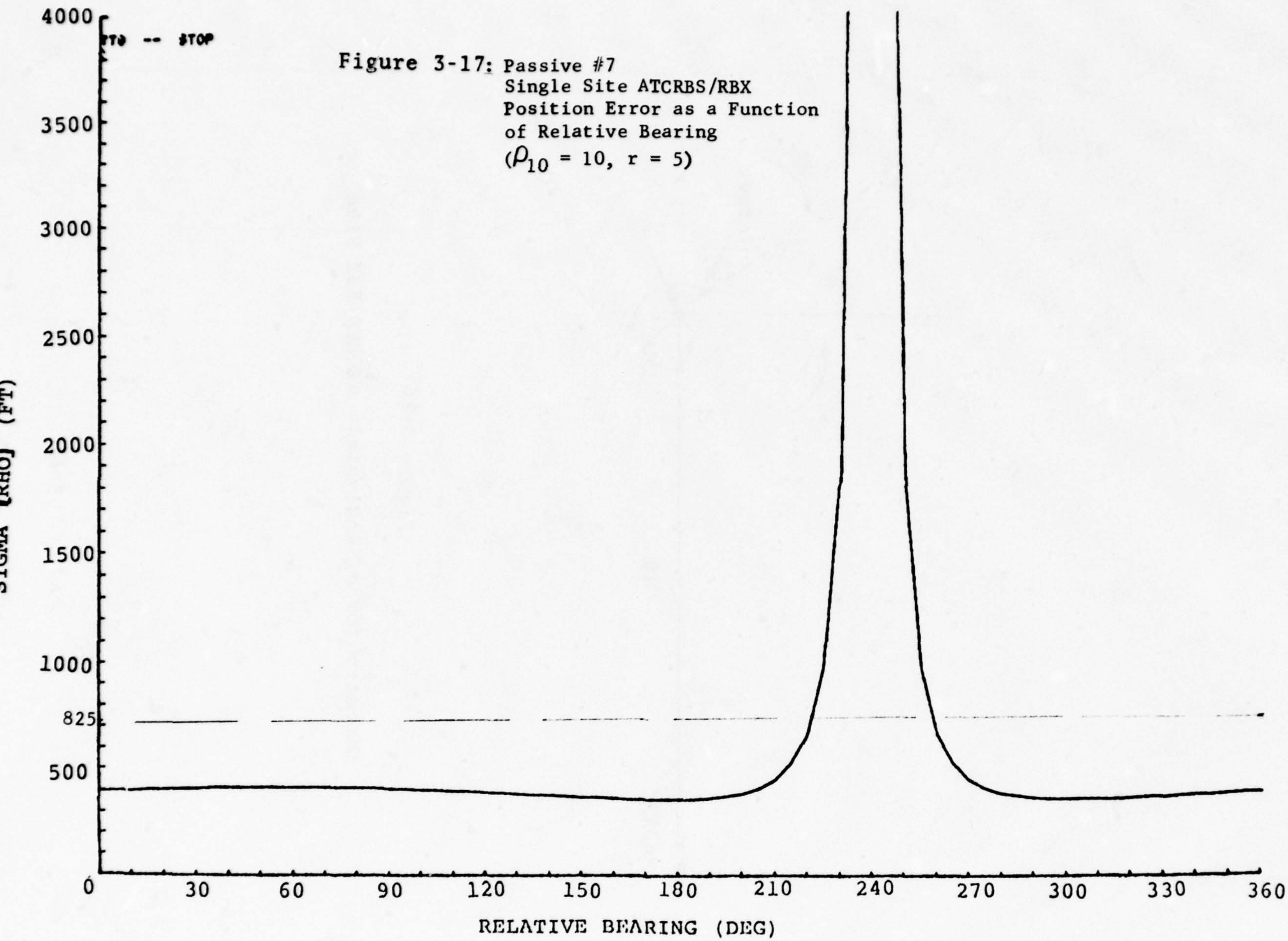


Figure 3-17: Passive #7
Single Site ATCRBS/RBX
Position Error as a Function
of Relative Bearing
(ρ_{10} = 10, r = 5)

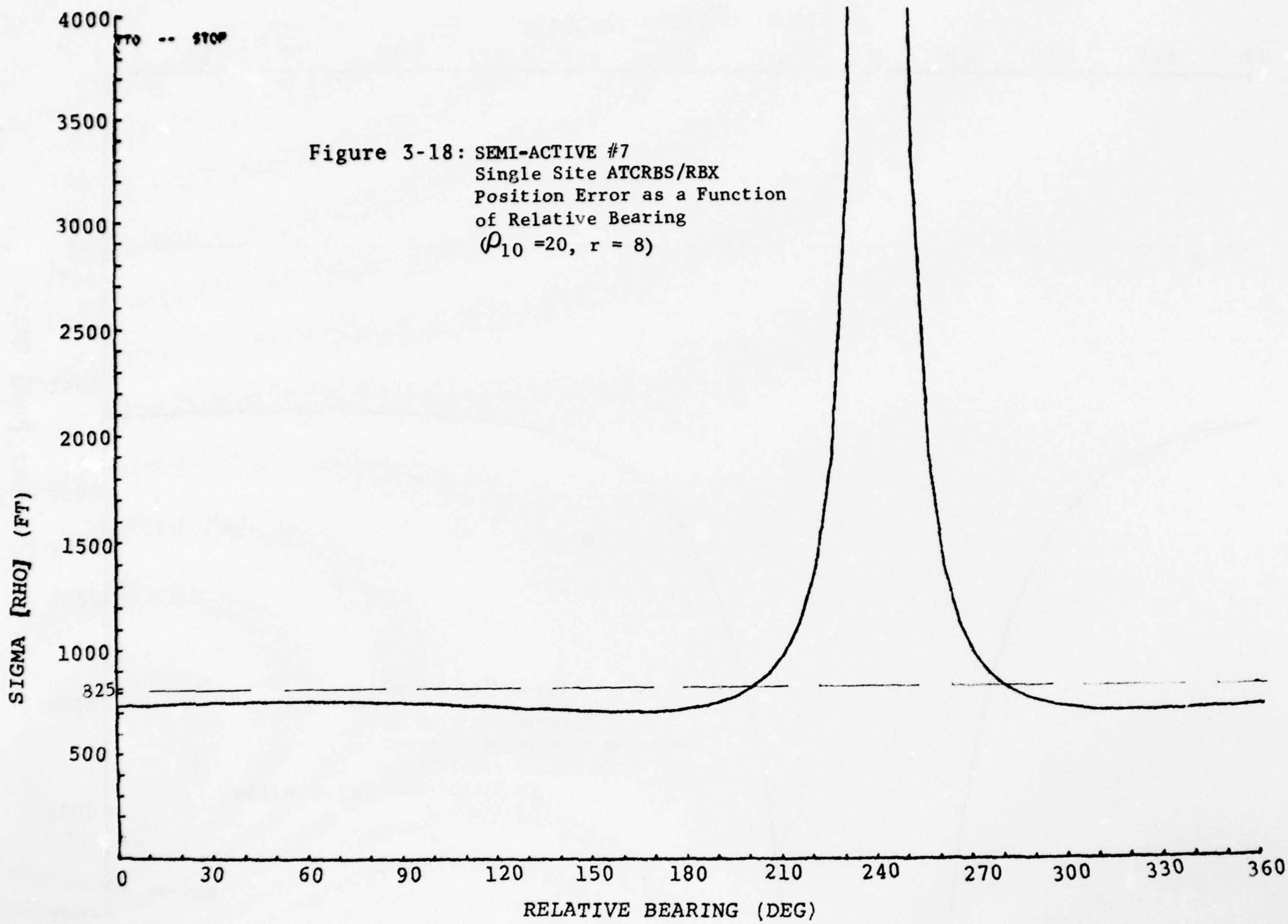


Figure 3-18: SEMI-ACTIVE #7
Single Site ATCRBS/RBX
Position Error as a Function
of Relative Bearing
(ρ_{10} =20, r = 8)

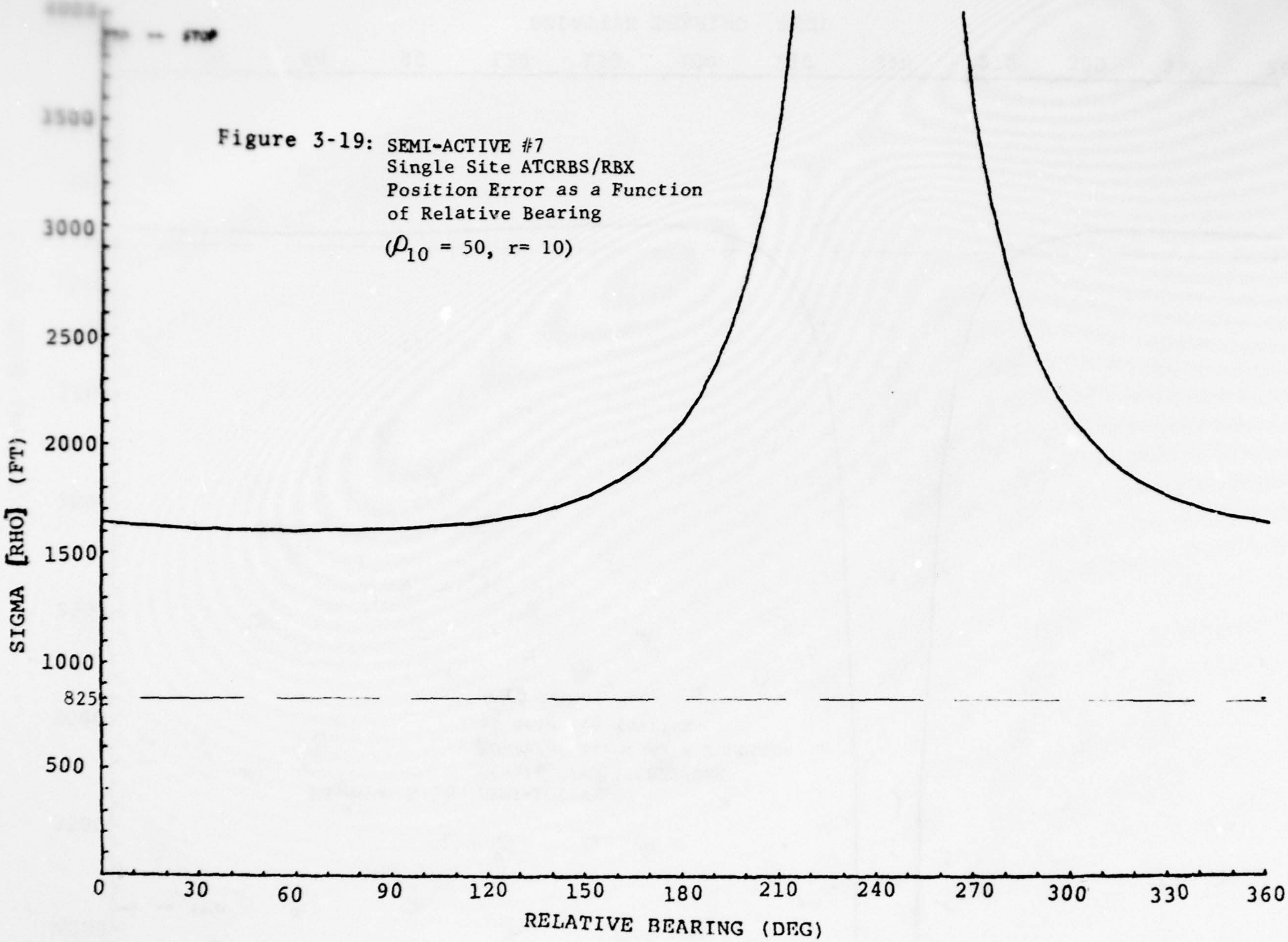


Figure 3-19: SEMI-ACTIVE #7
Single Site ATCRBS/RBX
Position Error as a Function
of Relative Bearing
(ρ_{10} = 50, r= 10)

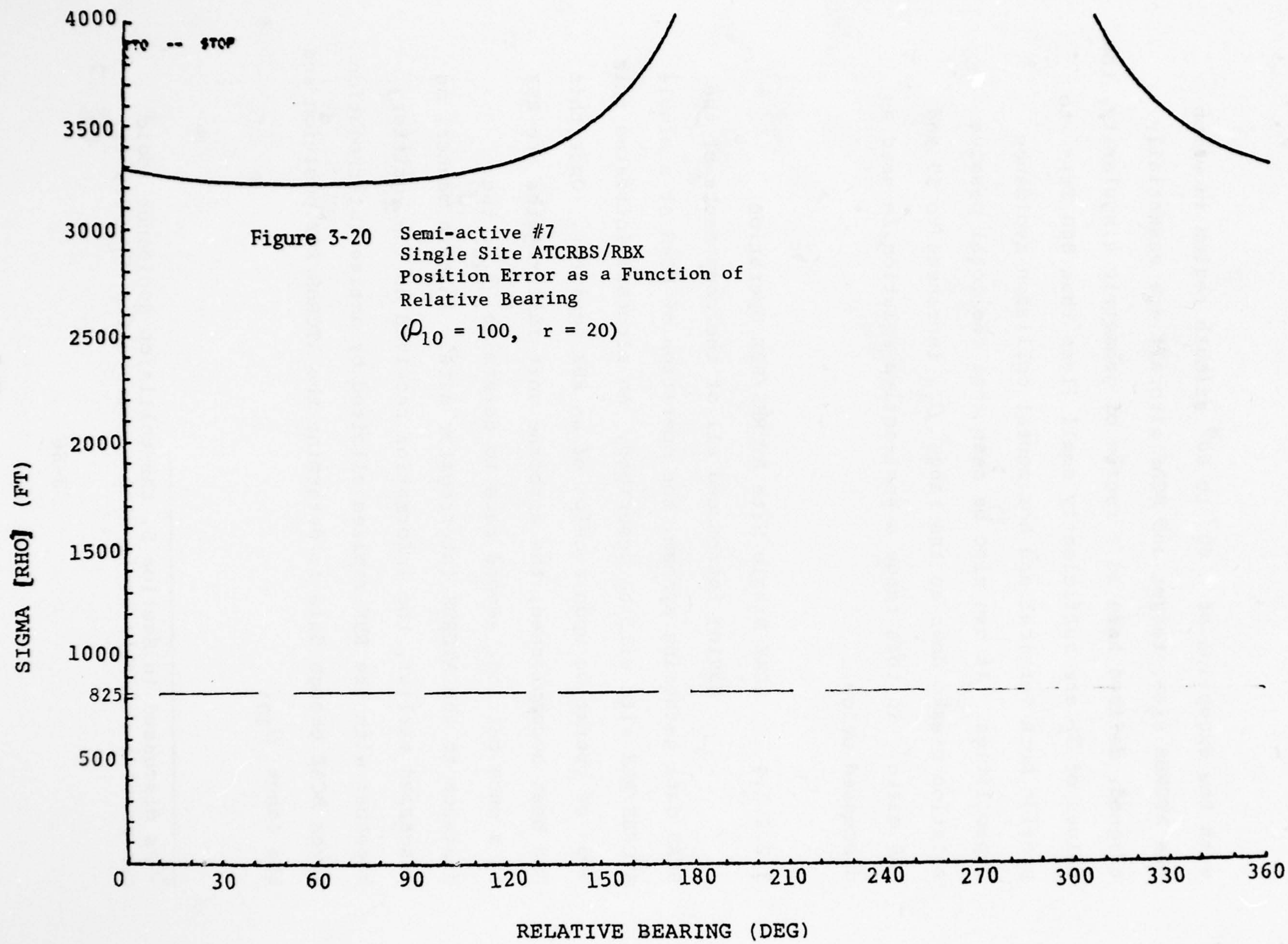


Figure 3-20 Semi-active #7
Single Site ATCRBS/RBX
Position Error as a Function of
Relative Bearing
(ρ_{10} = 100, r = 20)

with the exception of a 40° to 60° azimuth region in which the ATCRBS site, target and BCAS aircraft are essentially aligned, defined here as a region of geometric singularity, the values of σ_{ρ} are sufficiently small (less than 800 ft)* to provide both vertical and horizontal collision avoidance capabilities. It can also be seen that the total passive solution breaks down as the range ρ_{10} increases to 50 and 100 miles. In this range a semi-active solution is used as discussed below.

3.2.2.1.4 BCAS Single Site ATCRBS/RBX Operation

Having introduced all of the components of the BCAS data gathering system, the operation of BCAS at a single ATCRBS/RBX site will be described. An aircraft initiates this mode of operation upon receipt of an RBX squitter. Once this has been accomplished, the airborne unit interrogates the RBX at a once per four second rate to determine ρ_{10}, the distance to the ATCRBS interrogator site. In this manner, as discussed earlier, the information received on the squitter together with the RBX replies elicited by active interrogation gives BCAS enough data to determine the ATCRBS/RBX position and the range ρ_{10}.

*/ As discussed in Section 5, the collision avoidance logic can provide reliable horizontal maneuvers for $\sigma_{\rho} < 800$ ft.

If the range ρ_{10} is greater than 20 nm, BCAS goes semi-active everywhere (Mode 5). In this mode, tracks are formed by combining the inputs obtained from both the active (see Section 3.2.1) and passive modes.

In combining active and passive data, there are more measurements then there are unknowns. A study has been performed to determine which measurement data are best to use to minimize σ_ρ for all semi-active modes used in BCAS.* This study is discussed in Section 4.2 and the results are summarized here.

In regions where Mode 5 is used, the semi-active mode provides sufficiently small σ_ρ 's so that vertical and horizontal collision avoidance maneuvers can be made reliably. However, in the area of the singularity only vertical collision avoidance maneuvers can be made reliably.

When the range ρ_{10} is less than 20 nm BCAS operation will be passive except in the area of the passive singularity where BCAS will go semi-active. Both the passive mode and semi-active modes allow vertical and horizontal maneuvers.

---

*/There are times when the inaccuracy in a measurement is so large that it is best not to use the measurement data to compute target positions.

As in the all-active mode the BCAS air-to-air data link is used to resolve "tie breakers" between two BCAS aircraft in conflict. The availability of an RBX on the ground, however, adds another dimension in that a BCAS aircraft preparing for a collision avoidance maneuver can data link down its intended maneuver to ground control. Ground control has the option of utilizing this information; to coordinate a maneuver with the non-BCAS equipped target, to remove another aircraft from the BCAS maneuvering airway, to transmit an alternate command to the BCAS aircraft via the RBX data link which BCAS selects as its command to the pilot, or lastly to do nothing.

3.2.2.2 Dual Site - ATCRBS/RBX (Modes 4 and 6)

The dual site - ATCRBS/RBX geometry is illustrated in Figure 3-21. In this case, we will once again have more measurement information than we have unknowns so that there is the question of which are the best data to use to determine target position. Intuitively, we know that if two sites are used then singularity regions will not overlap so that one could essentially take the best of two single site solutions. The analysis performed and described in Section 4.2 determined that it is possible to do better than this. When there is good geometry BCAS will operate passively outside of the singularity

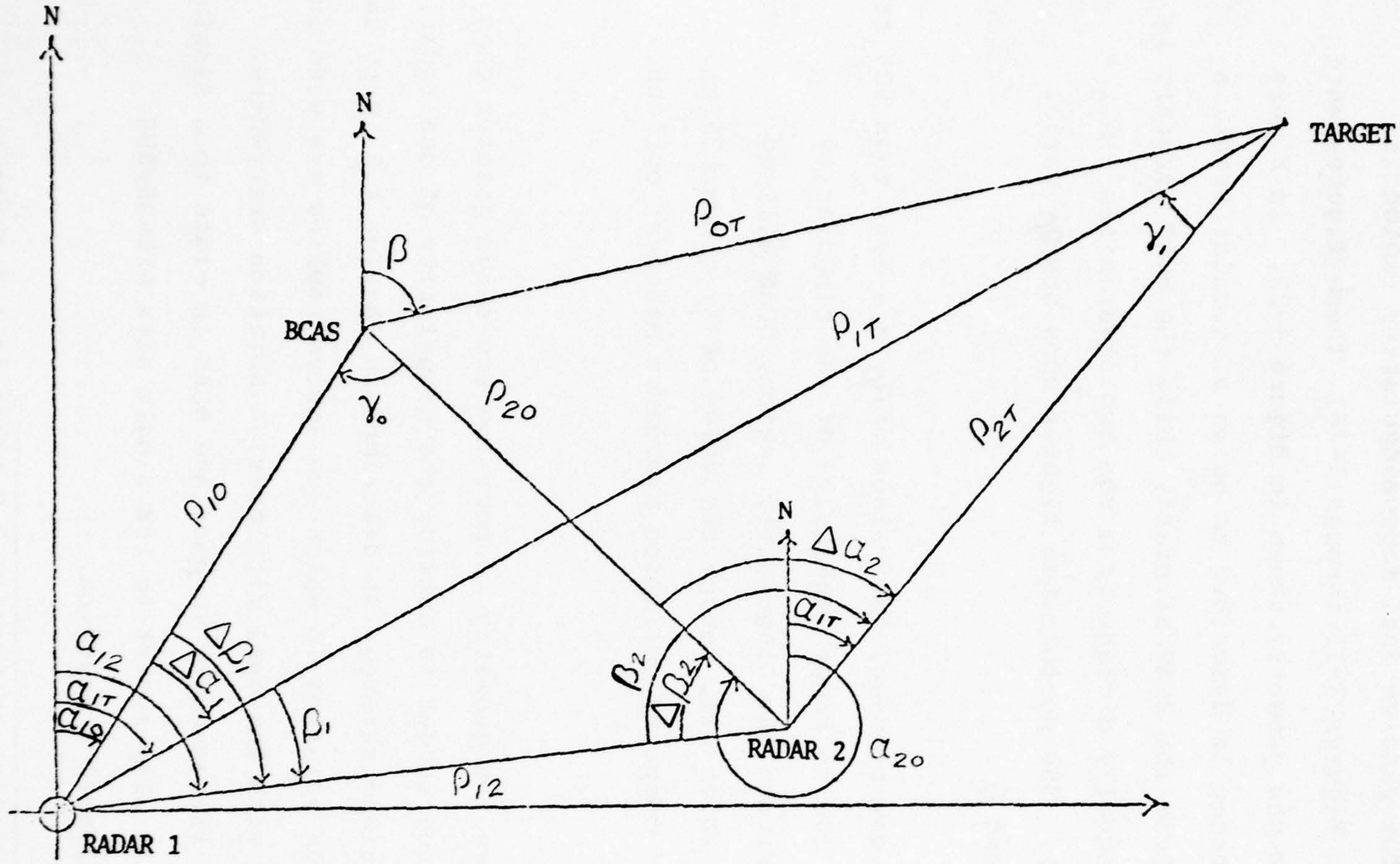


Figure 3-21

Dual Site ATRCBS Geometry

regions*. The passive dual mode singularity region is described in Figures 3-23 through 3-26. These figures were derived from the geometry shown in Figure 3-22. In Figure 3-22, the target is described to be on a circular track, a distance r from the BCAS aircraft, while the BCAS aircraft is seen to be equally distant from the two radar sites ($\rho_{10} = \rho_{20} = \rho$). The performance figures show how σ_ρ varies with ρ , N and β .

As can be seen, the values of σ_ρ are less than 825 ft. even out to 100 nm range (exclusive of the singularity regions). Within the singularity region, BCAS will go semi-active which will reduce the value of σ_ρ below 825 ft. allowing for complete collision avoidance maneuver options everywhere.

When the geometry is poor and the range greater than 20 nm, but the target is outside the singularity of one radar, then the optimum strategy as described in Section 4.2 is to use a semi-active solution in which the active replies are used in conjunction with the dual site passive solution everywhere. However, if the geometry is poor and BCAS is close to a single site, then it will revert to the single site ATCRBS/RBX passive/semi-active solution.

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*/At the beginning of Section 3.2 there is a discussion of good and poor dual site geometry.

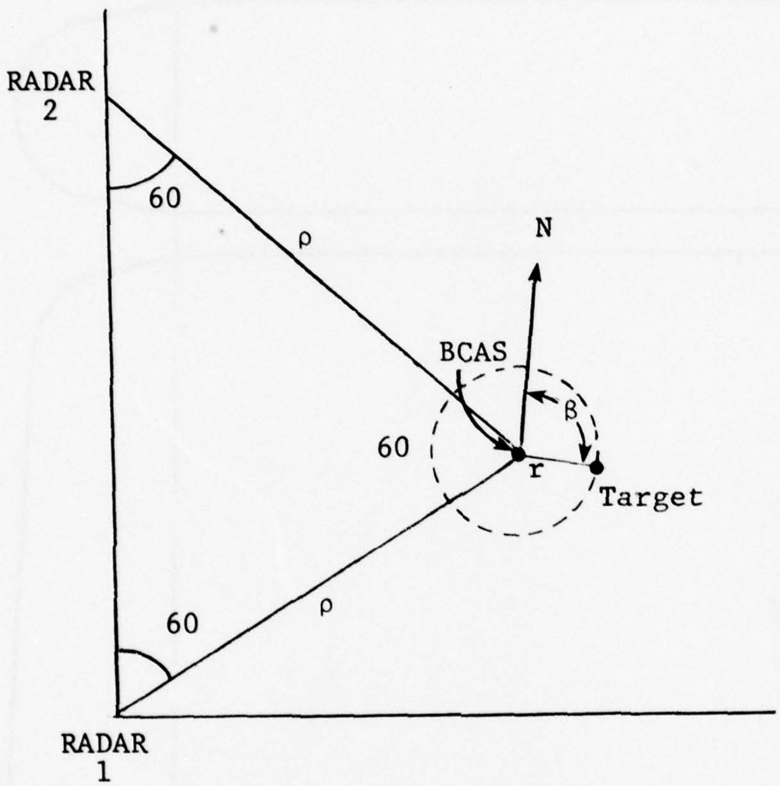

Figure 3-22

Dual ATCRBS Site Geometry
for Computed σ_ρ

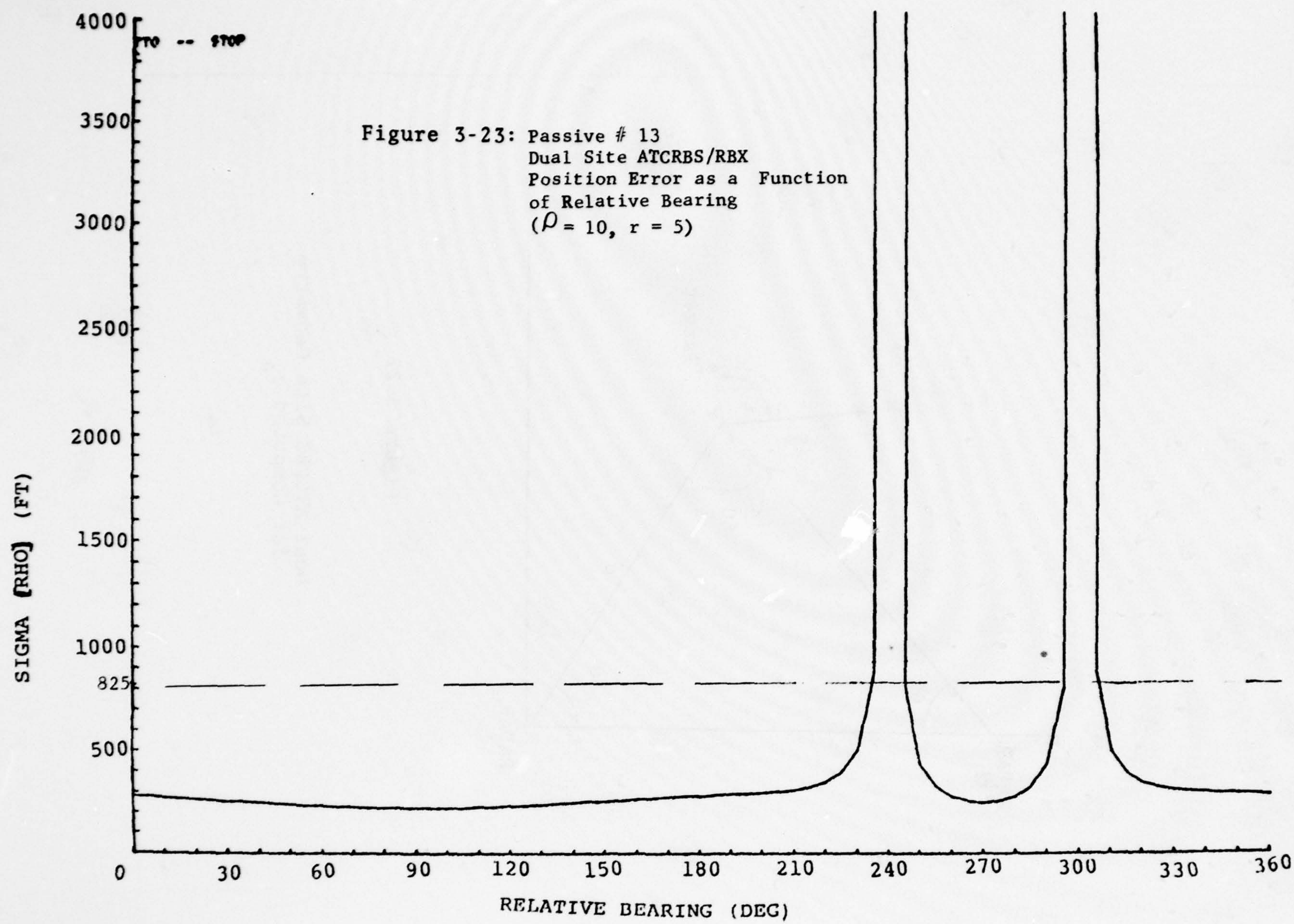

Figure 3-23: Passive # 13
Dual Site ATCRBS/RBX
Position Error as a Function
of Relative Bearing
(ρ = 10, r = 5)

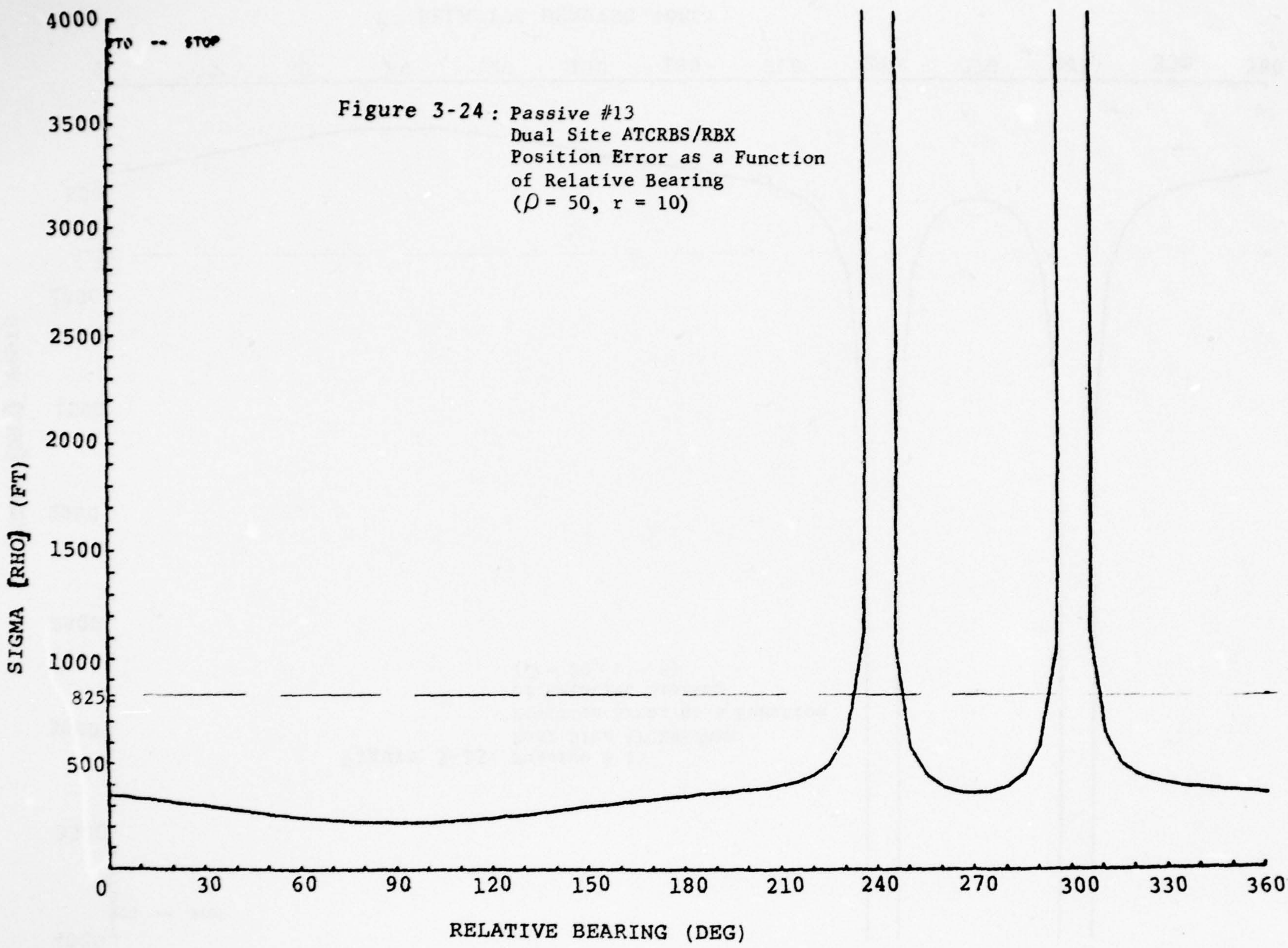

Figure 3-24 : Passive #13
Dual Site ATCRBS/RBX
Position Error as a Function
of Relative Bearing
(ρ = 50, r = 10)

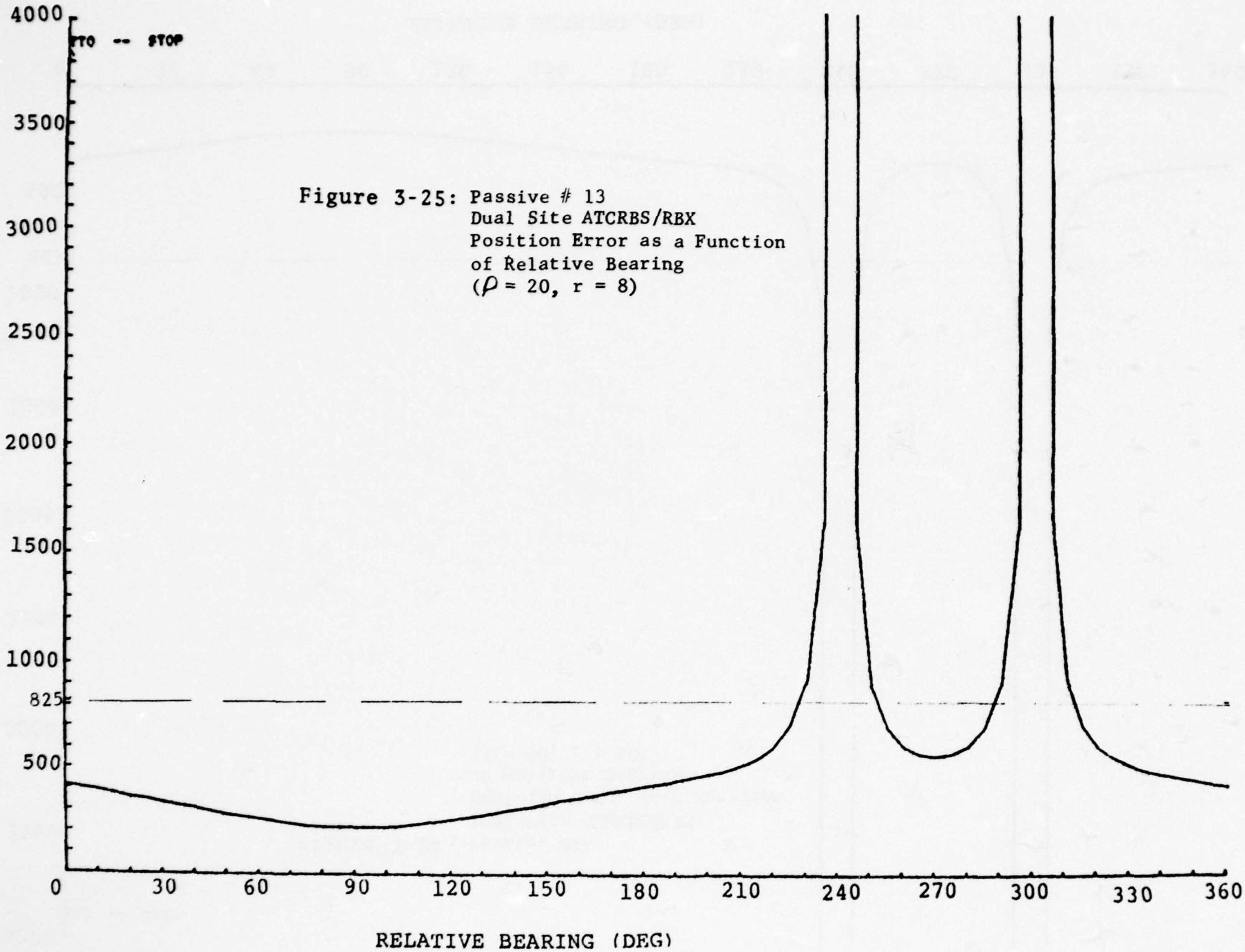

Figure 3-25: Passive # 13
Dual Site ATCRBS/RBX
Position Error as a Function
of Relative Bearing
(ρ = 20, r = 8)

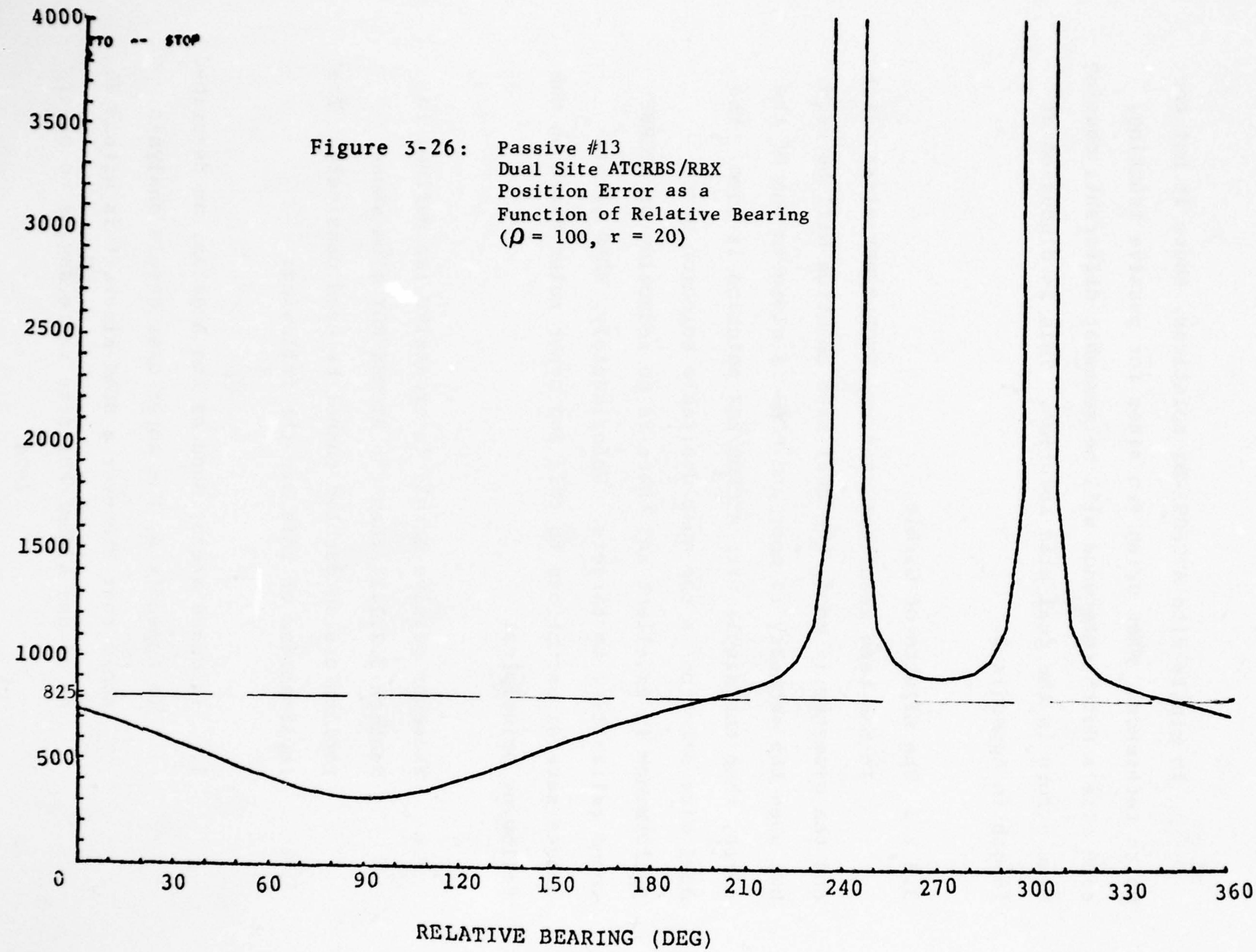

Figure 3-26: Passive #13
Dual Site ATCRBS/RBX
Position Error as a
Function of Relative Bearing
(ρ = 100, r = 20)

In single site ATCRBS/RBX solutions, there is but one North reference. When using two sites for passive tracking, each site's North reference will be somewhat different, causing bias errors in the dual site solution. This is discussed at length in Appendix G.

3.2.2.3 The Effects of Garble

It has been seen that when two ATCRBS/RBX sites exist and the geometry is good, the dual site solution will be used, but when the geometry is poor and BCAS is close to one of the sites, then the single site ATCRBS/RBX solution is used. The dual site solution is the most desirable solution since performance is excellent and there is no reduction of ATCRBS round reliability to targets. Unfortunately, BCAS garble causes several exceptions to this and other rules based on the following principles:

- o Whenever passive garble is excessive (as defined in Section 3.2.1.1) then the ATCRBS/RBX site whose replies are so garbled cannot be used passively. The implications of this are the following:

  1. In dense areas, such as Los Angeles, as described in Appendix A, the worst case garble analysis shows that whenever a BCAS aircraft is within 20 nm of one ATCRBS/RBX site there may be no other

ATCRBS/RBX site that can be used, because of excessive garble, for a totally passive solution. In such cases, BCAS will have to go semi-active if it is to operate. Although the passive mode has potentially less garble, it has less capability to reduce garble effects on track reliability than to the active mode in which the greater amount of potential garble can be dealt with through the use of a directive antenna and the whisper/shout technique.

In going semi-active in the Los Angeles basin or other dense areas, there is great concern that the BCAS not have too great an impact on ATCRBS round reliability. As will be seen in Section 4.2.1, where the directional antenna design is discussed and again in Section 6 under Performance Summary, the reduction in round reliability can be kept to less than 2% for 100 semi-active BCAS aircraft.

2. If the garble from one or more sites is excessive when BCAS is greater than 20 nm from either of the sites, then BCAS will go semi-active with one site or all-active if both sites have excessive

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garble. It should be noted that just as in the Los Angeles basin, excessive passive garble ordinarily will not be found uniformly in all directions but rather in one or two of the 20° sectors. Indeed, when there is no ATCRBS/RBX within 20 nm, it is highly improbable that passive garble will be excessive due to the strong correlation of radar site location and traffic density.

3.2.2.4 A Summary of ATCRBS/RBX Operation

To summarize, in an ideal ATCRBS world where all ATCRBS sites are RBX-equipped, BCAS will operate in a dual-site passive everywhere geometry, garble permitting. In the singularity zones, however, BCAS operates in a semi-active mode. If only one site exists then BCAS will utilize the single site passive/semi-active solution when within 20 nm of the radar and the semi-active solution everywhere else. When no sites are available, the BCAS will go active. However, as the analysis demonstrates, under worst case conditions the ATCRBS round reliability degradation can be kept under 2%.

Finally, the question of three-site passive solution, or more specifically, the lack of one in this BCAS concept, is addressed. There are two major reasons why BCAS hasn't a site passive solution (n>2). The first is that the software required to carry a track file for each passive site represents a significant part of the BCAS software. The concept intent is to keep the software requirement to the minimum which will provide operation everywhere.

Secondly, and more importantly, a third or fourth site would not necessarily permit an all-passive solution (no singularities) because of the close correlation between traffic density and number of sites. A 3-ATCRBS/RBX coverage environment would most probably occur in a dense aircraft environment such as Los Angeles in which the passive garble would be excessive from any site but the nearest. Thus, by adding multi-site passive modes, BCAS would only increase its operational complexity without a corresponding improvement in performance.*

3.2.3 Single and Double Site ATCRBS Solutions (Modes 2 and 3)

If the ATCRBS world were truly ideal, all targets would be Mode C-equipped. But just as it will take time to equip the general aviation fleet with encoding altimeters, so it will take time to equip each ATCRBS site with an RBX, Thus,

*/An analysis is underway to determine the validity of this hypothesis.

the implementation of BCAS service will initially see large regions in which there are few (or no) ATCRBS sites equipped with an RBX capability.

In areas with either a single or dual site ATCRBS without RBX's, BCAS will operate with degraded performance. Even without the RBX, BCAS will still be able to provide PWI and vertical collision avoidance maneuvers everywhere and horizontal collision avoidance maneuvers in some regions of airspace. Without the use of the RBX, the degree to which BCAS must operate in the active mode increases, making it highly unlikely that this mode of BCAS could operate successfully in very dense airspace such as the Los Angeles basin.

If an omnidirectional North reference is transmitted by the ATCRBS interrogator site, a single-site semi-active air-to-air collision avoidance system can be designed to provide accurate 3-dimensional target position (range, bearing, and altitude). When two such sites are used with good geometry, a <u>passive</u> solution, augmented by a semi-active solution for passive singularities, can be utilized to track all targets. As it turns out, a BCAS aircraft equipped with a directional antenna can also make use of these North referenced solutions <u>without</u> the necessity of having an RBX or a North pulse kit installed at the ATCRBS site. It does so by (i) measuring the beacon antenna rotation rate, (ii) determining bearing to the beacon relative to its onboard North reference (compass), and (iii) determining time the mainbeam passes the BCAS aircraft. From these three measurements, time of North passage of the ATCRBS beam can be inferred, the procedure is as follows:

An ATCRBS interrogation is detected by the BCAS 1030-MHz receiver by processing the received signal in an omni mode. Using the multiple beamforming capability of the antenna signal processor (see Section 4.2.1), sum beams can be formed in each of 9 directions to determine a coarse angle of arrival (based on sum beam signal level), and a difference beam can be formed in the appropriate sector to more accurately measure the angle of arrival. This is repeated over each mainbeam interrogation which exceeds the SLS level (12 to 16 interrogations). The average of these measurements gives ATCRBS site bearing at mainbeam passage time. Mainbeam passage time is found by centermarking on the received interrogations.

The above procedure is repeated on the following beam passage (about 4 seconds later), which gives the beacon rotation rate. Based on the indicated measurements, North reference of the ATCRBS site can be computed relative to the onboard compass indication of magnetic North. In Appendix I.1 it is shown that the net computed North reference error is substantially less than 1^{o}, even at maximum range (100 nm). The Appendix also shows that the requirement that the BCAS aircraft reply to the interrogations upon which the site location measurements are being made does not restrict its ability to track targets near the site.

To summarize, the stated bearing accuracy can be achieved for the following reasons:

- Monopulse detection is used on each sweep
- There are at least 12 sweeps per scan
- The link budget is very favorable, largely because of the high ATCRBS effective isotropic radiated power (EIRP) and the BCAS antenna gain
- There is a minimum of garble on the 1030-MHz frequency

Thus within 4 seconds the ATCRBS bearing and North reference are determined. Having this information on one or two sites allows for single or dual site solutions equivalent to the North reference solution.* The accurancy results for the one and two ATCRBS-only algorithm are presented in Appendix E.

3.2.4 Mixed Mode Operation (Mode 7)

It is highly probable that as RBX's are implemented there may be one RBX and one or more ATCRBS sites in its vicinity. In such situations a very good dual site solution exists using one ATCRBS site and one ATCRBS/RBX site. BCAS would then remain passive everywhere but in the singularity regions and would go semi-active in regions of singularity.

To obtain this dual mode performance a North reference must be estimated for the ATCRBS site. In the previous sections it has been shown that such a North reference could be obtained using the directional antenna. A second method for obtaining a North reference is essentially a "tracker" of this reference from the RBX site.

---

*/The North reference obtained using the directional antenna should be equivalent in accurancy to the measurement of "own azimuth" obtained with a North pulse kit (1). Furthermore, a two-site solution thus obtained has no North pulse bias since all bearings are referenced to the BCAS aircraft heading. This differs from the general North pulse references of any two ATCRBS sites (see Appendix G).

The North pulse transfer technique is more accurate at BCAS distances between 50 and 100 nm from the ATCRBS site then that achieved by using the directional antenna (.3° compared to .5°) but is less accurate at distances close to the ATCRBS site (1.0° compared to .5°).

The North pulse transfer technique is described in Section 3.4.5 and so will not be presented here.

The accuracy performance for this mode is given in Appendix E.

3.3 BCAS In The All-DABS Environment

In the all-DABS environment each aircraft is equipped with an encoding altimeter, and DABS transponder capable of responding to both DABS and ATCRBS interrogations and which squitters its ID and altitude once a second via DABS reply. Many aircraft will, in addition, be BCAS equipped. Each DABS ground site will have a colocated RBX transponder which functions for ranging and data link as previously described.

The multimodes of DABS are described in Figure 3-27. As with the all-ATCRBS environment a single interrogation mode

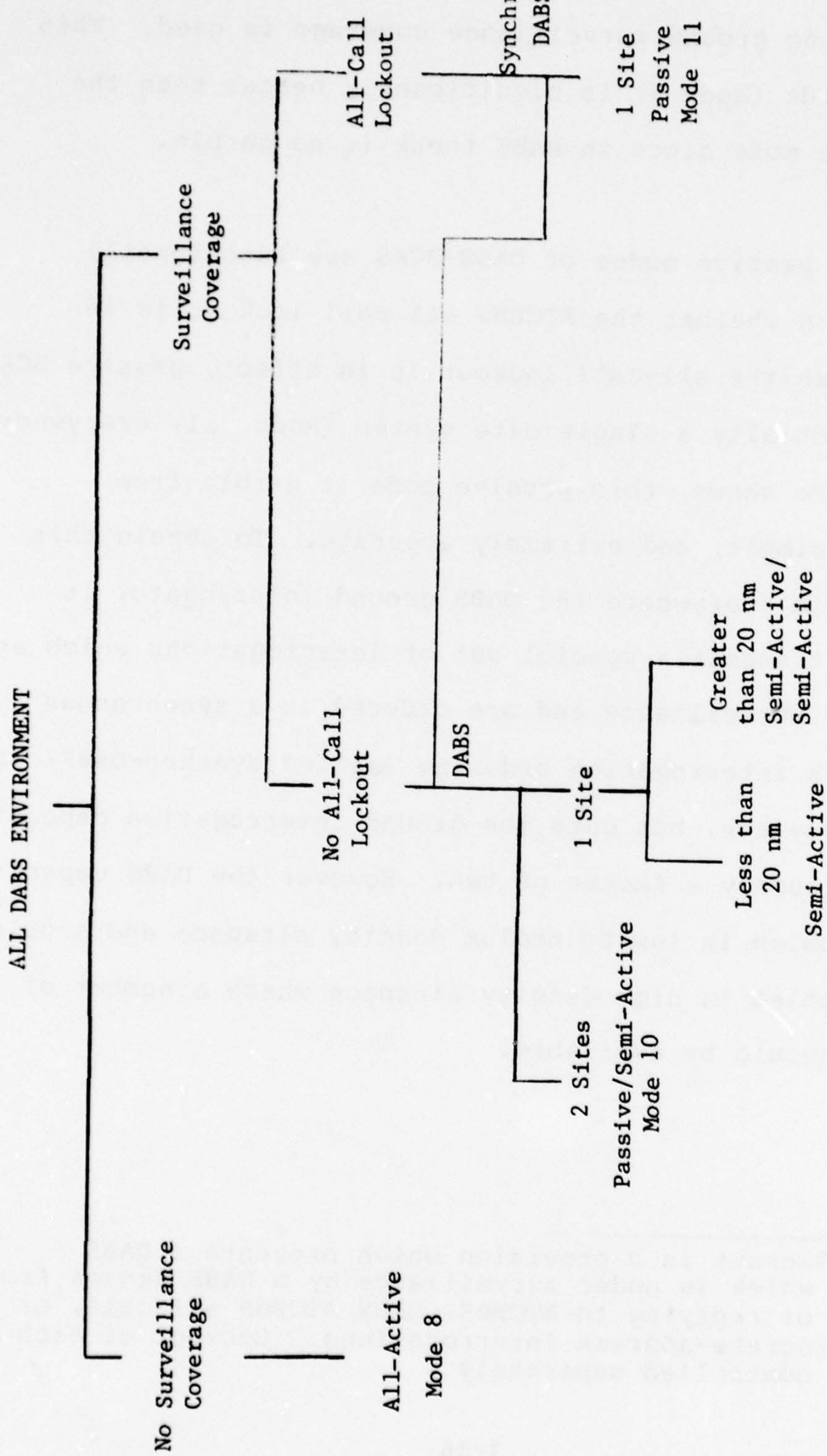
ALL DABS ENVIRONMENT
No Surveillance Coverage
All-Active
Mode 8
Surveillance Coverage
No All-Call Lockout
DABS
1 Site
2 Sites
Passive/Semi-Active
Mode 10
Less than 20 nm
Semi-Active
Greater than 20 nm
Semi-Active/Semi-Active
Mode 9
All-Call Lockout
Synchro-DABS
1 Site
Passive
Mode 11

Figure 3-27

for areas of no ground surveillance coverage is used. This all-active mode (Mode 8) is significantly better than the ATCRBS active mode since in DABS there is no garble.

The passive modes of DABS-BCAS are functionally dependent upon whether the ATCRBS all-call lockout is in effect.* When the all-call lockout is in effect, passive BCAS becomes essentially a single site system (Mode 11) everywhere and as will be shown, this passive mode is garble-free everywhere, simple, and extremely accurate. To obtain this garble freedom everywhere the DABS ground interrogator is required to transmit a special set of interrogations which are not used for surveillance and are ordered in a synchronous manner. This interrogation ordering (called synchro-DABS) is simple to generate, but cuts the ground interrogation capacity of DABS by roughly a factor of two. However the DABS capacity is not a problem in low to medium density airspace and should not be a problem in high density airspace where a number of DABS sites should be available.

---

*/All-call lockout is a provision which prevents a DABS transponder which is under surveillance by a DABS sensor from squittering or replying to ATCRBS, DABS ATCRBS all-call, or auziliary discrete-address interrogations. Lockout of each function is controlled separately.

When synchro-DABS is not used, BCAS requires that the ATCRBS all-call lockout not be used as well.* As will be shown, BCAS has to measure azimuth on the ATCRBS interrogations when not using synchro-DABS. In addition, it will be shown that BCAS garble exists in the DABS world when there is no synchro-DABS. There are 2 modes to DABS in non synchro-DABS regions. Mode 9 which is a single site mode and Mode 10 which is a dual site mode.

The performance of BCAS in the DABS world is summarized in Table 3-2. It can be seen that its performance is exceptionally good almost everywhere.

3.3.1 BCAS in Regions of No Surveillance (Mode 8)

In areas of operation discussed in this section BCAS will go active and will provide PWI and a vertical collision avoidance maneuver capability everywhere.

3.3.1.1 Ordinary Targets

The discussion required here almost parallels that in the corresponding ATCRBS section (3.2.1.1) and can be handled briefly. The only new possibility that arises is that the target can now be a non-BCAS equipped DABS aircraft.

---

*/If the all-call lockout is not used then synchro-DABS is still desired but not required.

		COLLISION AVOIDANCE CAPABILITY		
BCAS Mode		PWI	Vertical Maneuver	Horizontal Maneuver
8		✓	✓	
9	Singularity >20 nm	✓	✓	+
	Everywhere else	✓	✓	✓
10		✓	✓	✓
11		✓	✓	✓

Table 3-2
BCAS Collision Avoidance Capability in DABS

✓ Everywhere

\+ In a few areas

Since there are no ground sites in view, BCAS operates actively. When a squitter from a DABS aircraft is received it is parallel processed digitally and found in one of nine 40° azimuth sectors to determine target bearing (rough estimate), ID, and altitude. Each squittering target is than interrogated by its unique ID so that only the addressed target will respond*. The direct interrogation provides BCAS with a direct range measurement ρ_{OT}. Targets are tracked in range (measured by the round trip interrogation/reply interval), bearing (monopulse detection), and altitude (decoded from the reply). Tracking is substantially simpler than in the (garbled) ATCRBS case.

If a non-BCAS equipped threat is detected, the BCAS aircraft can determine its own evasion maneuver and, if the target is suitably equipped, can use the DABS data link simply to inform the target aircraft of the threat situation, and if desired, request it to maneuver. Since message receipt by the target will be acknowledged in its reply, the integrity of collision avoidance service is very high in this mode.

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*/In order for a DABS aircraft to determine whether it is being interrogated by a ground site or a BCAS aircraft, one DABS address bit will be reserved to identify BCAS interrogators.

3.3.1.2 Pop-up Targets

As in the all-ATCRBS environments some low altitude targets may occasionally be out of radar coverage. In contrast to the ATCRBS case, these targets are passively detectable by BCAS because of the transponder squitter. When a squitter is received, it can be checked for ID match with targets in the track file. If the ID is new, a track should be initiated.

Squitter-detected targets can be interrogated for preliminary altitude and range estimates. Targets lying inside certain relative altitude, range, or range rate limits can be tracked actively by discrete interrogation once per second. The number of such targets should be small and pose no burden to the airborne interrogator, just as in the over-ocean case.

Furthermore, an aircraft is unlikely to remain in a coverage gap for long; it may be on final approach (ultimately of no interest), taking off (about to enter coverage) or passing through either a coverage gap or sector hand-off. Failure of DABS sensor could, of course, prolong the outage period, although the DABS network management function should rapidly reassign primary and secondary coverage responsibilities of the adjacent sensors.

The significant advantages in the all-DABS approach to out-of-coverage targets are that (i) they can be detected at more distant range than in the all-ATCRBS case, lessening the possibility of pop-up, and (ii) they are interrogated more often without engendering synchronous garble, enabling quicker and more reliable threat detection.

3.3.2 Surveillance Coverage - All Call Lockout in Effect (Mode 11)

In this environment and within 100 nm of a single DABS site, the BCAS aircraft operates passively (5). By listening to both DABS replies and the squitter from the RBX transponder colocated with the interrogator, BCAS can obtain its own position and that of the target once per passage of the main beam (approximately 4 seconds). Active use is restricted to intermittently interrogating another aircraft whose replies are being garbled by ATCRBS or DABS fruit (replies to an adjacent site) and to interrogating the RBX for ranging.

The subsections which follow provide the details of how BCAS operates in this DABS environment. The first section, 3.3.2.1, explains the interrogation scheduling procedure used at a DABS/ATCRBS site. Section 3.3.2.2 presents and explains the measurements taken in this passive mode to determine target positions. The reply processor and multi-site considerations are discussed in the subsections 3.3.2.3 and 3.3.2.4.

3.3.2.1 DABS Channel Management

In order to understand the measurement procedure, it is necessary to first explain the scheduling of functions at a DABS/ATCRBS site. Figure 3-28 illustrates the allocation of time at the interrogator. Time is partitioned into blocks (or periods) whose length equals one-half the ATCRBS PRP for the site.*

If, for example, PRP = 2.5 ms (400 pulses/s), the block length is 1250 us. Blocks alternate between DABS and ATCRBS service.

Two types of DABS interrogation formats must be employed when both CAS services via synchro-DABS and DABS surveillance are desired, and these are used on alternate DABS blocks. The first is called a surveillance block, the second is a synchronous block.

In a surveillance period, aircraft interrogations and replies (an interrogation-reply pair is called a transaction) are scheduled into groups called cycles, which consist of a set of interrogations followed by the replies to those interrogations as shown in Figure 3-29. A cycle terminates when the next scheduled interrogation would overlap the expected arrival time of first reply in the cycle. A DABS block can consist of several cycles as shown. The interrogations are arranged in increasing range order (nearest in first) in such a way that

*/ATCRBS interrogations are never jittered or staggered at a DABS/ATCRBS site.

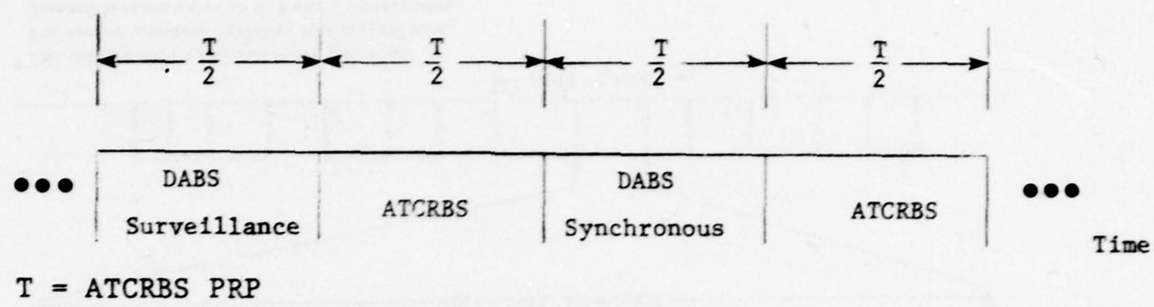
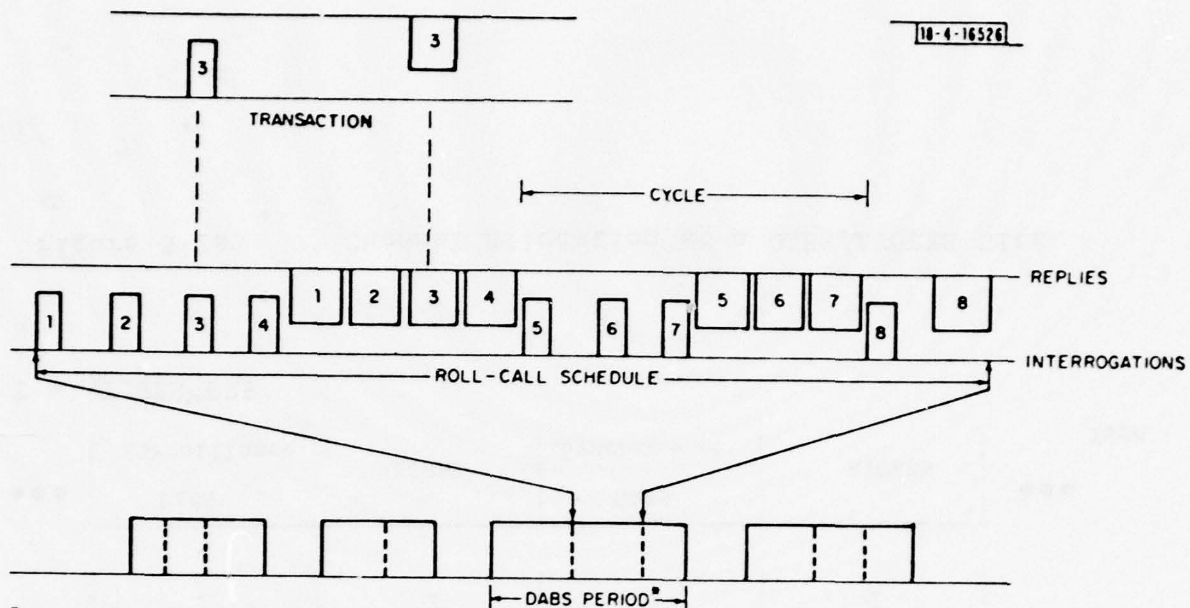


Figure 3-28: Channel Allocation at a DABS/ATCRBS Site



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

Figure3-29: DABS Surveillance Block

the replies will not overlap at the interrogator (although they may overlap at other points in space), thus eliminating synchronous garble from the interrogator's standpoint. At the ground, these replies are processed for surveillance updates on the interrogated craft; range and azimuth are measured and altitude is decoded from the reply.

The format of the synchronous block is an extension of the synchro-DABS concept (14). The concept of synchronous interrogation is to time the interrogations of several aircraft all lying in one DABS beam in such a way that they all issue replies simultaneously. The reply instant is denoted as T_o and occurs at the center of the DABS block as in Figure 3-30.

Synchronous interrogations must be scheduled in a manner that ensures that the replies will not overlap at the beacon. This is accomplished by selecting for interrogation a set of aircraft within the beam having the property that the radial spacing between each aircraft in the set exceeds the spatial length, L_r, of the reply ($L_r = cT_r$, where T_r = duration of reply). This guarantees garble freedom of the replies at the DABS sensor. Aircraft are interrogated in reverse range order (most distant first), with the time separation between interrogations equal to the range delay

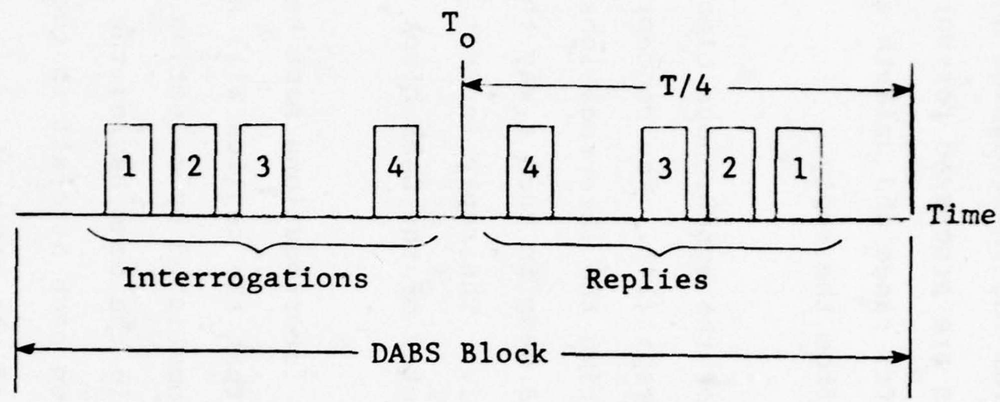


Figure 3-30: Synchronous Interrogations in "Synchro-DABS"

between aircraft. This method does not, however, assure garble freedom for receivers at other positions in space, as the example in Figure 3-31 shows.

Garble freedom in all airspace can be assured by delaying the response from the latter of two interrogated aircraft until the trailing edge of the wavefront of the reply from the former has passed the latter, and so on. No aircraft replies until all the replies of the more distant (from the site) aircraft have passed it. In this manner, the expanding spherical shells containing each reply never intersect at any one point in space, providing complete garble freedom. Figure 3-32 shows the reply sequence and a two-dimensional picture of the resulting wavefronts. Interrogations so ordered are called synchronous in the remainder of this report.

The reply times are under ground control, since the interrogator knows the range of each aircraft in the roll call. Reply time is encoded in the interrogation in a 6 bit "epoch field". The least significant bit in this field is called the subepoch and represents a 16 us delay. The reply time will be $T_o + (16k)$ us, $0 \leq k \leq 63$. The epoch field is included in the reply as well so that any receiver detecting the reply can tell when it was transmitted relative to T_o. If desired, the azimuth and range measured on the previous

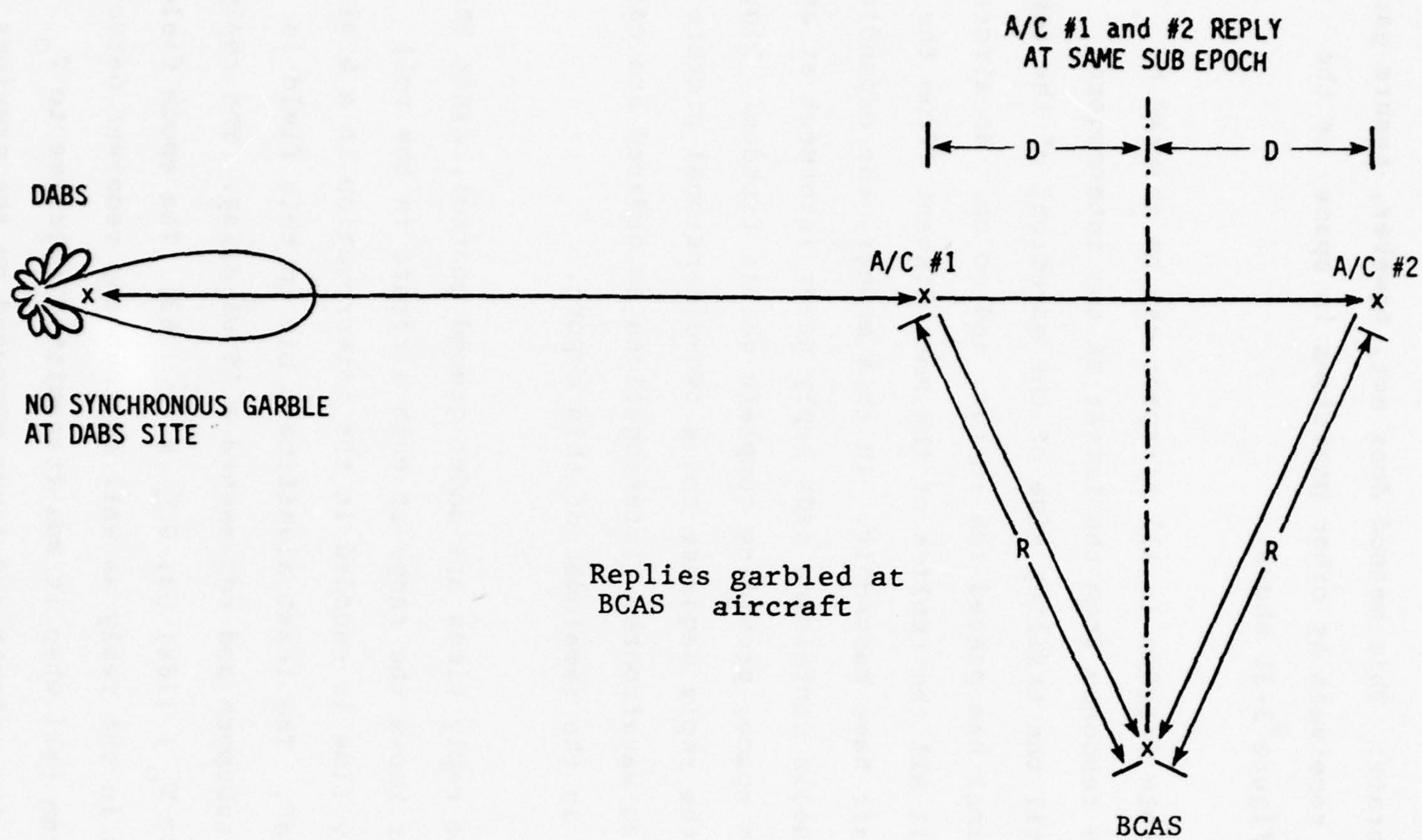


Figure 3-31: Illustration of Synchronous Garble at BCAS Using Synchro-DABS Interrogations

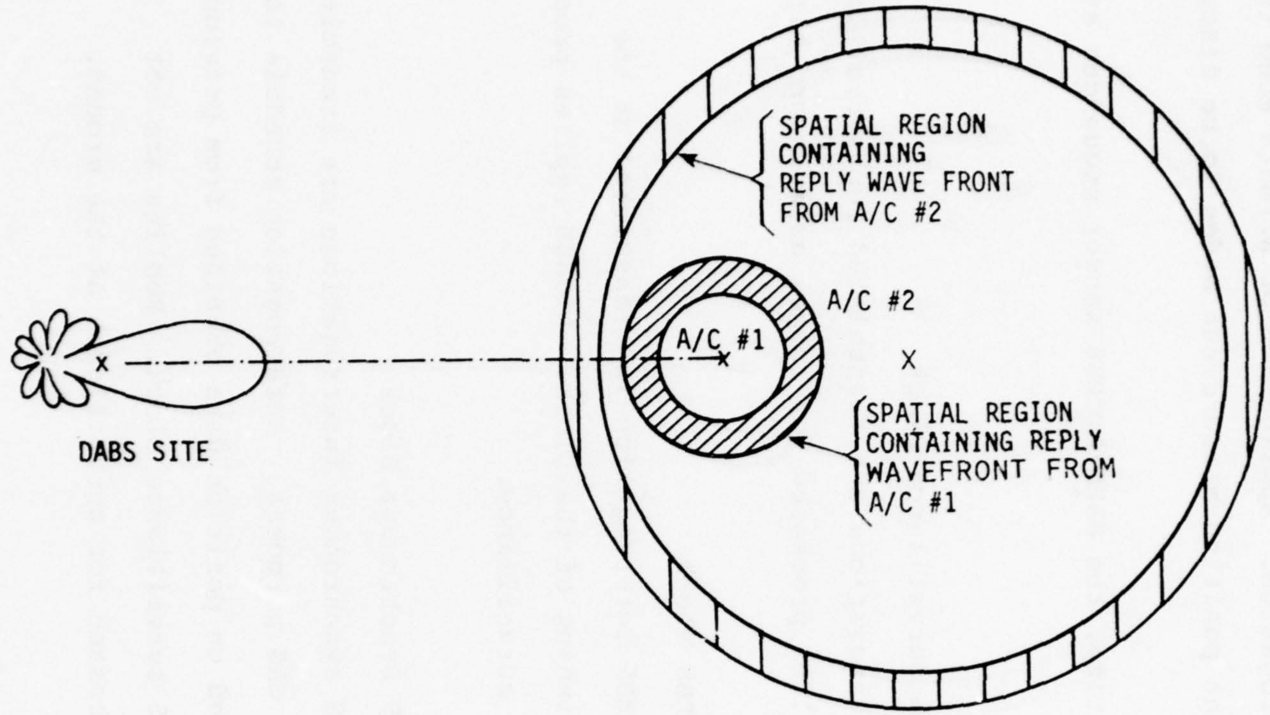


Figure 3-32: Illustration of Garble-Freedom in all Space Achieved with DABS Synchronous Interrogations

surveillance call can be echoed in the message field of the synchronous interrogation. Application of azimuth echo is found in one of the position measurement modes to be discussed.

To summarize, the DABS/ATCRBS sensor sequences events as follows:

1) DABS Surveillance Block
   Interrogations are transmitted for surveillance; replies processed for range, azimuth and altitude.

2) ATCRBS Block
   ATCRBS interrogation is transmitted at the beginning of the block. ATCRBS replies processed for surveillance.

3) DABS Synchronous Block
   DABS synchronous interrogations are transmitted for CAS purposes. Interrogation schedule is based on position data obtained from previous DABS surveillance block. Replies are not processed for surveillance at the ground.

4) ATCRBS Block
   ATCRBS interrogation transmitted at the beginning

of the block (a fixed time after the T_o of the previous DABS block). ATCRBS replies processed for surveillance. The cycle repeats starting at 1).

Each DABS aircraft is scheduled for at least one surveillance and synchronous interrogation per scan, and possibly two or more in cases where extended length messages are being communicated. Multiple hits are not required at the ground for accurate azimuth measurements in DABS, because the off-boresight monopulse measurement which is made can be quite accurate on a single hit (0.1^{o}). Thus, in some cases, the BCAS aircraft will have only one synchronized reply per scan to work with in determining target position.

3.3.2.2 Geometry and Position Measurement Algorithms

In this section, we explain how the BCAS equipped aircraft makes use of the information available in the interrogations and replies to determine both its own position and that of any nearby target aircraft.

A desirable feature of the ATCRBS algorithm presented in Section 3.2.2.1 is that differential arrival times can be computed without having to detect the SLS pulse (P_2) of the interrogation to which the target responds. This circumstance holds because ATCRBS interrogation times occur in a periodic fashion easily discernible to the BCAS processor.

Due to the irregularity of DABS interrogations, the ATCRBS technique cannot be extended in a straight forward manner to preserve this feature for the the DABS environment. BCAS will include in each synchronized interrogation azimuth data measured on the data in its reply, allowing any BCAS aircraft which receives the reply to make use of the data.

The overall measurment geometry for the DABS situation is shown in Figure 3-33; the notation used coincides with that in the ATCRBS section.

In the DABS environment, the BCAS aircraft can measure its own position relative to the sensor (ρ_{10}, α_{10}, h_O) from the DABS/ATCRBS signals in space. In addition, range to the target ρ_{OT}) can be measured directly by interrogating the RBX. None of these measurements require P_2 pulse correlation. Figure 3-34 shows what happens if this set of data is augmented by reception of a target synchronous reply carrying azimuth (α_{1T}). It is seen that the azimuth plane and the range sphere intersect in a circle. The altitude plane intersects this circle at two points, one of which is a false solution.* By using the directional antenna the ambiguity can quickly be resolved by the following procedure.

*/The extraneous solution merges with the true one in the event that the circle is tangent to the altitude plane.

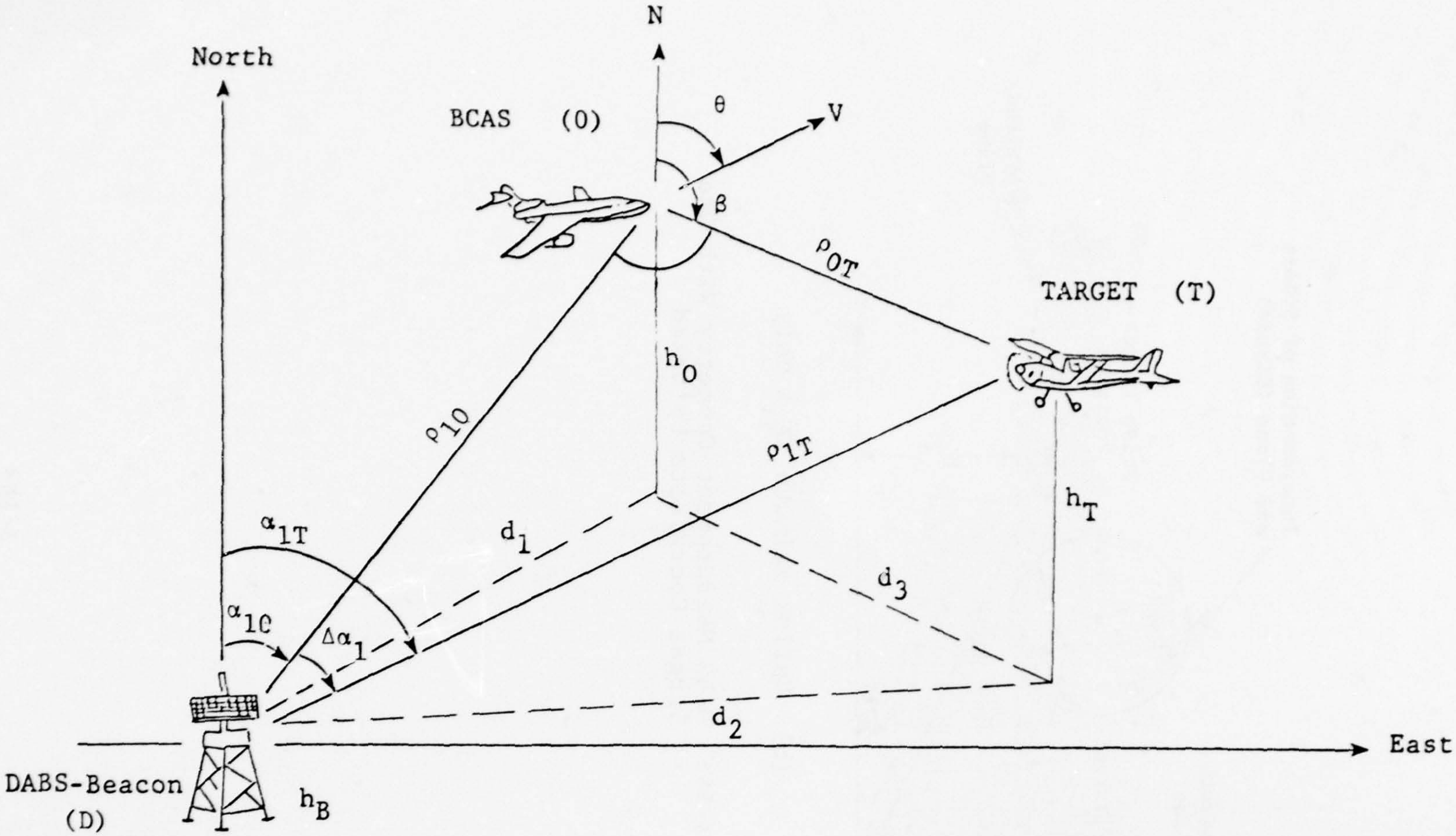
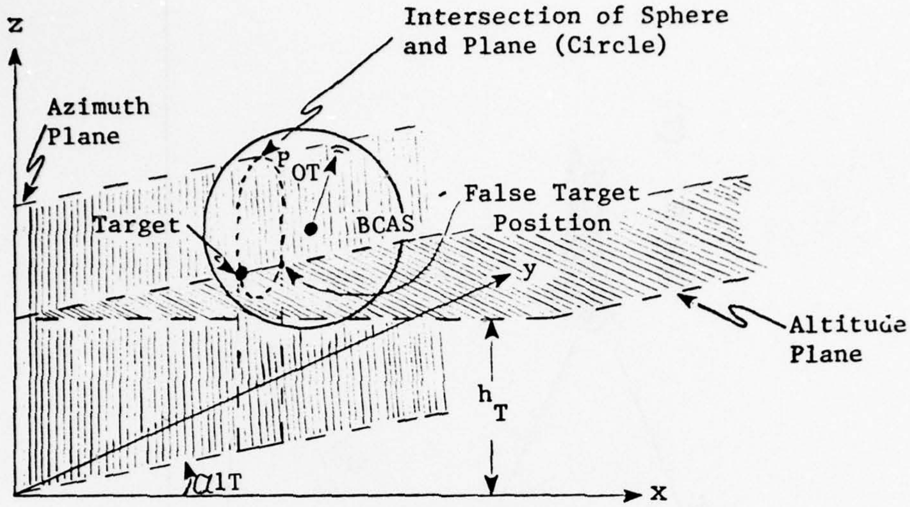


Figure 3-33: Single Site Geometry: All-DABS Environment



(b) Uplink azimuth (α_{1T}) only

Figure 3-34: DABS Measurement Geometry With One Target Coordinate Uplinked

Once a target's position has been computed using the "azimuth echo" information, the bearing to both the target and to the false solution is known. As mentioned earlier, BCAS can "parallel process" its received phased array signals to pick up a rough bearing on the DABS squitter of the target within a 1 or 2 second period. The bearing obtained using monopulse detection in this way is sufficiently accurate to resolve the ambiguity in the target range from site (α_{1T}).

The static measurements required for this target position calculation are summarized below. A flow chart presentation of the algorithm including dynamics is given in Figure 3-35.

a) ρ_{10} (Range - BCAS to Beacon)
Active Interrogation of RBX

b) α_{10} (BCAS Azimuth)
Decoded from synchronous interrogation

c) h_O (BCAS Altitude)
Decoded from target encoding altimeter

d) α_{1T} (Target Azimuth)
Decoded from target synchronous reply

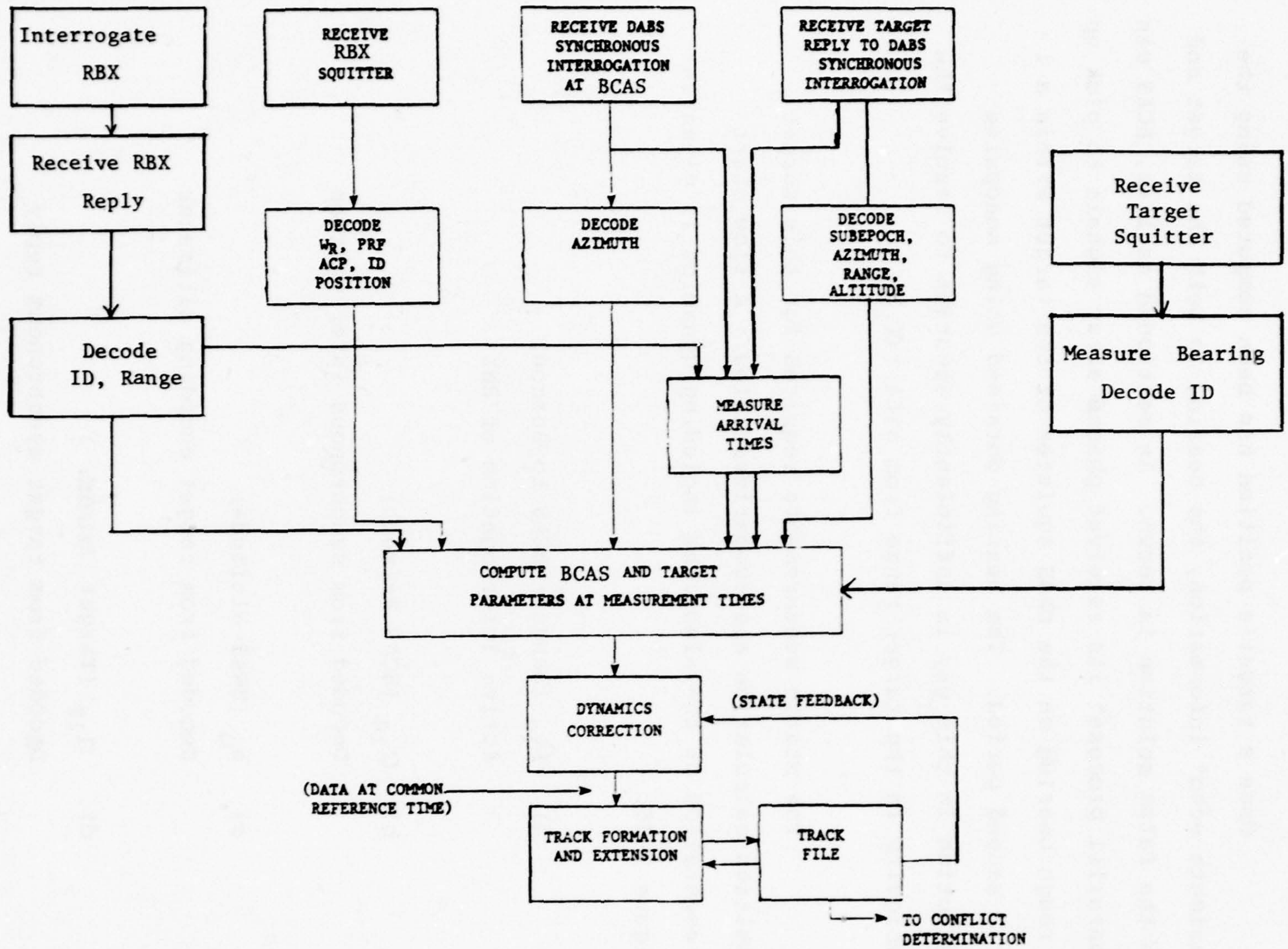


Figure 3-35: Flow Chart of Position Determination Algorithm, DABS Environment

e) h_T (Target Altitude)

Decoded from target synchronous reply

f) ρ_{OT} (Target Range)

Measured from synchronous reply

g) β (Target Bearing)

Measured roughly from received squitter/computed accurately from decoded and measured data.

3.3.2.3 Reply Processor Considerations

It is not necessary to dwell in depth on the DABS-environment reply processor, since it is not the pacing item in the concept, as it appears to be in the ATCRBS case. To reemphasize, in the DABS/ATCRBS single site case, all the signals (both interrogations and replies) with which the BCAS processor must work arrive garble-free at the BCAS aircraft. Features such as the azimuth-aided degarbling or "true zero" processing described earlier need not be incorporated. Since each DABS reception contains the address code of the transmitter or intended recipient, track association and extension become almost trivial, and formation is simplified inasmuch as correct ID can be obtained from one or two receptions.

3.3.2.4 BCAS in a High Density, Multiple DABS Site Environment

When the BCAS aircraft is in a region of fairly dense air traffic, there will be many occasions upon which BCAS and/or the target aircraft will have multiple coverage from DABS/ATCRBS sites. Although this situation can pose a synchronous garble problem not found in the single-site case, it can also present any opportunity for improved or extended coverage.

Consider the situation depicted in Figure 3-36 in which BCAS and the target lie in separate DABS sensor coverage zones. Although both have DABS coverage, they are interrogated by different ground sites. BCAS (under DABS beacon B_1 coverage) can detect target replies (under DABS beacon B_2 coverage), but cannot use them to measure target position because it does not know the DABS B_2 time-base. Since the target could be close enough to be a threat, BCAS requires a means to utilize the target replies. A solution to this problem is now presented.

BCAS receives interrogations from sensor B_1 and target replies in response to interrogations by sensor B_2, but cannot use the latter for position measurement due to lack of timing information. In order to get the information required, BCAS must be able to communicate with the RBX at the ground site which is interrogating the target. the vehicle for this is the BCAS/RBX link.

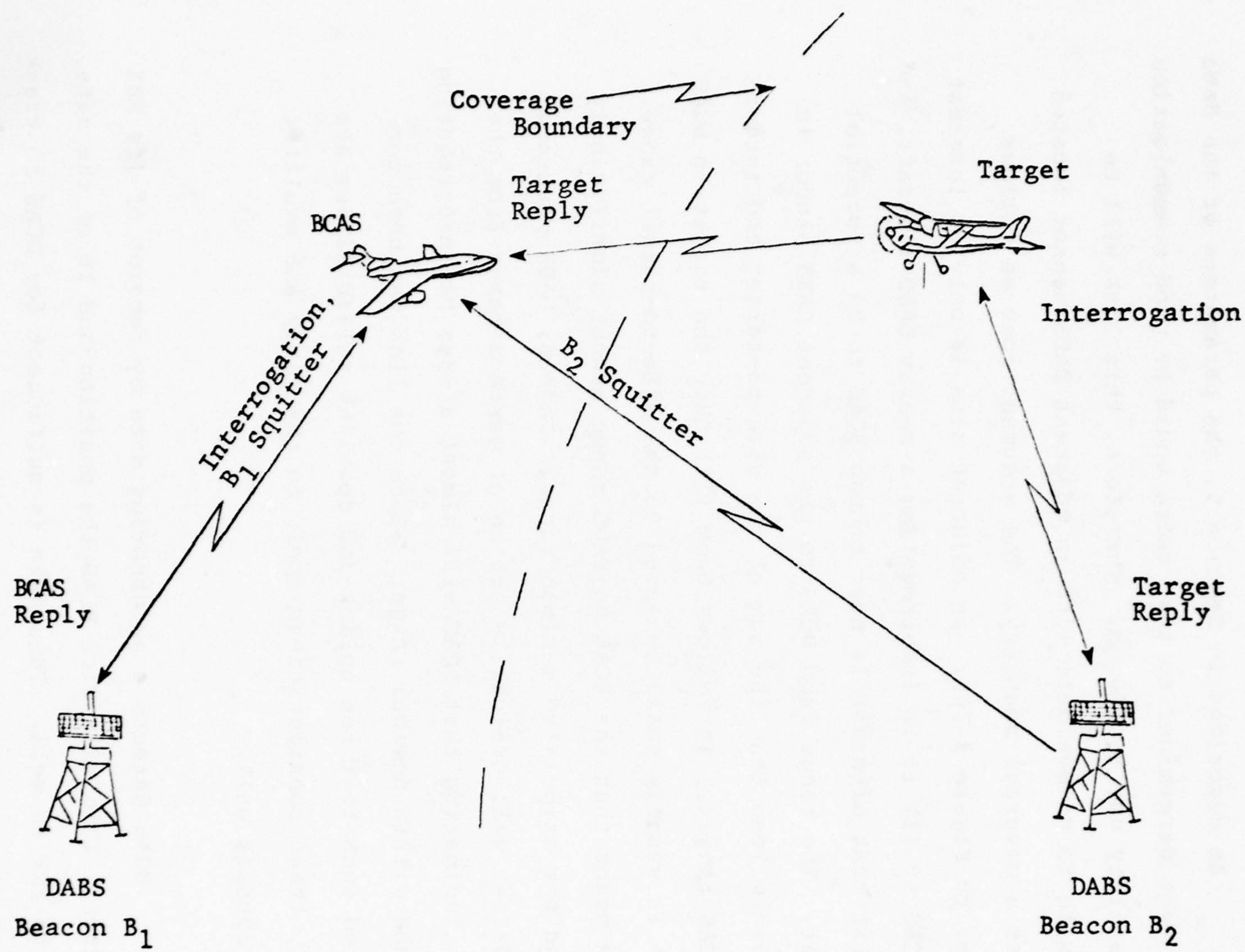


Figure 3-36: BCAS Tracking Aircraft Interrogated by Another Site

As described in Section 5, the parameters of the data link were determined so that there would be good communication reliability out to 100 nm. Therefore, this link will be adequate to communicate with an adjacent DABS sensor located across a coverage boundary. The argument goes as follows (refer to Figure 3-36): an adjacent site is only of interest to BCAS if (i) it is interrogating a nearby DABS aircraft, and (ii) if that aircraft is near enough BCAS to be a potential threat. The range from BCAS to the adjacent DABS sensor is certainly less than the sum of the site-to-target and target-to-BCAS ranges. It follows from (ii) that the target-to-BCAS range is usually small compared to the site-to-target range which means that the BCAS-to-DABS range cannot significantly exceed the stipulated maximum range. Indeed, DABS coverage boundaries will ordinarily not be at maximum range from the site, indicating that BCAS will almost always be interrogating the RBX within nominal range. Since the link has been configured such that the uplink and downlink reliabilities are equal, these considerations apply to the reply and squitter functions as well.

BCAS detects a neighboring site by receipt of its RBX squitter. This will give BCAS the position and ID of the site, and its PRF as well. This data is sufficient for BCAS to track aircraft from such sites, as shown below and with reference Figure 3-36.

Upon receipt of a target reply to B_2, BCAS knows the time of reply relative to the T_o of radar B_2; it does not yet know T_o, however. It cannot be obtained directly, as B_2 is not interrogating BCAS. Instead, T_o is inferred by first measuring the BCAS-to-B_2 range, which can be computed directly from the position data in the B_1 and B_2 squitter receptions. It can also be measured directly by interrogating the RBX at B_2. Once range is known, BCAS can work backwards from the receipt of a B_2 ATCRBS interrogation to learn when that interrogation was transmitted. T_o occurs a fixed amount ahead of that time; the exact amount depends only on the PRF of the site, which BCAS also knows from the B_2 squitter. Knowing T_o, direct target-to-BCAS range and all of the other target parameters can be computed as the target is tracked. As in all other BCAS measurements, dynamic corrections must be made, but these can be done exactly as in the single site case.

Garble will occur in the multi-site situation. However synchronous garble is not likely to be an issue, since adjacent sites will have differing PRF's and a desired reply from a B_1 interrogation is unlikely to be garbled more than once by a fruit return elicited by B_2. Self-site garble will not occur; that is, if BCAS is tracking targets T_1 and T_2 from

B_2, the synchronous replies from T_1 and T_2 will not garble at BCAS (or anywhere else) because of the interrogation strategy.

There remains the problem of ATCRBS fruit. In part, this is more properly treated as a transition issue and is discussed as such in Section 3.4. However, since as there is a low level ATCRBS fruit problem in any environment in which ATCRBS is present, it must be accounted for in the concept formation where the reply processor is concerned.

The DABS signals which could garbled at BCAS are transponder replies (target or RBX), which are PPM-modulated 1 MHz data rate signals. The garbling ATCRBS replies are PAM signals of durations 0.45 us and rate 1 MHz. Thus, the "ON" pulses of each type are quite similar. Measures similar to those described for the ATCRBS tracker can be employed for garble detection and, in some instances, correction.

A DABS PPM reply contains exactly one "ON" pulse per bit period. A garble distortion which adds a pulse in the "OFF" slot or, more rarely, concels the "ON" pulse, leaving a blank bit, is readily detectable, but not necessarily correctable. Unlike the all-ATCRBS situation, successive reply garbles will be totally independent, since they are single hits spaced in time by a full scan of the antenna. In that case succesive returns can be correlated for error correction of fixed data (e.g., aircraft ID). In performing the correlation one can exploit the principle that garble rarely destroys the the "ON" pulses, but will quite likely fill in the "OFF" slots. No azimuthal end effects such as are found in the ATCRBS target tracker are present here, because end effects require reply runs, which do not exist when all-call lockout is in effect.

3.3.3 No All-Call Lockout - Single and Dual Sites (Modes 9 and 10)

When there is no all-call lockout and synchro-DABS is used, the performance is equivalent to that described previously in Section 3.3.2 for the all-call lockout case. Indeed, it is recommended that synchro-DABS be made available at all DABS sites all the time.

However if synchro-DABS cannot be used then a quite different mode of operation is used which more closely resembles ATCRBS/RBX than synchro-DABS. The key characteristics of this mode are the following:

1. DABS will operate passively with target replies exactly as in the ATCRBS/RBX mode except that the

DABS All-Call replies will be used for azimuth centermarking, and decoding of target altitude and ID, in place of the ATCRBS Mode C and A replies used in the ATCRBS/RBX modes.

2. The DABS All-Call reply uses Pulse Position Modulation and is similar to PAM so that the reply processor need not differ greatly from that designed for the ATCRBS modes.

3. DABS All-Call reply is approximately 3 times as long as the ATCRBS reply, which will increase the garble problem relative to ATCRBS.

4. DABS squitters provide essentially ungarbled ID, rough bearing, and accurate altitude information.

The DABS squitters are processed in parallel in nine 40° azimuth sectors over a second of time and then the whole receiver pattern is rotated half a beamwidth to decode for another second. This process in repeated once every four seconds resulting in accurate accounting of target ID's, altitudes and rough bearing (within 10°)*. This information is then

*/Two seconds out of every 4 are thus left for BCAS to reply to ground interrogations, interrogate actively when necessary, etc.

correlated with garbled 1090-MHz DABS all-call target replies to obtain range to target and a more accurate target bearing.

The tradeoff between increased garble in DABS and the ability to correlate with data obtained by DABS squitters, to determine how DABS - BCAS performance compares to ATCRBS/RBX-BCAS performance is a problem under investigation.

3.4 BCAS IN THE TRANSITION ENVIRONMENT

The transition environment is that which exists during the process of evolutionary upgrading of the ground-based ATC surveillance system from ATCRBS to DABS. In transition, some DABS/ATCRBS ground sites have RBX's and some don't, but all DABS sensors are RBX equipped. The airborne transponder population is a mix of DABS/ATCRBS units and ATCRBS units (Modes A and C/A).

Since each DABS ground interrogator interleaves ATCRBS and DABS interrogations, replies (to a single interrogation) received by BCAS aircraft will be either all ATCRBS or all DABS. The BCAS aircraft can sequentially process and track ATCRBS transponder-equipped aircraft and DABS transponder-equipped aircraft. Thus, the operation of BCAS in a mixed airspace environment is basically an interleaving of the techniques used for ATCRBS target processing, as described in Section 3.2, and the techniques used for DABS target tracking, as described in Section 3.3.

3.4.1 Compatibility

With respect to the ATCRBS - DABS transition itself, the recommendation made by the air Traffic Control Advisory Commitee in 1969 will be followed that the replacement of ATCRBS by DABS be: (i) an evolutionary process, and (ii) both upward and downward compatible. The DABS design reflects this in that a DABS transponder can issue ATCRBS replies to ATCRBS as well as DABS interrogations and processes ATCRBS replies from any transponder.

The BCAS design is fully compatible with this surveillance transition. As evidenced in the two proceeding subsections of this report, BCAS has been designed to offer full BCAS service in both an all-ATCRBS and all-DABS environment.

3.4.2 Synchronous Garble and Fruit

The role of ATCRBS synchronous garble (for ATCRBS equipped targets) relative to BCAS functions has been recognized and dealt with in the tracker design. Although synchronous garble can be abated considerably by judicious tracking and signal processing, there is of course a limit point at which the system would break down. This limit point, however, may not be reached today for the surveillance system, even in the highest density traffic/interrogator environments. Furthermore, the transitional trend, assuming widespread implementation of synchro-DABS, is towards a decrease in a synchronous garble as ATCRBS transponders are replaced by DABS transponders. As we have seen, synchronous garble in synchro-DABS is not an issue.

Asynchronous garble ("fruit") in the ATCRBS environment is dealt with effectively by the ATCRBS tracker. In DABS tracking, ATCRBS fruit is partially mitigated by advanced signal processing. Fortunately, fruit levels high enough to cause serious ATCRBS degradation have rarely been observed, and, these levels are expected to decay with time as DABS is introduced.

3.4.3 Distribution of DABS and ATCRBS Interrogations

In the first implementation of BCAS, the environment would be essentially all-ATCRBS, and the anticipated performance would be as described earlier.

As DABS becomes increasingly prevalent, there will be lesser amounts of ATCRBS garble and, correspondingly, a decreasing need to process long reply runs on ATCRBS or DABS all-call targets. Thus, there can be a shift in interrogator strategy towards allowing more DABS synchronous blocks and fewer ATCRBS blocks. ATCRBS cannot, and would not, be phased out entirely, both azimuth and TOA accuracy can be maintained for ATCRBS targets in decreased DABS time can be used for capacity increase (to help compensate for the longer synchronous reply) or multiple synchronous calls for improved CAS accuracy.

3.4.4 Pop-up Targets

The pop-up target was an issue in the all-ATCRBS environment because targets out of ground coverage are not passively detectable. The clear volume for relatively garble-free active interrogation is not as large as one might like. In DABS, however, out-of-coverage targets are passively detectable and can be tracked actively until they enter coverage or are no longer of interest. Thus, during the transition, the pop-up target problem should decrease for BCAS, and furthermore, the amount of active interrogation required to track out-of-coverage targets should decrease.

3.4.5 Additional Transitional Modes

If a BCAS aircraft is flying from a DABS or ATCRBS/RBX coverage zone into an ATCRBS region, BCAS can very accurately transfer a North reference to the ATCRBS site (or sites), allowing BCAS to continue to operate semi-actively (2 sites everywhere or 1 site - - no singularity) very accurately.*

This can be done in the following way. If a three dimensional target position is known by BCAS as a result of tracking the target via a DABS site(s) or ATCRBS/RBX site(s): and if this same target is under coverage of an ATCRBS site, then with the aid of Figure 3-37 it can been seen that the position of the ATCRBS site can be determined by solving the "inverse BCAS" problem, i.e., the known BCAS and target positions are used to form a "single-site" solution for the beacon location. Given the beacon location, time of mainbeam passage at the BCAS can be obtained by centermarking, and North reference is easily computed once the beacon rotation rate is measured.

The differential azimuth and the differential range A+ B- C (Relative to the ATCRBS site) can be measured just as in the single-site passive ATCRBS mode. In order to do this, the site PRF and rotation rate must be measured, which takes at most two mainbeam passages. The target range B is known from

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* /By very accurately we mean computed North reference accuracies of 1° and 100 nm, 0.5° at 50 nm and 0.3 at 10 nm.

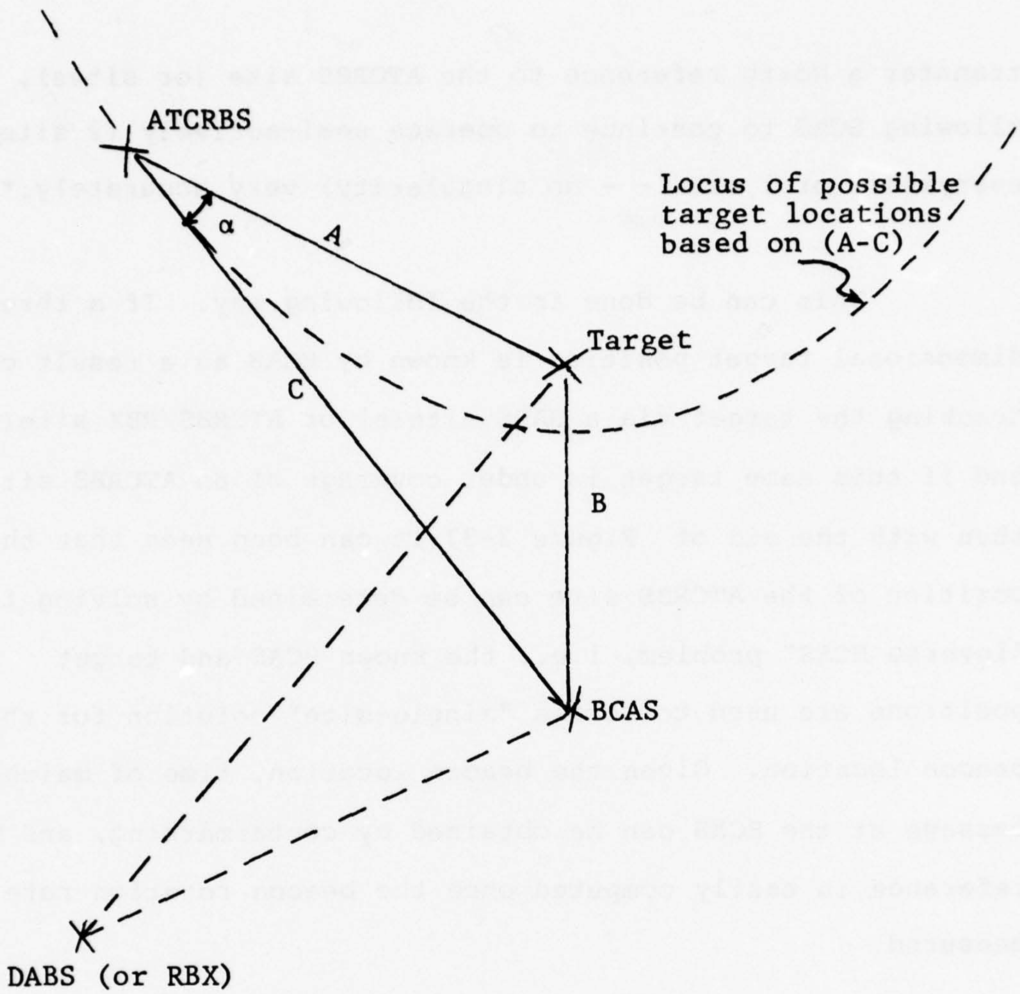


Figure 3-37

Transfer of North Reference to ATCRBS Site the previously established track (measured by synchro-DABS reply arrival time when the second site is DABS, by active interrogation when the second site is RBX.

The two range measurements combine to give knowledge of A-C. This localizes the ATCRBS site to a hyperbola whose foci are BCAS and the target. As Figure 3-37 shows, there are two possible positions for the ATCRBS which are consistent with measured differential azimuth. The ambiguity is easily resolved by knowing that all ATCRBS beacons rotate clockwise; or, the ambiguity is just as easily resolvable with the directional antenna by beam forming in the two possible directions at the anticipated time interrogation.

As stated previously, given the site position, bearing to site is used to calibrate the centermark-determined time of main beam passage to a North reference.

It should be remarked that this solution possesses a singularity, just as some of the passive BCAS solutions do. The singularity occurs when the BCAS, target, and ATCRBS site are nearly colinear ($\alpha \simeq 0$). Interestingly enough, however, the singularity in measurement of the ATCRBS site location <u>does not</u> prohibit North reference transfer. The reason is that the singularity tends to localize the site along the linear asymptote to the hyperbola, which is almost constant bearing as viewed by BCAS, especially when the target is near the BCAS. Since bearing (and not, for example, BCAS-to-ATCRBS range) is the critical parameter in transfering beam passage time to North time, the singularity has very little effect on the end result. One must be careful not to use the site position so calculated for any other purposes if the result shows the site to be behind and almost colinear with the target.

The computed North reference should remain valid even after the DABS site and/or DABS target used to make the measurements have vanished. The PRF and rotation rates determined can be used to track the BCAS bearing relative to the site once North reference updates are not longer possible. In other words, the site information is estimated to be more reliable in the short term than any mechanism available to the BCAS (in the absence of an RBX site) to update its own position, as for example, airspeed and compass-derived heading. These claims might not apply to an air carrier or military aircraft equipped with sophisticated inertial navigation instrtumentation, but they should be applicable to most of the G/A fleet.

Finally it should be pointed out that the North reference transfer to an ATCRBS site allows for a 2 site solution in which 1 site is ATCRBS and the second a DABS or ATCRBS/RBX. This mode of operation (Mode 7) has been discussed in Section 3.2.4.

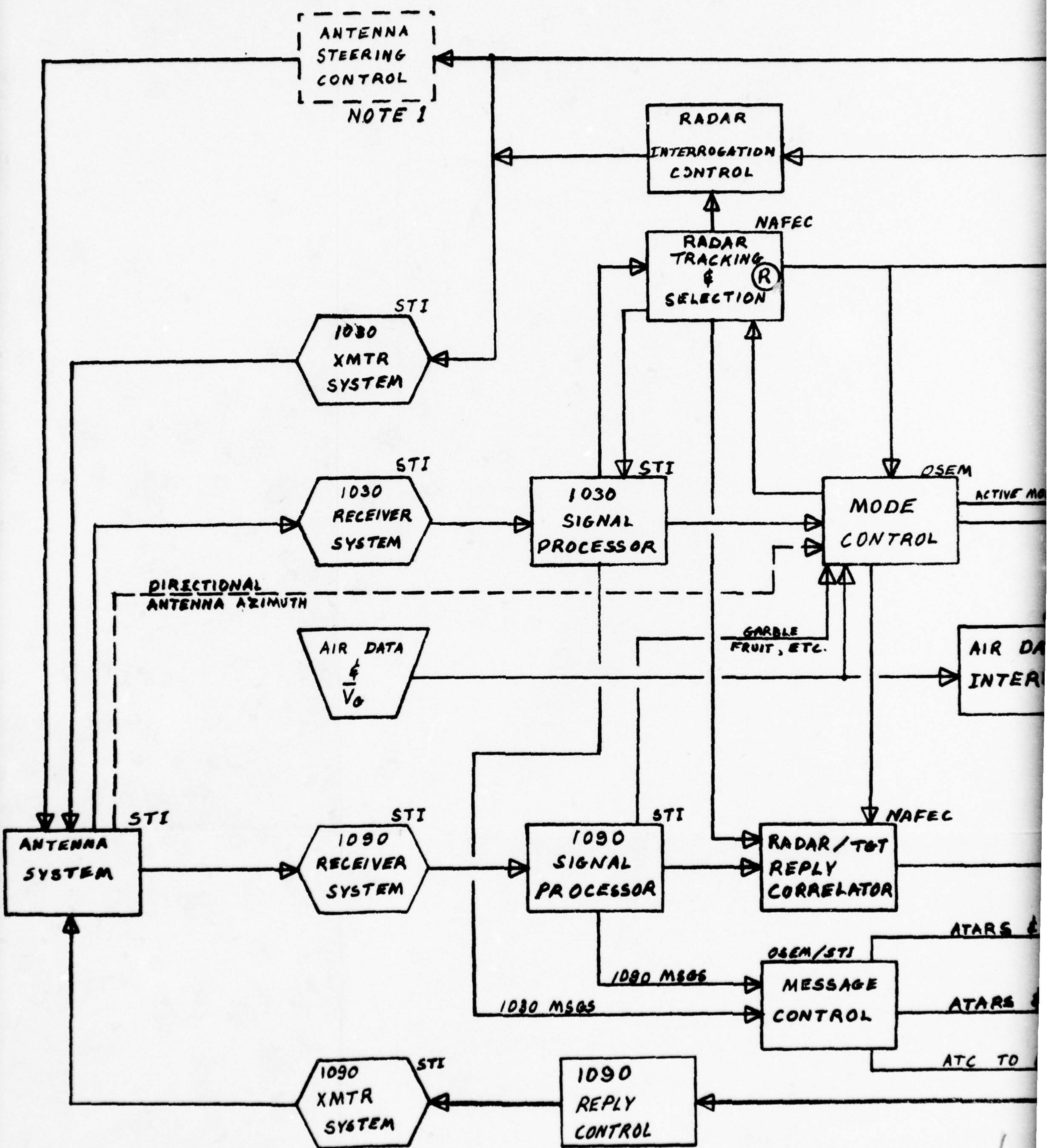
4.0 BCAS Avionics

4.1 BCAS Design Concept Overview

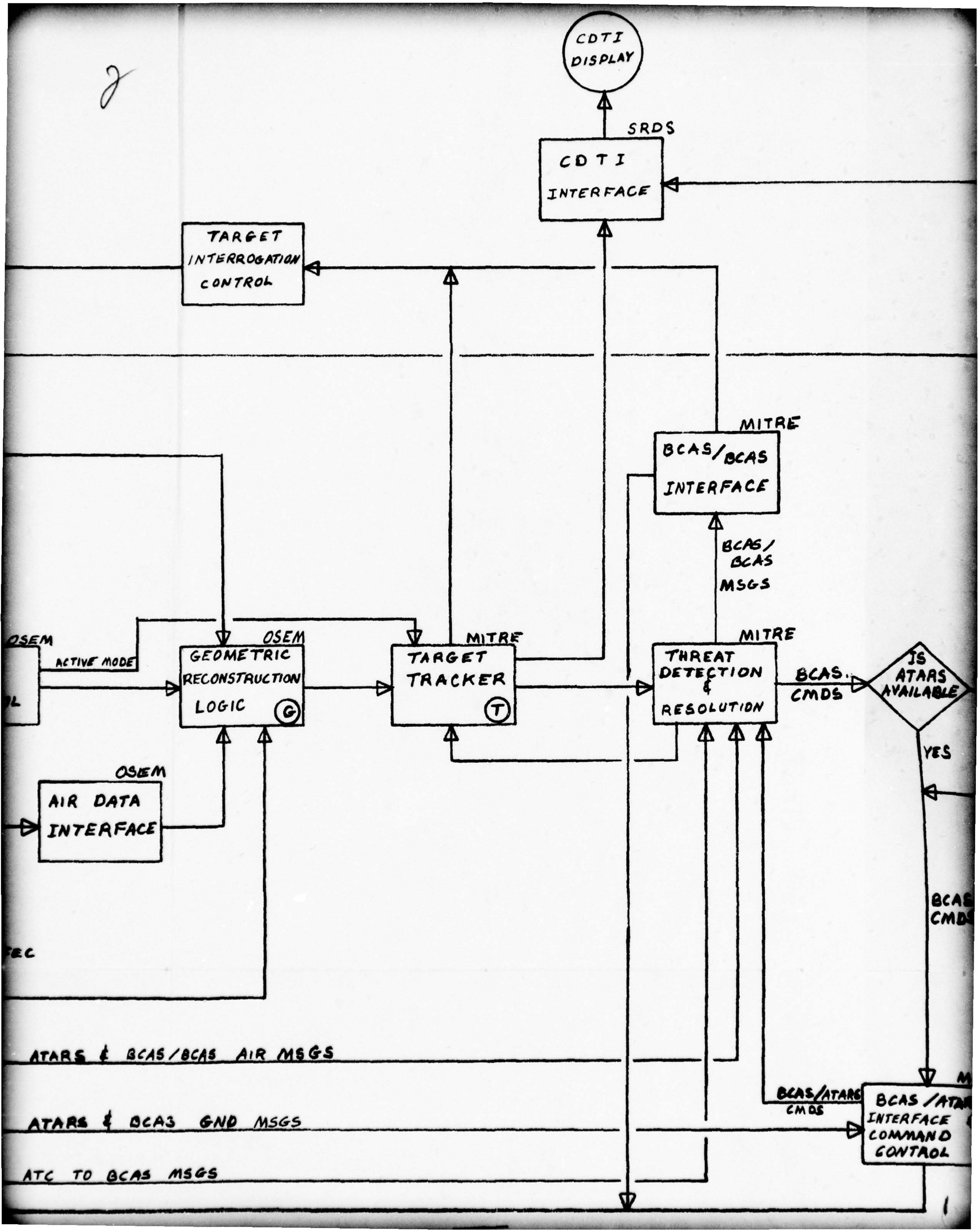
Figure 4-1 presents an overview of the BCAS avionics design. In this section, the functions of the key elements in the BCAS design, starting with a received reply will be described.

The BCAS antenna system is made up of two small phased array antennas (6-8 elements each) which can form omni and directive beams for either the 1030 MHz or 1090 MHz signal and for either the transmit or receive modes of operation.

Both 1030 MHz BCAS interrogations and ground interrogations, and 1090 MHz target replies to ground and BCAS interrogations are received by the BCAS antennas. With respect to a given antenna, each element is processed from RF to IF independently at either 1090 MHz or 1030 MHz center frequency where all information is transmitted in parallel to the appropriate signal processor. An omni beam is formed at the other RF and converted to IF as a single channel. In both signal processors the signal is demodulated to baseband where data on the directive channel is digitally combined to form directive (multiple) beams. Under normal conditions without modifications from mode control, information in the 1090 MHz signal processor will be enhanced by parallel processing in nine 40° digitally formed beams, while the 1030 MHz signal is processed as an omni

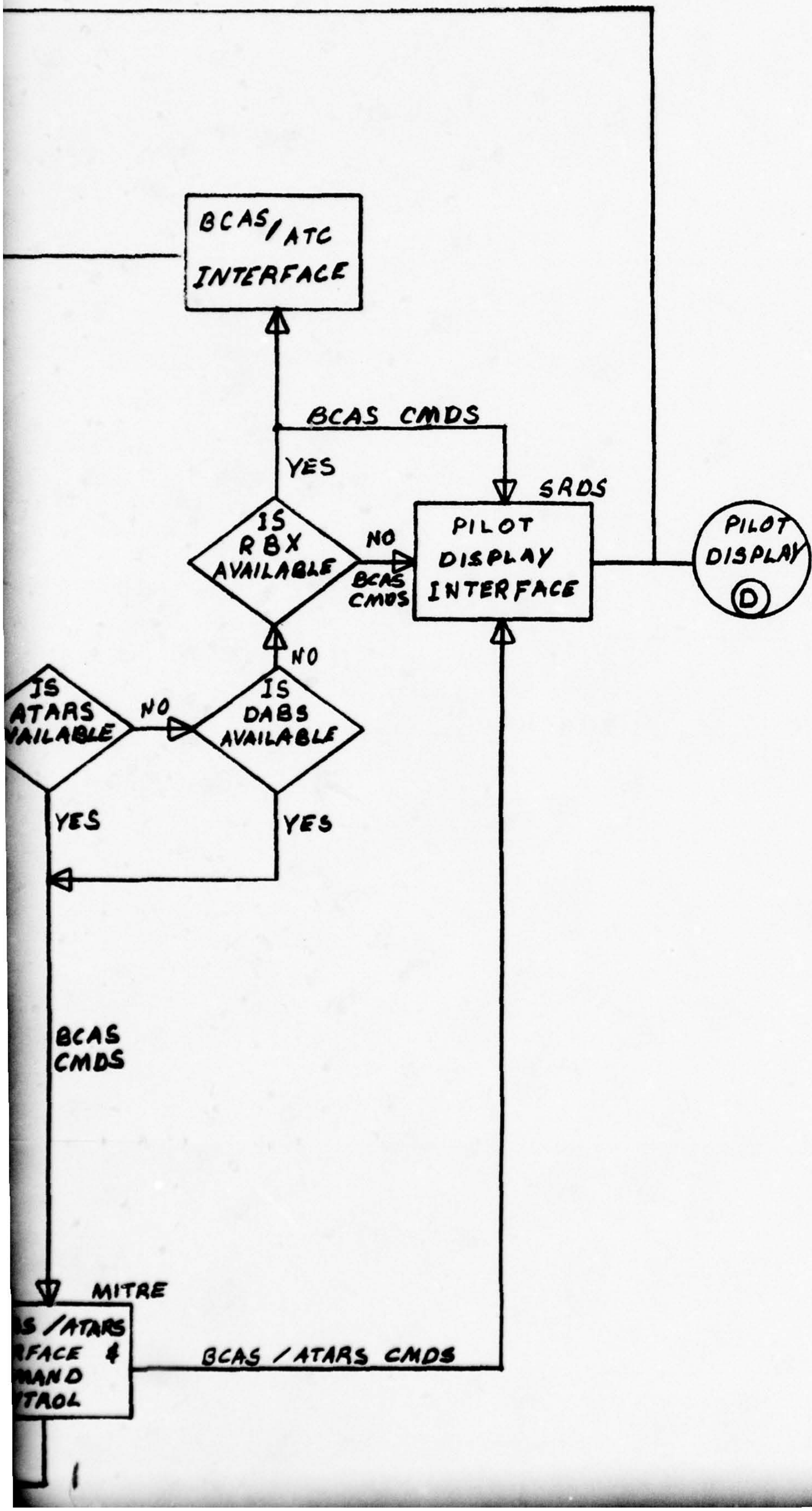


ANTENNA STEERING CONTROL
NOTE 1
RADAR INTERROGATION CONTROL
NAFEC
RADAR TRACKING & SELECTION
R
STI
1030 XMTR SYSTEM
STI
1030 RECEIVER SYSTEM
STI
1030 SIGNAL PROCESSOR
OSEM
MODE CONTROL
ACTIVE MO
DIRECTIONAL ANTENNA AZIMUTH
AIR DATA & V_G
GARBLE FRUIT, ETC.
AIR DA INTER
STI
ANTENNA SYSTEM
STI
1090 RECEIVER SYSTEM
STI
1090 SIGNAL PROCESSOR
NAFEC
RADAR/TGT REPLY CORRELATOR
ATARS &
OSEM/STI
1090 MSGS
MESSAGE CONTROL
1030 MSGS
ATARS
ATC TO
STI
1090 XMTR SYSTEM
1090 REPLY CONTROL



CDTI DISPLAY
SRDS
CDTI INTERFACE
TARGET INTERROGATION CONTROL
MITRE
BCAS/BCAS INTERFACE
BCAS/ BCAS MSGS
OSEM
ACTIVE MODE
OSEM
GEOMETRIC RECONSTRUCTION LOGIC
MITRE
TARGET TRACKER
MITRE
THREAT DETECTION & RESOLUTION
BCAS. CMDS
IS ATARS AVAILABLE
YES
OSEM
AIR DATA INTERFACE
BCAS CMDS
ATARS & BCAS/BCAS AIR MSGS
BCAS/ATARS CMDS
ATARS & BCAS GND MSGS
INTERFACE COMMAND CONTROL
ATC TO BCAS MSGS

3



LEGEN

- (T) TARGET MODE FLAGS &
- (D) DISPLAY SATURATION FL
- (G) GEOMETRIC RECONSTRUC
- (R) RADAR SELECTION MODE

FIGURE 4-1

TITLE: FAA BCAS

DATE: 10 MARCH

4

LEGEND

(T) TARGET MODE FLAGS & DATA

(D) DISPLAY SATURATION FLAG & RESOLUTION LOGIC

(G) GEOMETRIC RECONSTRUCTION MODE FLAGS & DATA

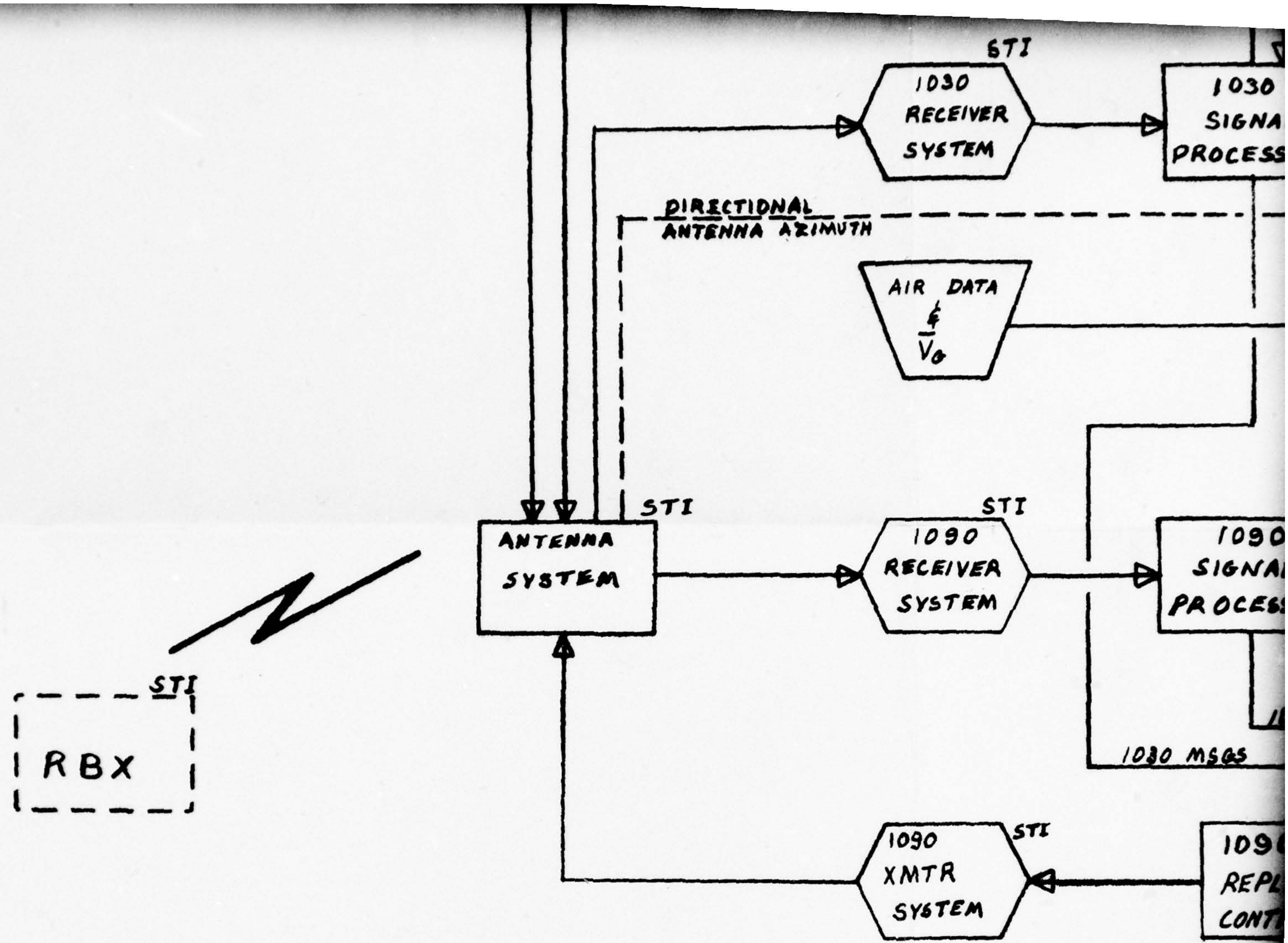
(R) RADAR SELECTION MODE FLAGS & DATA

FIGURE 4-1

TITLE: FAA BCAS BLOCK DIAGRAM

DATE: 10 MARCH, 1978

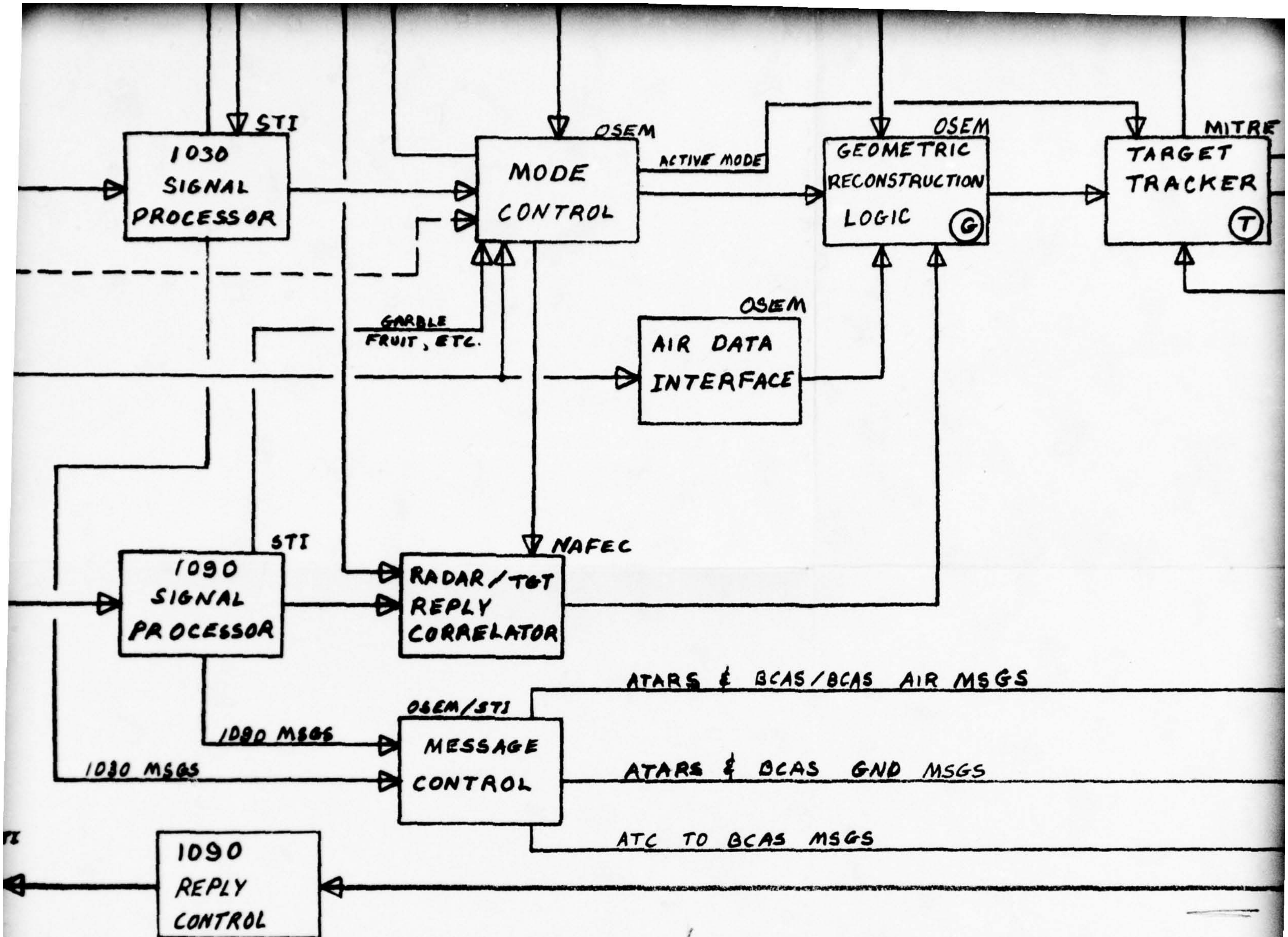
REV #	REVISION DESCRIPTION	DATE
1	RADAR TRACKING FEEDBACK & 1090 CONTROL	17 MR 78



NOTE[S]

NOTE 1: DIRECTIONAL ANTENNA OPTIONAL

5



NOTES

OPTIONAL

6

FIGURE 4-1

TITLE: FAA BCAS BLOCK DIAGRAM

DATE: 10 MARCH, 1978

REV #	REVISION DESCRIPTION	DATE
1	RADAR TRACKING FEEDBACK & 1090 CONTROL	17 MAR 78

DRAWN BY PVH 9 MAR 78

directionally received signal. Mode control modifies this when it wants to determine the BCAS aircraft bearing to an ATCRBS site. Under these conditions, which are well defined and known a priori by BCAS, BCAS will form a 1030 MHz directive beam and a 1090 MHz omni beam. Thus, BCAS does not allow simultaneous directive beam forming at both the 1090 MHz and 1030 MHz frequencies, but no requirement for this is found. This enables BCAS to time share the same beam forming circuitry with the advantage that BCAS hardware requirements are considerably reduced.

In addition to beam forming, the 1090 MHz signal processor determines F_1 F_2 bracket pairs, measures TOA's, differential azimuths or bearing (a function of mode), and demodulates message data. The 1030 MHz signal processor measures bearing to an ATCRBS site and demodulates 1030 MHz message data.

The reply processor is fed by the 1090 MHz signal processor.* In the reply process the functions of target report generation, track formation, track extension, track merging, track elimination and track smoothing are carried out for all modes of BCAS. To enable BCAS to do this multimodal

*/DABS squitters are also obtained from message control.

reply processing, the reply processor receives inputs from the radar tracker and is controlled by mode control.

The radar tracker is fed by the 1030 MHz signal processor which receives all ground site interrogation information. The RBX 1030 MHz squitter data is demodulated from the message control and BCAS's own position information which is obtained from the air data interface and the RBX 1030 MHz reply to a BCAS 1030 MHz interrogation.

The BCAS radar tracker selects those ground radars in its vicinity which are best equipped (DABS-RBX-ATCRBS in that order) and which provide the best geometry. Note that this geometry is determined only by the geometric relationship of the BCAS aircraft to the ground sites.*

The radar track data and the reply processor target report information are fed into the Mode selector. The mode selector determines first if the target report generation is excessive so that the passive and/or active mode garble flags has (have) to be set. If no garble flags are set, then the mode selector uses the track information to determine for successive intervals of time which mode BCAS will operate in,

*/The one exception to this rule occurs in the transfer of a North reference. In this case the position of the target aircraft has to be used to carry out the transfer.

how DABS and ATCRBS targets will be handled (sub-modes) and for each sub-mode whether the singularity or non-singularity solution is required. Note that this solution is not dependent upon actual knowledge of target positions but only on the geometric relationship between the BCAS aircraft, the position of the selected ground sites and the position of the main beams of the selected ground sites. The mode solution information is fed into mode control. Mode control is the quarterback of the BCAS design. That is to say, mode control coordinates all operations to insure that information is being processed correctly in the signal processor and reply processor. The signal processors have to know whether to form omni-beam patterns or directional beam patterns and the reply processor needs to be told whether a target track contains active and/or passive one or two site information. In addition, the RF and antenna section is told where to form its interrogator beam, when to go active, in what state to put its switch matrices, etc.

Returning to the reply processor, when it has confidence that it has established a reliable target track, it passes this track to the tracker which further smoothes the track, and passes these smoothed tracks to the threat detection and resolution logic. If a non-BCAS target is considered a threat, a tentative command is generated. If there is no ATCRBS and no

DABS but an RBX is available then the BCAS command is displayed to the pilot and data linked to the ground. The ATC reply, in message control, is used to modify the BCAS threat detection and resolution logic for that target.

Finally, if the target is a BCAS equipped target then prior to issuing a BCAS command, the BCAS command intent is transmitted to the BCAS target. The BCAS target reply is then sent to the threat detection and resolution logic which then determines the BCAS command.

Thus the BCAS transmits when it has to coordinate with other BCAS aircraft and ATC. BCAS also transmits when responding to ground interrogations and when mode control requests interrogations as for example when the target solution requires active data or the target is a DABS target. All interrogation commands are sent to the transmiter control which controls the antenna phasing, the transmitter power level, the modulation, and the message content.

This completes an overview of the BCAS avionics design. The remainder of the section will examine the key elements of the design in greater detail.

4.2 Design Details

4.2.1 BCAS Antenna, Transmitter and Receiver Systems

4.2.1.1 The BCAS Antenna

The BCAS antenna is an eight-element* circular phased array, as shown in Figure 4-2. The elements are quarter-wave dipoles. Either symmetric or asymmetric dipoles can be used; the choice will slightly vary the elevation pattern of the antenna, but the part which is of prime importance for BCAS, the azimuth pattern, will be uniform in any case.

Opposite elements are separated by a distance of 12" - 18" (exact diameter is a design parameter to be further investigated). Behind the circular array stands a cylindrical ground plane, approximately one quarter wavelength inside the element radius. The combination of one element and the ground plane produces a radiation pattern equivalent to two opposite polarity dipoles located on the element radial and spaced one half wavelenght apart. Other effective spacings can be achieved by alternative design.

For pattern synthesis purposes the antenna can be regarded as an array of eight identical directive elements, each with its directivity rotated by 45^{o} relative to its

*/Six-element arrays are also being studied.

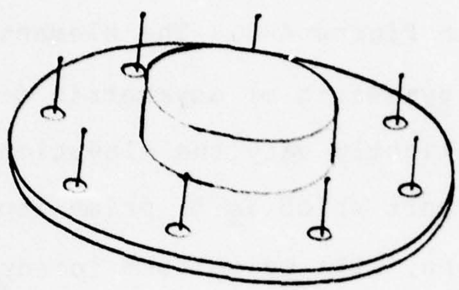


FIGURE 4-2: CIRCULAR PHASED ANTENNA ARRAY.

nearest neighbor. Amplitude and phase of the element signals can be controlled on both transmit and receive for beam forming. Only patterns formed by element phasing will be considered in this report.

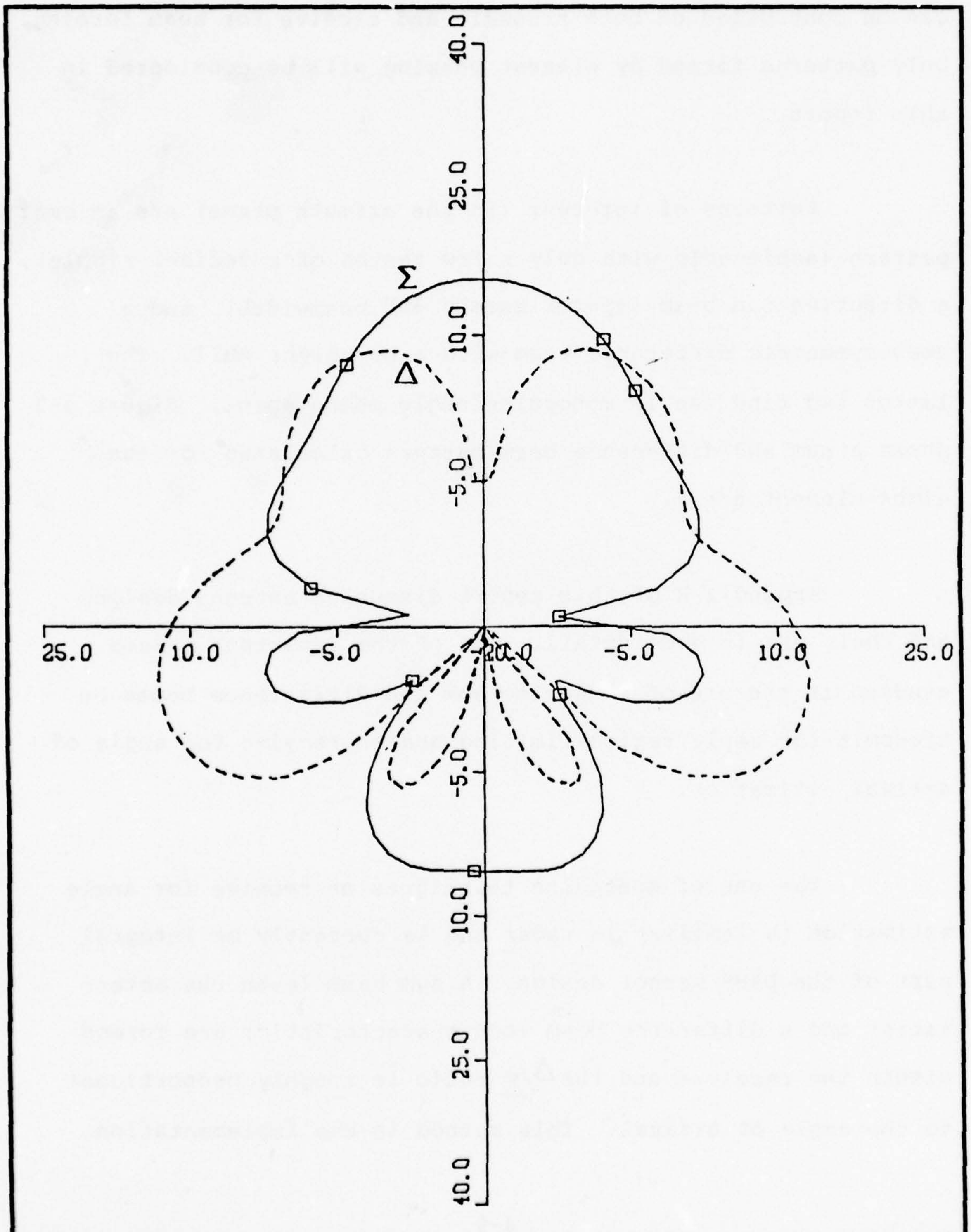
Patterns of interest (in the azimuth plane) are an omni pattern (achievable with only a few tenths of a decibel ripple), a directive sum beam (approximately 40° beamwidth), and a skew-symmetric difference beam with a boresight null. The latter two find use in monopulse angle measurement. Figure 4-3 shows a sum and difference beam pattern calculated for the eight-element array.

Appendix H of this report discusses antenna designs and their use in some detail. One of the important issues studied is the use of monopulse sum and differrence beams on transmit for reply region limiting and on receive for angle of arrival estimation.

The use of monopulse techniques on receive for angle estimation is familiar in radar and is currently an integral part of the DABS sensor design. A sum beam (even characteristic) and a difference beam (odd characteristic) are formed within the receiver and the Δ/Σ ratio is roughly proportional to the angle of arrival. This method is one implementation

FIGURE 4-3

TYPICAL Σ + Δ PATTERNS



of amplitude comparison monopulse. Phase comparison monopulse is also of interest for the BCAS application and will be studied in future work.

The technique of monopulse interrogation is less familiar. The idea is illustrated in Figure 4-4. The P_1 and P_3 pulses of an ATCRBS interrogation are transmitted on the beam, but the P_2 (SLS) pulse is transmitted on the beam. Only aircraft within a narrow angular region around the beam boresight will receive a sufficiently large P_1/P_2 power ratio to trigger a reply. Outside that region, the P_2 beam covers the P_1 and no replies are elicited.

The study in H.3 shows that large ratios of P_2/P_1 power ($>$ 9dB) are needed on transmit to restrict the reply sector to a small fraction of the sum beamwidth. Half-beamwidth sectors appear to be practical, i.e., 20^o out of 40^o 3 dB beamwidth.

One of the reasons that large P_2/P_1 ratios are required is the null of the beam at boresight. Alternative beams for P_2 transmission which do not have boresight nulls are investigated in Appendix H.

A second interrogation technique which accomplishes reply region limiting by a different technique is developed

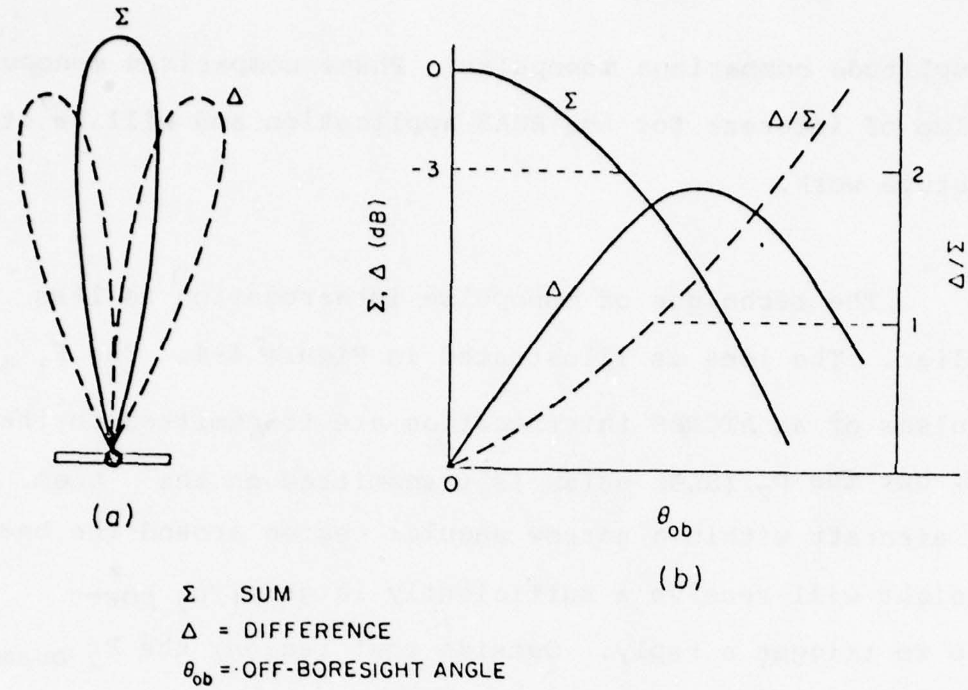


Figure .4-4 Typical Σ & Δ patterns

in Appendix H. As indicated in Figure 4-5, the P_1 and P_3 pulses of an interrogator are transmitted on separate beams. The beam forming is exactly what would be done on receive for squinted-beam amplitude comparison monopulse (as in the British ADSEL system, which is similar to DABS). The two beams are pointed slightly to either side of boresight; only aircraft within a narrow region around that boresight will receive both a P_1 and P_3 which are above the transponder MTL and will reply. In this form, this technique depends on absolute signal levels in the aircraft receiver, and does not as tightly control the reply region. However, the technique could be combined with a P_2 transmission of some sort (for example, an omni), which would introduce a measure of relative level control into the reply restriction. On the other hand, transmission of P_1P_3 with P_2 pulse technique is attractive from the point of view that when only a P_1 or P_2 is received, the transponder is not suppressed, minimizing the amount that active BCAS impinges upon the ATC surveillance system.

The BCAS concept requires a BCAS aircraft to be equipped with the two array antennas, one topand one bottom-mounted in order to transmit to and receive from all targets of interest. The interconnection and switching of these antennas is described in the following two sections.

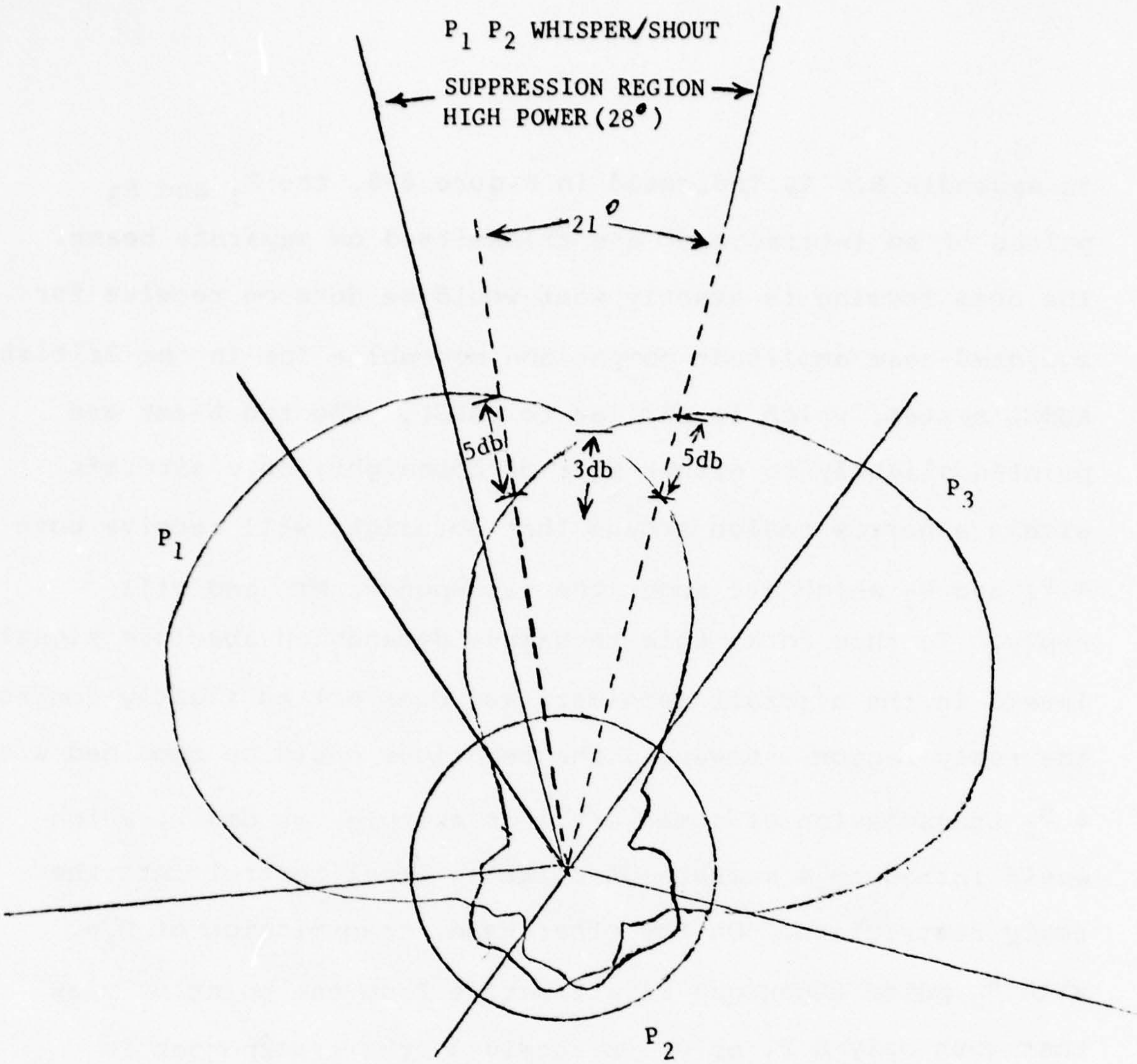


FIGURE 4-5: P_1 P_2 WHISPER/SHOUT SUPPRESSION REGION LOW POWER (162°)

USE OF SEPARATE P_1 AND P_3 BEAMS TO FORM NARROW INTERROGATION BEAMS

$\frac{P_1}{P_2}$ = 16db.

ON P_1 P_3 INTERROGATION

P_1 P_2 WHISPER/SHOUT SUPPRESSION

FOR P_2 TRANSMITTED ON P_3 BEAM

4.2.1.2 RF Section Transmitter

BCAS must be capable of transmitting both ATCRBS and DABS interrogations, which can be accomplished with a single 1030 MHz transmitter. A modulator ahead of the transmitter will generate the necessary waveforms (DPSK for DABS interrogations, PAM for ATCRBS and DABS all-call interrogations). The auxiliary transmitter which would be required to generate the DABS P_5 SLS pulse is not needed for BCAS. Like any DABS-equipped aircraft, BCAS must be capable of responding to both ATCRBS and DABS interrogations and correspondingly must be equipped with a 1090 MHz transmitter and modulator.

The RF transmit section of the avionics is shown in Figure 4-6. The functional block diagram is predicated on the assumptions that (i) simultaneous transmission on top and bottom antennas is never required, and (ii) transmission on one antenna and simultaneous reception on the other is never required. With regard to the latter, it is part of the BCAS requirement that transmission take priority over reception.

The requirements for the transmit chain are driven primarily by the need to transmit DPSK-modulated DABS interrogations. A crystal oscillator which can retain phase coherence over a few bits provides a low level signal source which can be

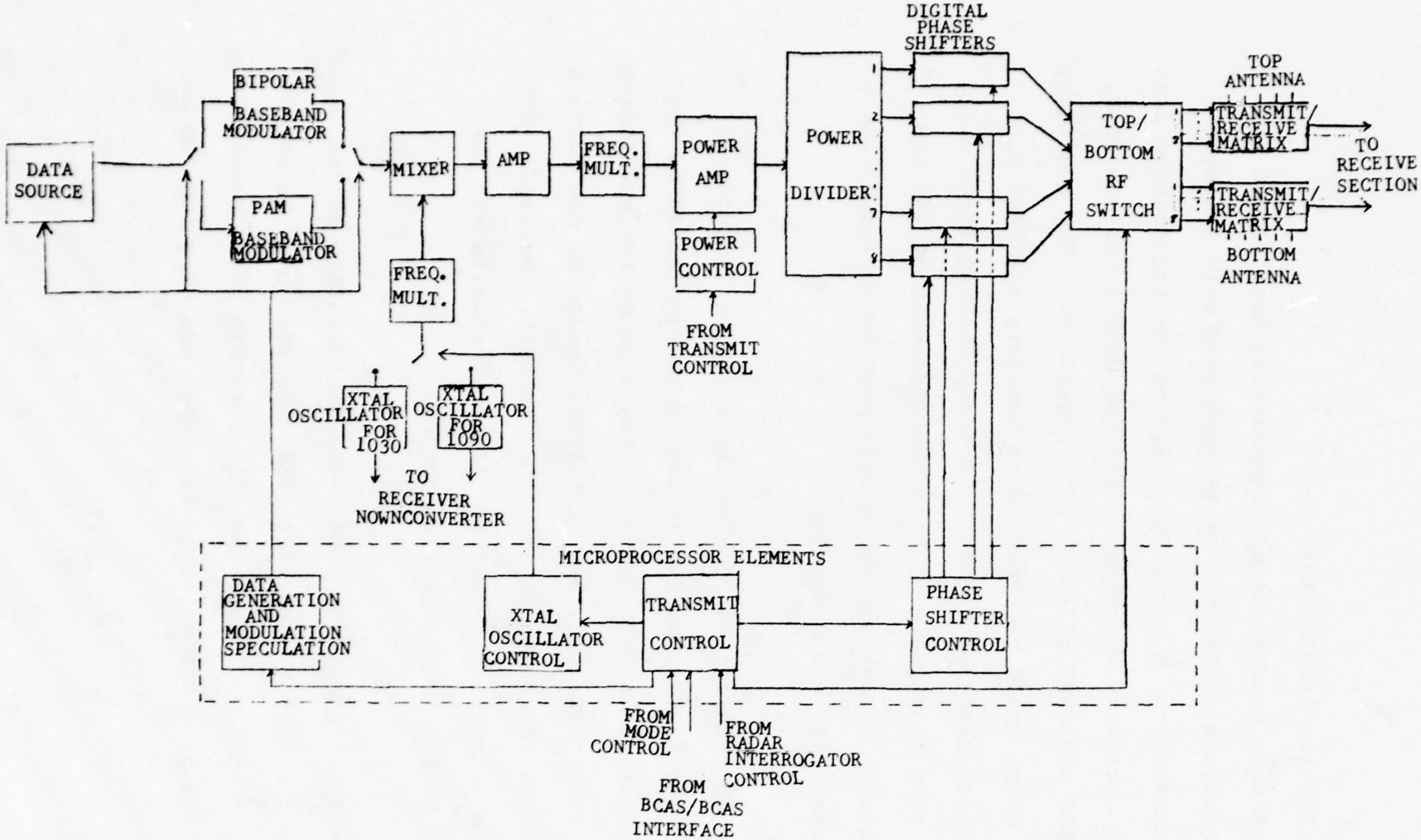


FIGURE 4-6

BCAS TRANSMITTER SECTION

amplified and up-converted (via frequency multiplication) both before and after the modulator. After final amplification, the signal is power divided into as many channels as there are array elements (at most eight). These array signals pass through digitally controlled phase shifters which are driven from the interrogation control logic in the microprocessor. The phase shifters are bypassed to configure the antenna for an omni transmission. The phase shifter outputs are fed to a Top/Bottom RF switch matrix which selects the proper antenna and from there to the Transmit/Receive switch will be set to the transmit position.

The ATCRBS or DABS all-call transmission path is similar, expect the PAM section of the modulator is used.

When BCAS replies to an ATCRBS or DABS interrogation, the 1090 MHz oscillator is used. In the transmit mode, this oscillator will be PAM-modulated to generate a sequence of ones and zeroes. This oscillator is also used as a reference for down-converting received replies at 1090 MHz in the RF receiver avionics.

4.2.1.3 RF Section/Receiver

In this section, we describe the receiver avionics from the antenna element outputs to the IF stage (Figure 4-7).

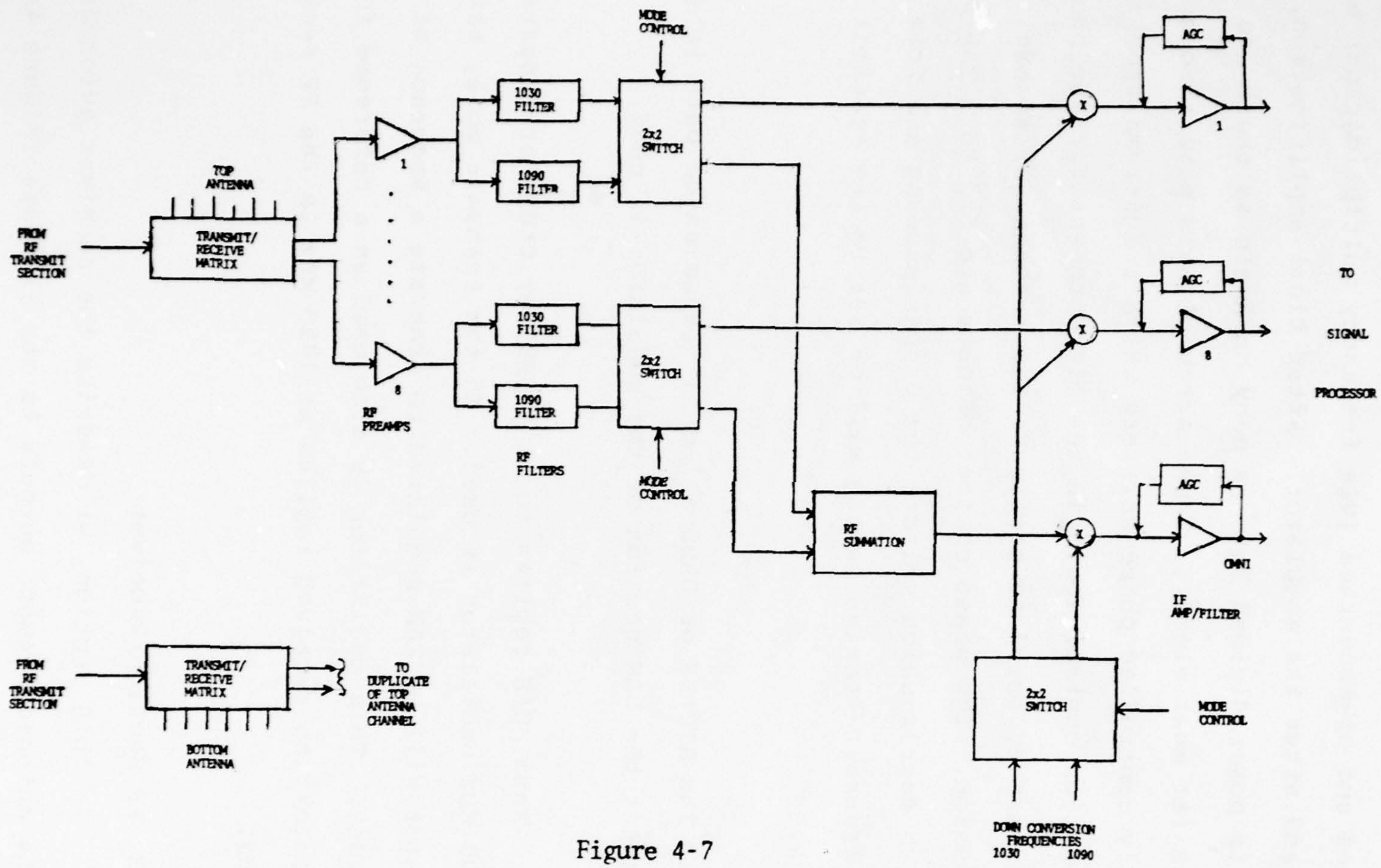


Figure 4-7

RF RECEIVER SYSTEM

The processing for one of the antennas is described below. Because the receiver listens on both antennas simultaneously, a second identical channel is provided for the other antenna.

The T/R switch is set for receive, which routes each element's signal into a wideband RF preamp. The preamp will pass both 1030 and 1090 MHz. Each preamplifier output is split into two paths which separately filter for 1030 MHz and 1090 MHz, respectively. For each element, the 1030 MHz and 1090 MHz outputs are presented to a 2x2 switch. The objective here is to be able to generate an omni beam directly at one of the RF's while preserving the individual element's signals at the other frequency for directive (and possibly multiple) beam forming later on. Thus, for example, BCAS can listen omni-directionally for an ATCRBS interrogation (at 1030 MHz) and at the same time listen for replies to an active interrogation (coming in on 1090 MHz) and form sum and difference beams for bearing estimation. It will not be possible to simultaneously form directive beams at the two received frequencies on one antenna, but no requirement to ever do this presents itself.

The switch position is commanded by Mode Control. The eight omni outputs are summed at RF prior to IF conversion, whereas the eight element signals at the other RF are down-converted directly. The diagram shows that to down-convert properly, frequencies must be interchangeable and are corresponding by input to a 2x2 switch driven by the same Mode Control command as the other switches.

After IF conversion, the signals are amplified and band limited to 6 MHz. Nine IF signals per antenna are thus presented to the Signal Processor circuitry for data extraction.

4.2.2 Signal Processor

The Signal Processor is the receiver avionics which processes the analog IF and generates digitized raw data which is used by the Reply Processor/Target Tracker and the Radar Tracker. Typical outputs are decoded altitude and IF, TOA estimates, bearing estimates and demodulated data.

The Signal Processor takes its inputs from the receiver front end outputs. Recall that these outputs are one omni and eight directional element analog signals at IF (see Figure 4-7). The omni channel contains replies from either 1030 MHz or 1090 MHz, and the other eight channels (called the directional channels) are at the other frequency; the specific configuration is commanded by Mode Control.

The processing in the omni channel differs from that of the directional channel. The omni is the simplier of the two and is described first, with reference to Figure 4-8.

The omni channel contains two basic paths: the coherent and the incoherent paths. The incoherent path is for the processing of PAM data; the coherent path processes DPSK data. The PAM path must always be enabled, whereas the DPSK path is enabled only when the omni channel is processing 1030 MHz (only DABS interrogations are DPSK-modulated).

On the incoherent path, the input IF is envelope detected. The resulting video is channeled to an SLS Detector which continually compares outputs separated by 2.0 us. Reply demodulation timing (generated further down the path) provides read inputs to the SLS circuitry and causes the SLS to declare reply/no reply, which affects the reply control and suppression circuits. The video is sampled at a rate which will provide several samples per pulse (4 MHz - 20 MHz), binary quantized, and fed to a shift register long enough to hold one reply.

Data in the shift register is continually monitored by detection logic, the nature of which is determined by the current operational mode. The logic governs determination of

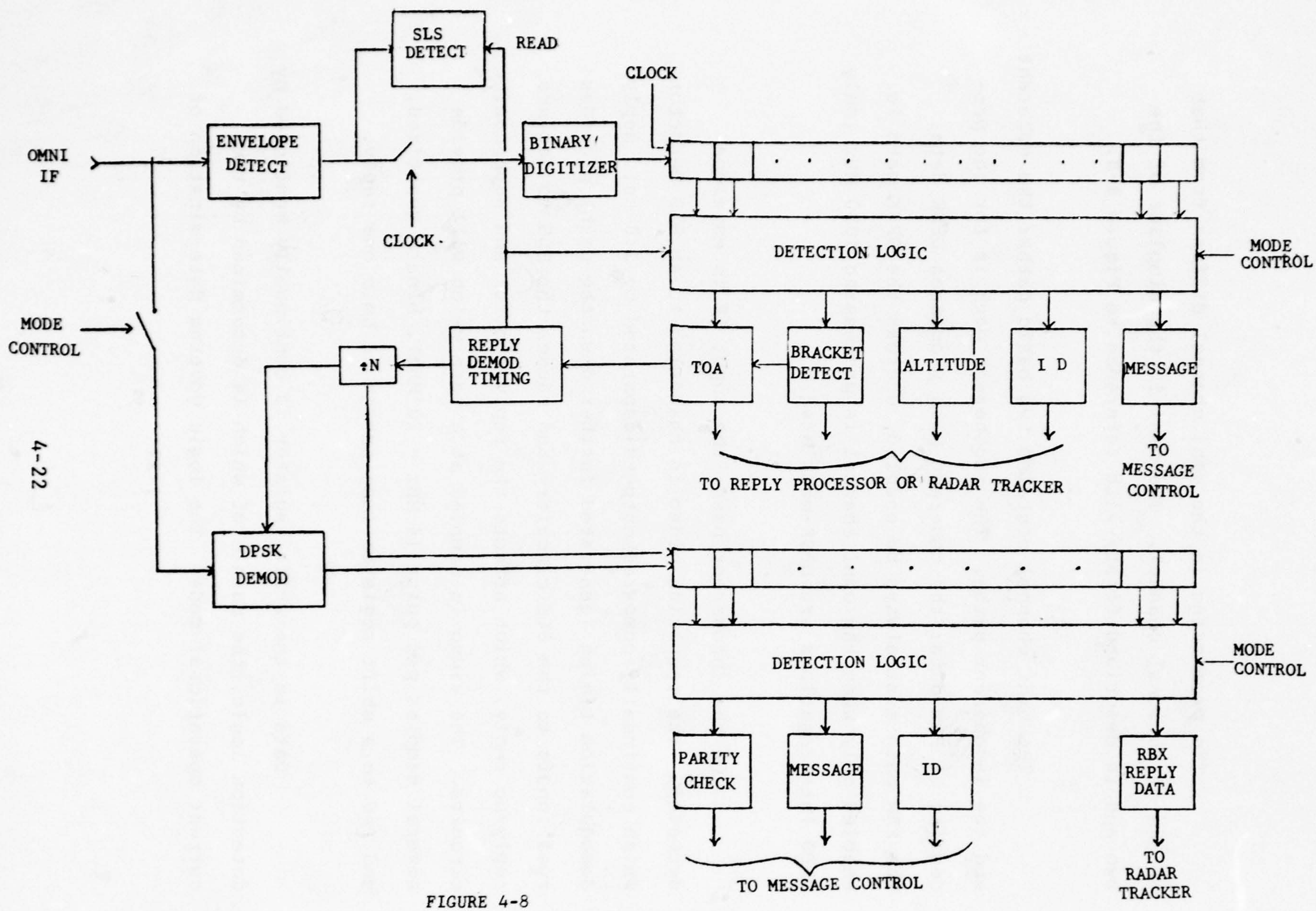


FIGURE 4-8

SIGNAL PROCESSOR-OMNI PORTION

bracket detection, TOA, ID and altitude decodes, message demodulation, etc. These raw data are made available to the Reply Processor or the Radar Tracker.* In addition, TOA is passed along to the Reply Demodulation Timing so that other functions within the logic which are time dependent can be clocked appropriately.

The coherent path has much the same function as the other-determination of raw data for the subsequent processors. Timing for the DPSK demodulation is derived in the PAM processing circuit, because a DABS interrogation is always preceded by a PAM P_1 P_2 pair (for suppression of ATCRBS transponders). Note that the clock driving the coherent path is divided down from that which drives the incoherent path because one timing sync is achieved, only one sample per bit is needed (4 MHz clock rate). The derived bits are shifted into a register which under logic control derives ID, parity check, and demodulated messages from the signal. Data outputs go to either the Radar Tracker, Threat Detection and Resolution, or Message Control. Note that none of this data goes directly to the Reply Processor, because DPSK is never used in a DABS/ATCRBS reply.

---

*/As discussed earlier, the omni signal processor will be set to receive 1030 MHz replies and, therefore, its processed data will normally go to the radar tracker.

The directive channel (Figure 4-9) takes in the IF array signals. In-phase (I) and quadrature (Q) baseband signals are generated using gradrature components of the nominal IF carriers. These are derived from the same crystal oscillators which provide a frequency reference for the RF and IF sections. If all the signals received by BCAS were at exactly 1030 MHz or 1090 MHz, the quadrature signals would be exactly at baseband. Uncertainty in transponder center frequency ($\pm$ 3 MHz), however, prevents this. Over the duration of an ATCRBS reply pulse, the RF phase can be offset by more than a full cycle, which could significantly degrade the monopulse measurement.

This problem is solved by lowpass filtering* the baseband for double carrier rejection and A/D converting at a high rate (presumably the rate used on the omni channel incoherent path). The SNR per sample should be high enough to allow beam forming on a per sample basis in the manner discussed below.

The A/D samples are read into a buffer storage area to be saved for possible multiple beam forming. The actual structure would probably consist of two buffers, one being processed

*/The bandwidth of the lowpass filter is taken sufficiently wide to account for the frequency offset present.

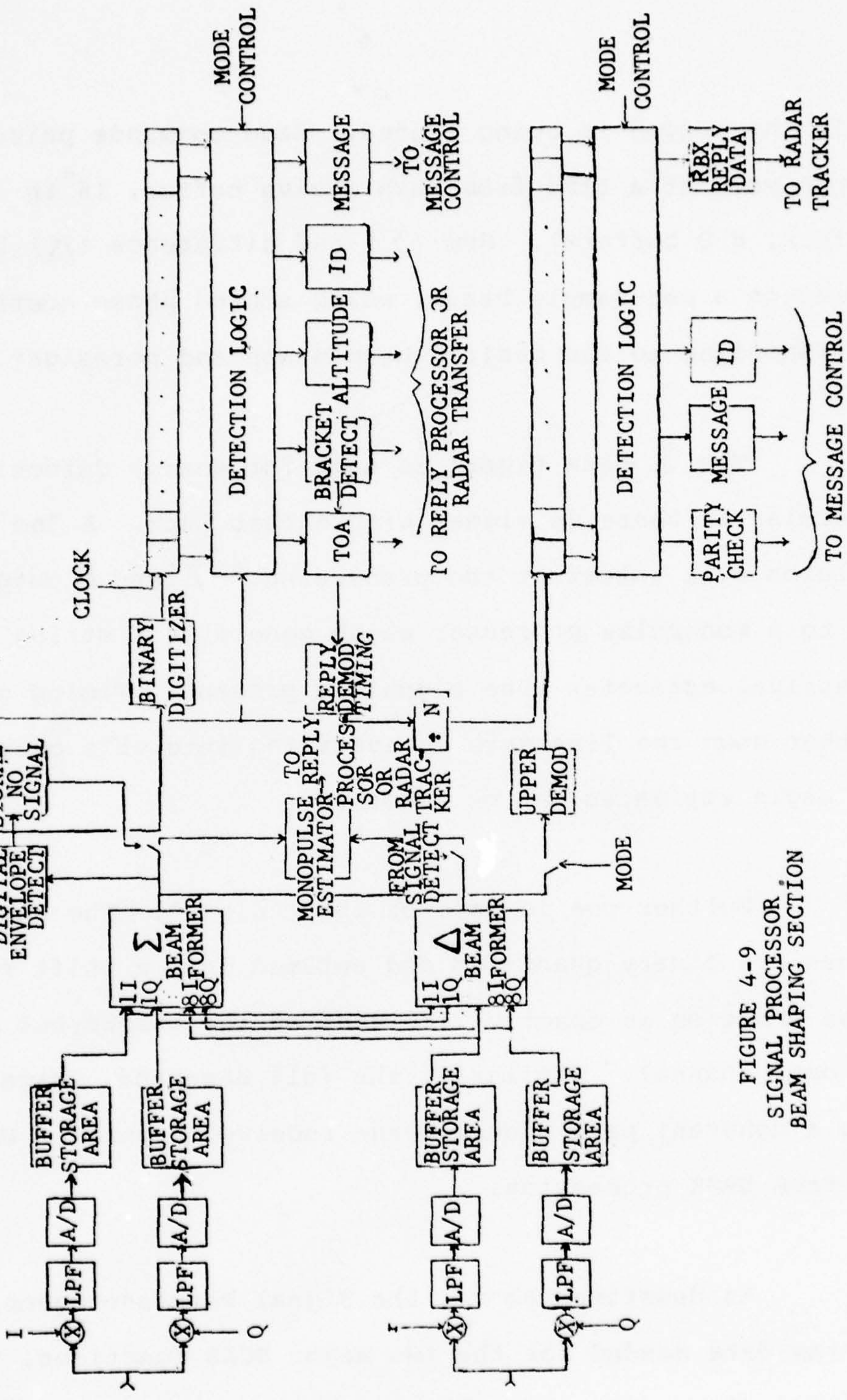


FIGURE 4-9
SIGNAL PROCESSOR
BEAM SHAPING SECTION

while the second is being loaded. Read commands pulse out one sample word at a time from each active buffer, 16 in all (8 I buffers, 8 Q buffers). Sum (Σ) and difference (Δ) beams are formed on a per-sample basis, using stored phase coefficients corresponding to the desired beam shape and boresight.

The Σ beam signal is used for energy detection to determine if there is signal within that beam. A "no signal" decision will interrupt the processing. Σ and Δ outputs are fed to a monopulse processor which generates a string of angle of arrival estimates when signal is present. Timing generated further down the line sets up averaging intervals over which the angle estimates can be smoothed.

Further use is made of the Σ signal. The envelope values are binary quantized and entered into a shift register whose function is exactly like that of the incoherent path on the omni channel. Similarly, the full baseband signal goes into a coherent path whenever the received signal is DABS 1030 MHz from DPSK processing.

As described above, the Signal Processor generates all the raw data needed for the two major BCAS functions, the tracking of targets and radar sites.

4.2.3 Mode Selector and Control Logic

There are five basic BCAS modes of operation which are (i) active, (ii) active and 1 site passive, (iii) active and 2 site passive, (iv) 1 site passive, and (v) 2 site passive. For each mode which utilizes passive information, the position solution will be functionally dependent upon the ground site(s) characteristics. That is different algorithms exist for position solution depending upon whether the ground site is synchro DABS, DABS, RBX or ATCRBS or any combination for 2 site solutions. In addition, the solution is geometrically dependent upon ground site(s) and BCAS geometry, directions that the ground site(s)' mainbeam is (are) pointing, and the distance BCAS is from an RBX or DABS site. Finally, the position solution is dependent upon whether a target is an ATCRBS or DABS target.

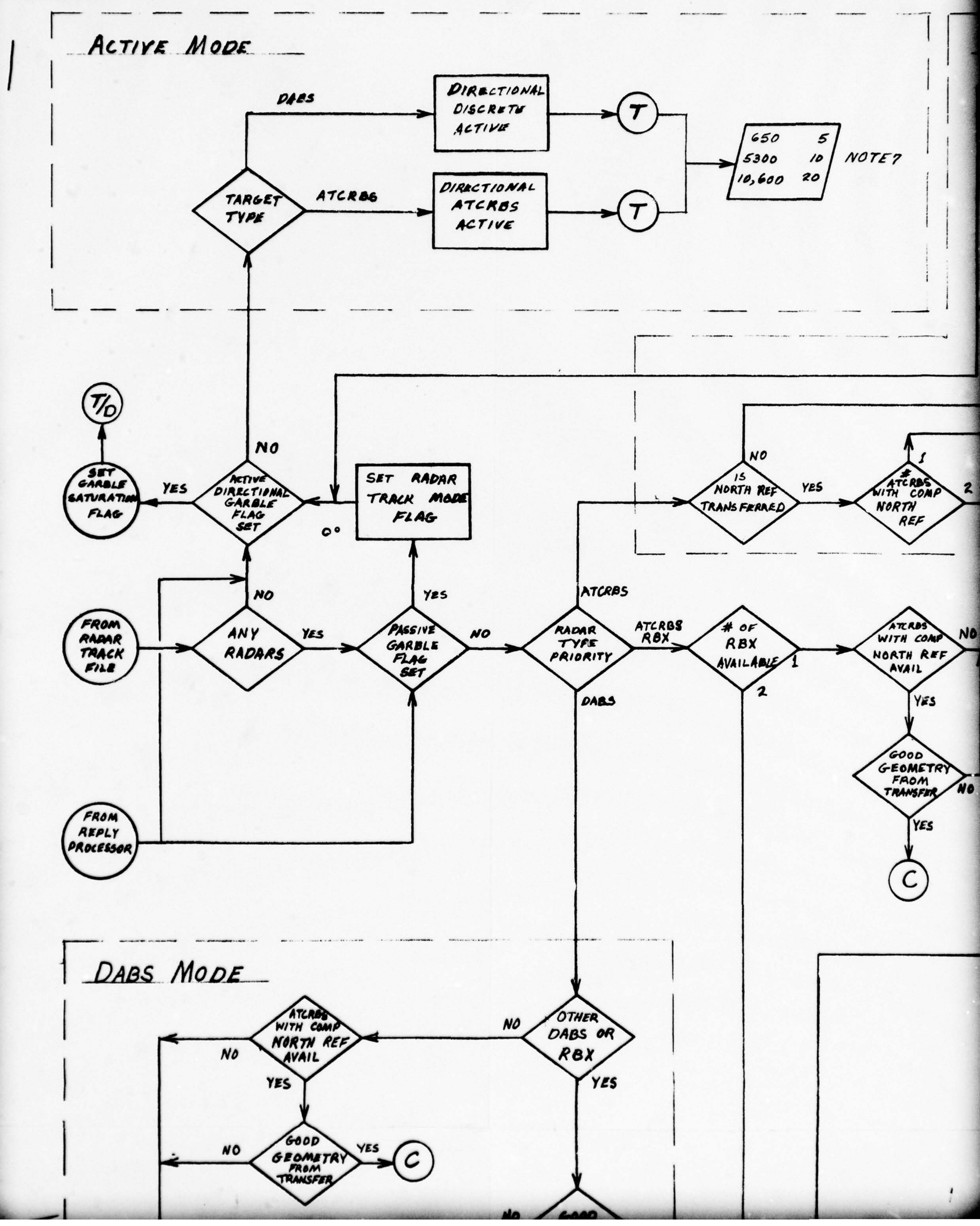
The mode solution utilizes the inputs from the target report generator, a part of the reply processor, to determine whether or not to set a garble flag. It utilizes knowledge of radar site positions, and their mainbeam locations as a function of time to determine which set of solutions (one for an ATCRBS target and one for a DABS target) are to be used.

Mode control, which receives the selected solutions, together with reply processor and radar track information, uses this information to control all basic elements of the BCAS design. The mode control logic thus determines: when the transmit control has to go active, the level of whisper/shout to be used, where to point the directive antenna, the RF switch matrix settings for 1030/1090 MHz - omni/directive reception (or course), how many mode files the reply processor has to associate with each target (Section 4.2.4.), etc. The mode selection and preliminary control logic is described in Figure 4-10.

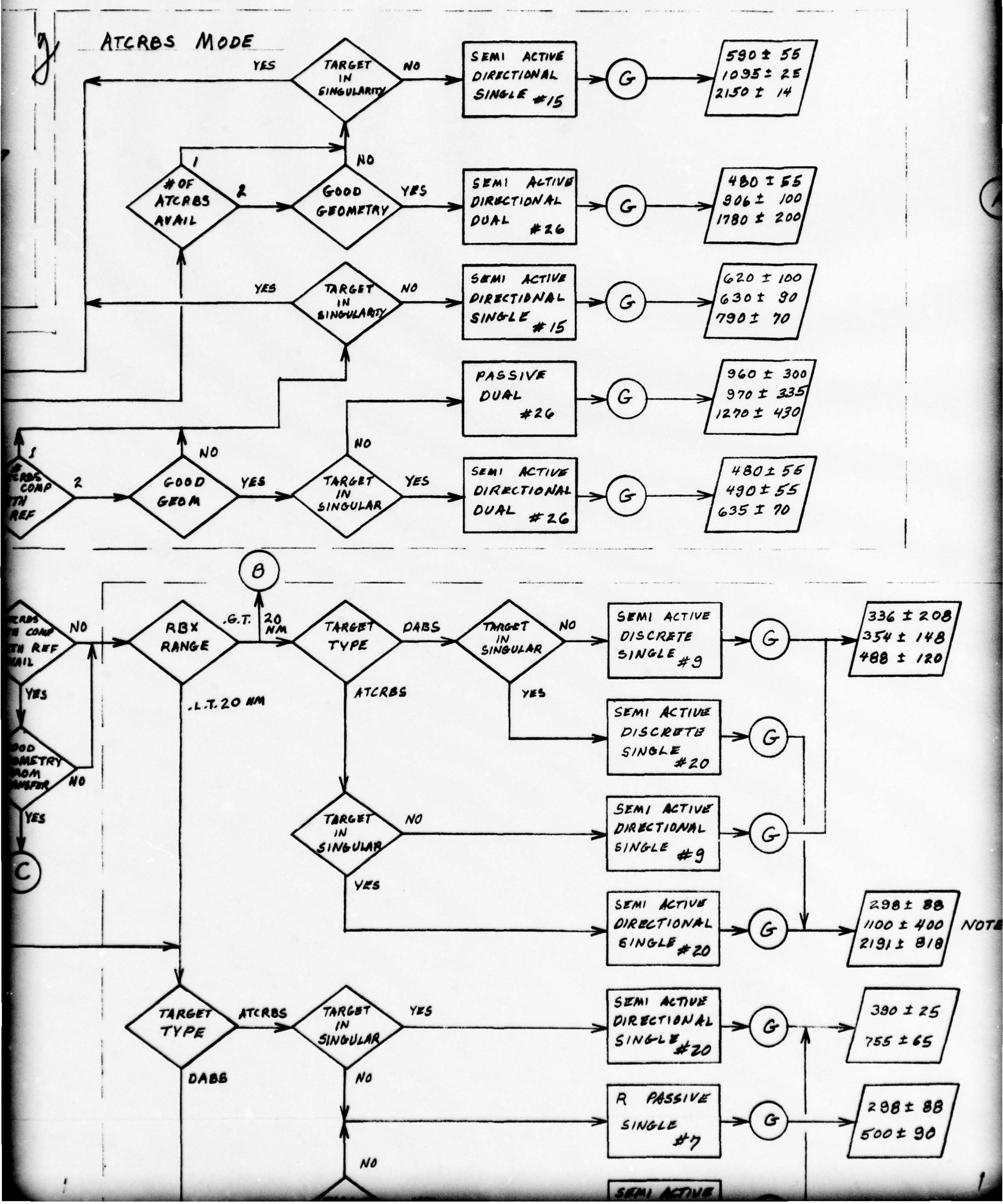
4.2.4 Reply Processor

The reply processor is the portion of the avionics which receives digitized reply data from the signal processor, stores it, and performs all the functions necessary to track targets. Reply processing is totally within the micro-processor and occurs under microprocessor control. Figure 4-11 shows the flow of operation.

The details of how reply processing works are different for each of the BCAS modes described in Section 3, and it would be inappropriate to try to describe each of those here. What is given in the following is a general description corresponding to Figure 4-11 which is valid for any BCAS. The design of a full reply processor is in progress.

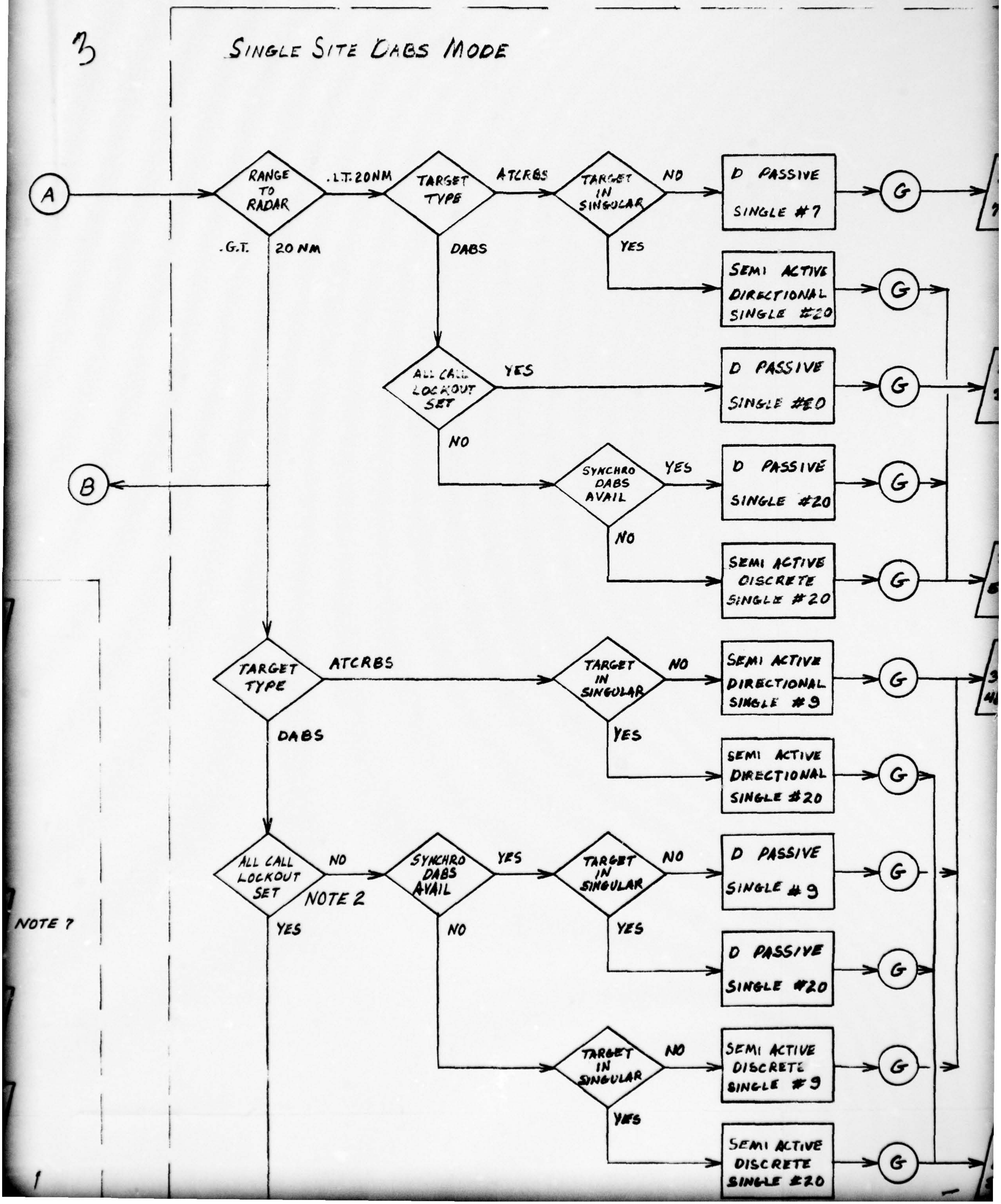


ACTIVE MODE
DABS
DIRECTIONAL DISCRETE ACTIVE
T
TARGET TYPE
ATCRBS
DIRECTIONAL ATCRBS ACTIVE
T
650 5
5300 10
10,600 20
NOTE 7
T/D
SET GARBLE SATURATION FLAG
YES
ACTIVE DIRECTIONAL GARBLE FLAG SET
NO
SET RADAR TRACK MODE FLAG
0°
NO
IS NORTH REF TRANSFERRED
YES
ATCRBS WITH COMP NORTH REF
1
2
FROM RADAR TRACK FILE
ANY RADARS
NO
YES
PASSIVE GARBLE FLAG SET
YES
NO
ATCRBS
RADAR TYPE PRIORITY
ATCRBS RBX
OF RBX AVAILABLE
1
2
DABS
ATCRBS WITH COMP NORTH REF AVAIL
NO
YES
GOOD GEOMETRY FROM TRANSFER
NO
YES
C
FROM REPLY PROCESSOR
DABS MODE
ATCRBS WITH COMP NORTH REF AVAIL
NO
NO
OTHER DABS OR RBX
YES
YES
GOOD GEOMETRY FROM TRANSFER
NO
YES
C
NO
GOOD

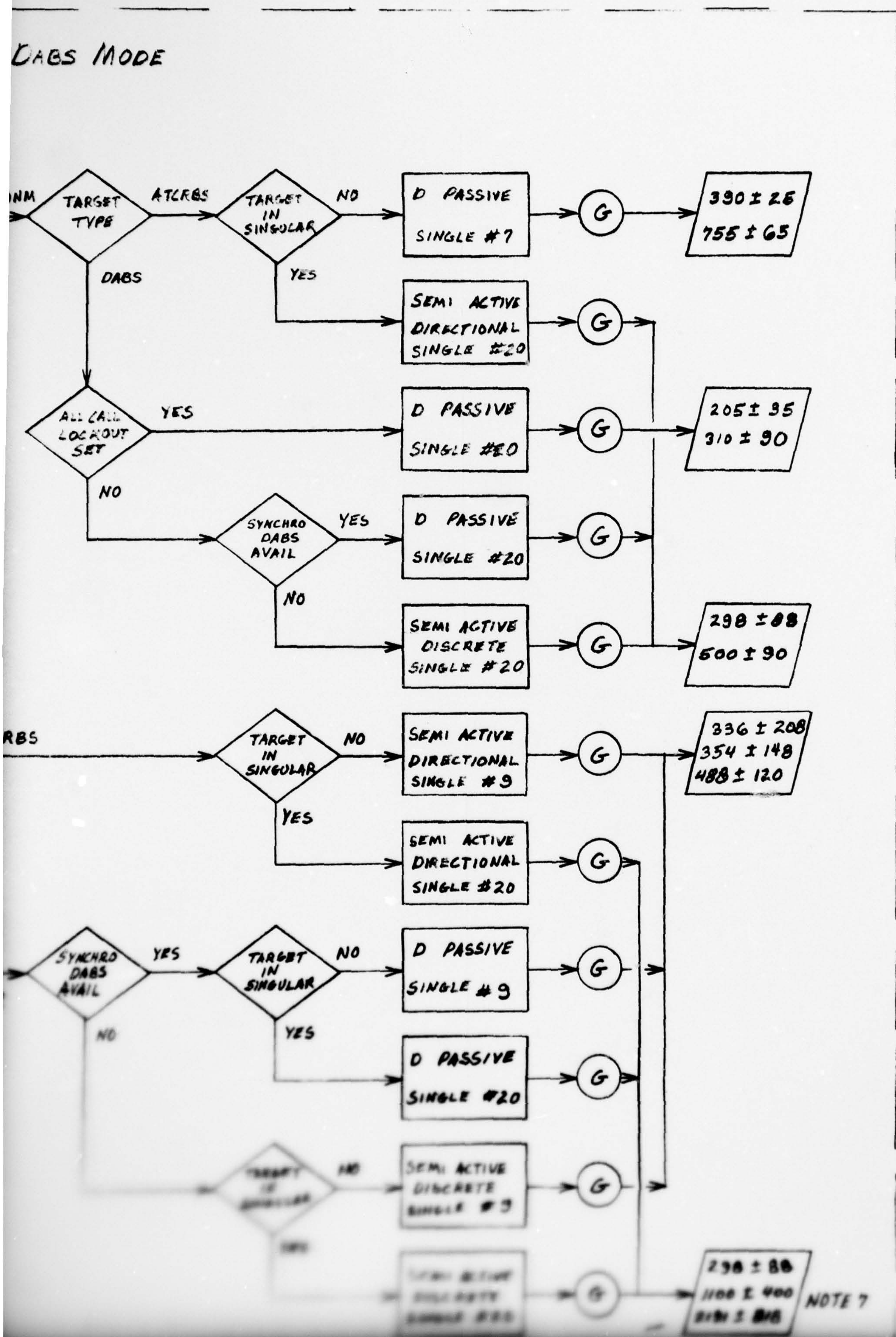


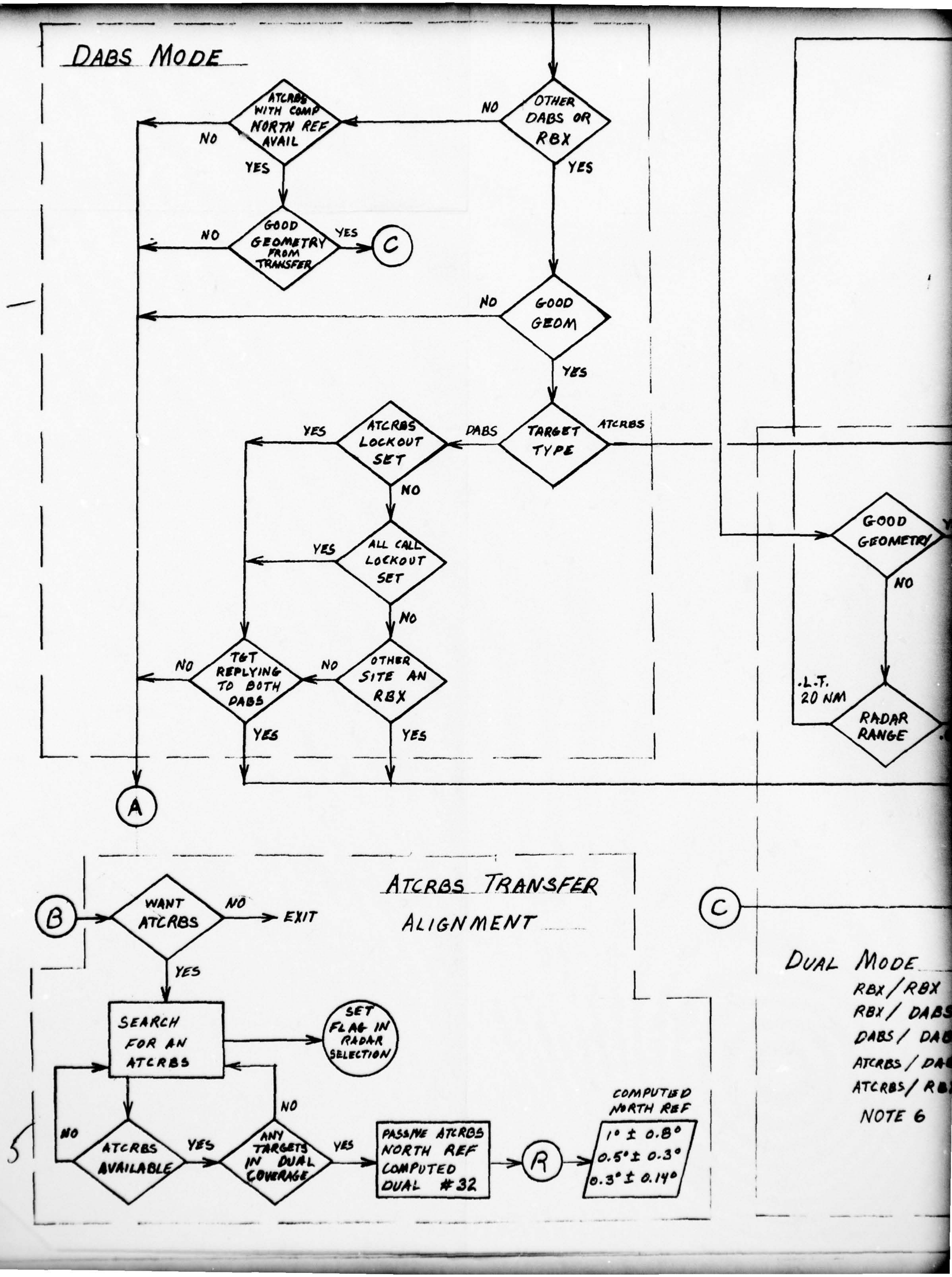
ATCRBS MODE
TARGET IN SINGULARITY
YES
NO
SEMI ACTIVE DIRECTIONAL SINGLE #15
G
590 ± 55
1095 ± 25
2150 ± 14
OF ATCRBS AVAIL
1
2
GOOD GEOMETRY
SEMI ACTIVE DIRECTIONAL DUAL #26
480 ± 55
906 ± 100
1780 ± 200
620 ± 100
630 ± 90
790 ± 70
PASSIVE DUAL #26
960 ± 300
970 ± 335
1270 ± 430
GOOD GEOM
TARGET IN SINGULAR
480 ± 55
490 ± 55
635 ± 70
B
RBX RANGE
.G.T. 20 NM
.L.T. 20 NM
TARGET TYPE
DABS
ATCRBS
SEMI ACTIVE DISCRETE SINGLE #9
336 ± 208
354 ± 148
488 ± 120
SEMI ACTIVE DISCRETE SINGLE #20
SEMI ACTIVE DIRECTIONAL SINGLE #9
SEMI ACTIVE DIRECTIONAL SINGLE #20
298 ± 88
1100 ± 400
2191 ± 818
NOTE
C
390 ± 25
755 ± 65
DABB
R PASSIVE SINGLE #7
298 ± 88
500 ± 90
SEMI ACTIVE

3

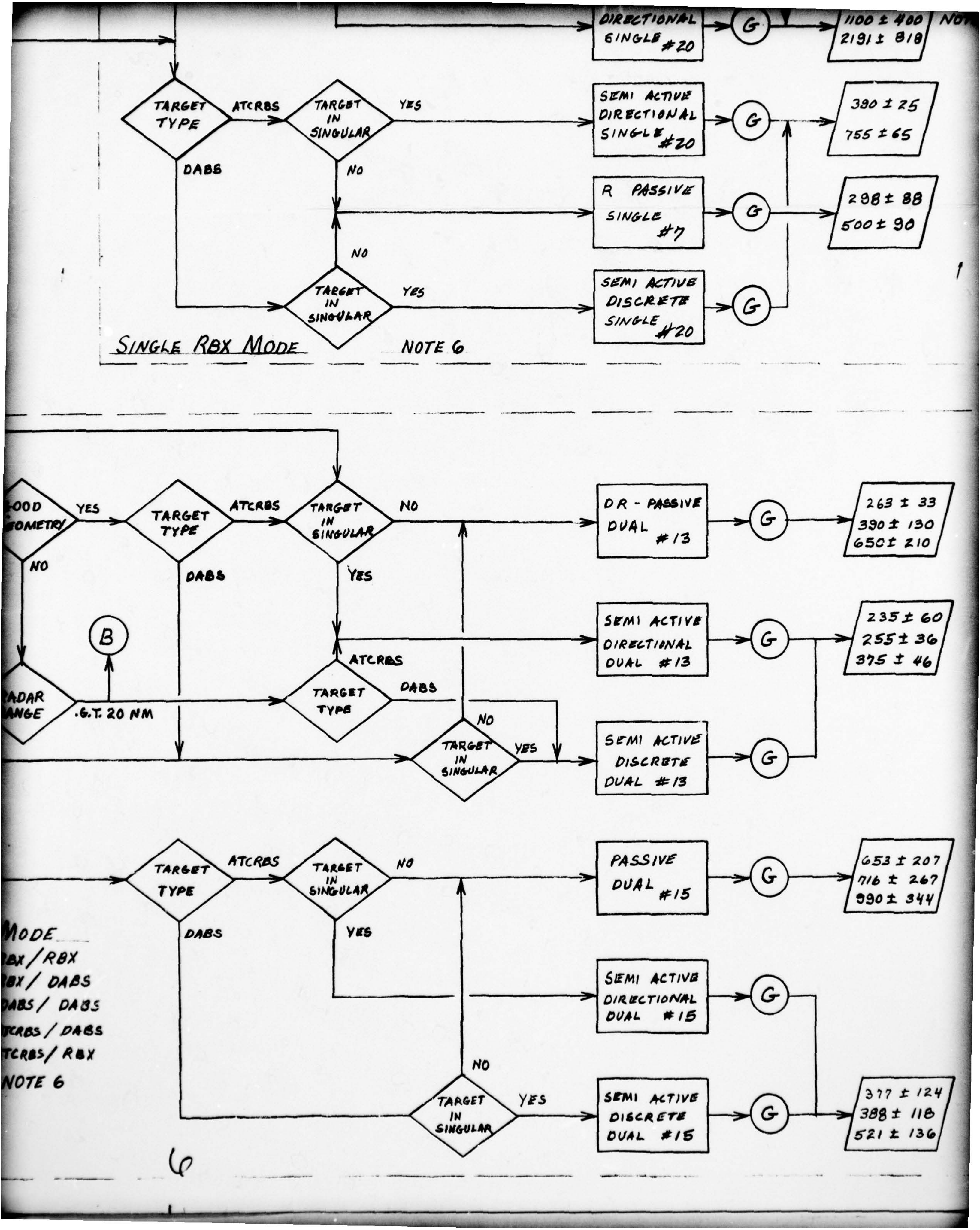


SINGLE SITE DABS MODE
A
RANGE TO RADAR
.LT. 20NM
.G.T. 20 NM
TARGET TYPE
ATCRBS
DABS
TARGET IN SINGULAR
NO
YES
D PASSIVE SINGLE #7
SEMI ACTIVE DIRECTIONAL SINGLE #20
ALL CALL LOCKOUT SET
YES
NO
D PASSIVE SINGLE #20
SYNCHRO DABS AVAIL
YES
NO
D PASSIVE SINGLE #20
SEMI ACTIVE DISCRETE SINGLE #20
B
TARGET TYPE
ATCRBS
DABS
TARGET IN SINGULAR
NO
YES
SEMI ACTIVE DIRECTIONAL SINGLE #9
SEMI ACTIVE DIRECTIONAL SINGLE #20
ALL CALL LOCKOUT SET
NO
NOTE 2
YES
SYNCHRO DABS AVAIL
YES
NO
TARGET IN SINGULAR
NO
YES
D PASSIVE SINGLE #9
D PASSIVE SINGLE #20
TARGET IN SINGULAR
NO
YES
SEMI ACTIVE DISCRETE SINGLE #9
SEMI ACTIVE DISCRETE SINGLE #20
G
NOTE 7

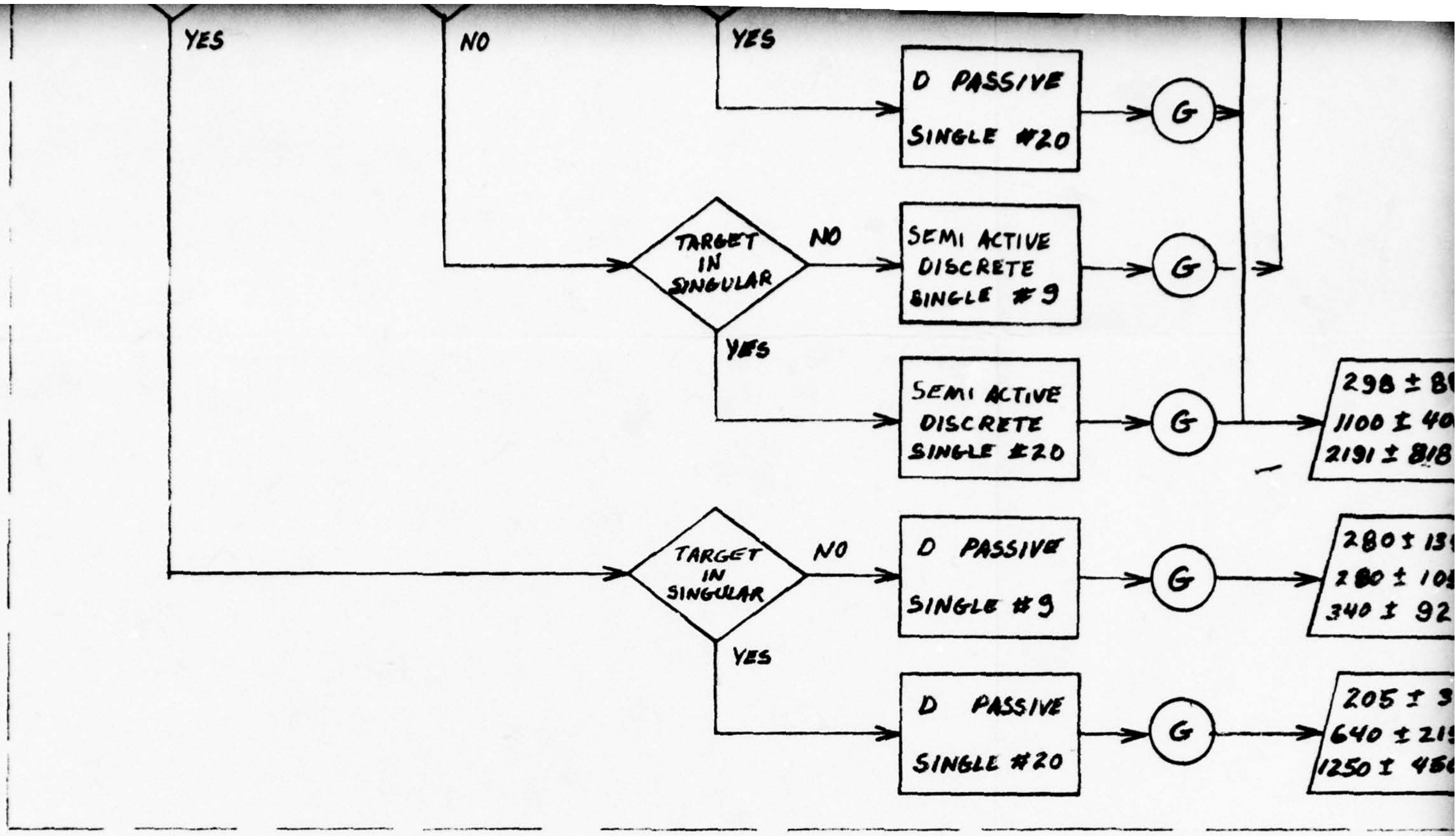

DABS MODE
NM
TARGET TYPE
ATCRBS
DABS
TARGET IN SINGULAR
NO
YES
D PASSIVE SINGLE #7
390 ± 25
755 ± 65
SEMI ACTIVE DIRECTIONAL SINGLE #20
ALL CALL LOCKOUT SET
YES
NO
D PASSIVE SINGLE #20
205 ± 35
310 ± 90
SYNCHRO DABS AVAIL
YES
NO
D PASSIVE SINGLE #20
SEMI ACTIVE DISCRETE SINGLE #20
298 ± 88
500 ± 90
RBS
TARGET IN SINGULAR
NO
YES
SEMI ACTIVE DIRECTIONAL SINGLE #9
336 ± 208
354 ± 148
488 ± 120
SEMI ACTIVE DIRECTIONAL SINGLE #20
SYNCHRO DABS AVAIL
YES
NO
TARGET IN SINGULAR
NO
YES
D PASSIVE SINGLE #9
D PASSIVE SINGLE #20
G
NOTE 7



DABS MODE
OTHER DABS OR RBX
NO
YES
ATCRBS WITH COMP NORTH REF AVAIL
NO
YES
GOOD GEOMETRY FROM TRANSFER
NO
YES
C
GOOD GEOM
NO
YES
TARGET TYPE
DABS
ATCRBS
ATCRBS LOCKOUT SET
YES
NO
ALL CALL LOCKOUT SET
YES
NO
OTHER SITE AN RBX
NO
YES
TGT REPLYING TO BOTH DABS
NO
YES
A
GOOD GEOMETRY
NO
.L.T. 20 NM
RADAR RANGE
ATCRBS TRANSFER ALIGNMENT
B
WANT ATCRBS
NO
EXIT
YES
SEARCH FOR AN ATCRBS
SET FLAG IN RADAR SELECTION
ATCRBS AVAILABLE
NO
YES
ANY TARGETS IN DUAL COVERAGE
NO
YES
PASSIVE ATCRBS NORTH REF COMPUTED DUAL #32
R
COMPUTED NORTH REF
1° ± 0.8°
0.5° ± 0.3°
0.3° ± 0.14°
C
DUAL MODE
RBX/RBX
NOTE 6


DIRECTIONAL SINGLE #20
1100 ± 400
2191 ± 818
TARGET TYPE
ATCRBS
DABS
TARGET IN SINGULAR
YES
NO
SEMI ACTIVE DIRECTIONAL SINGLE #20
G
390 ± 25
755 ± 65
R PASSIVE SINGLE #7
298 ± 88
500 ± 90
SEMI ACTIVE DISCRETE SINGLE #20
SINGLE RBX MODE
NOTE 6
GOOD GEOMETRY
RADAR RANGE
.G.T. 20 NM
B
DR - PASSIVE DUAL #13
263 ± 33
390 ± 130
650 ± 210
SEMI ACTIVE DIRECTIONAL DUAL #13
235 ± 60
255 ± 36
375 ± 46
SEMI ACTIVE DISCRETE DUAL #13
PASSIVE DUAL #15
653 ± 207
716 ± 267
990 ± 344
SEMI ACTIVE DIRECTIONAL DUAL #15
SEMI ACTIVE DISCRETE DUAL #15
377 ± 124
388 ± 118
521 ± 136
MODE
RBX / RBX
RBX / DABS
DABS / DABS
ATCRBS / DABS
ATCRBS / RBX
NOTE 6

6



NOTES

1: PWI IS ONLY PROTECTION AGAINST PROXIMATE (1 NM) AIRCRAFT BEARING IS REQUIRED FOR PROTECTION AND CANNOT BE PROVIDED IN THE ACTIVE MODE WITHOUT A DIRECTIONAL ANTENNA

2: SIMPLIFICATION AND ACCURACY IMPROVEMENT IN THE SINGLE SITE DABS MODE OCCURS IF SYNCHRO DABS WITH AZ. ECHO IS REQUIRED WHENEVER THE ALL CALL LOCKOUT BIT IS SET IN DABS

3: ALL SEMI ACTIVE OMNI MODES AND ACTIVE OMNI MODES WILL SATURATE IN HIGH DENSITY AIRSPACE AND NO PROTECTION IS PROVIDED UNLESS A DIRECTIONAL ANTENNA IS AVAILABLE

4: THE DIRECTIONAL ANTENNA CA

5: AN RBX IS NOT REQ'D AT DABS

6: R-PASSIVE REQUIRES LOW

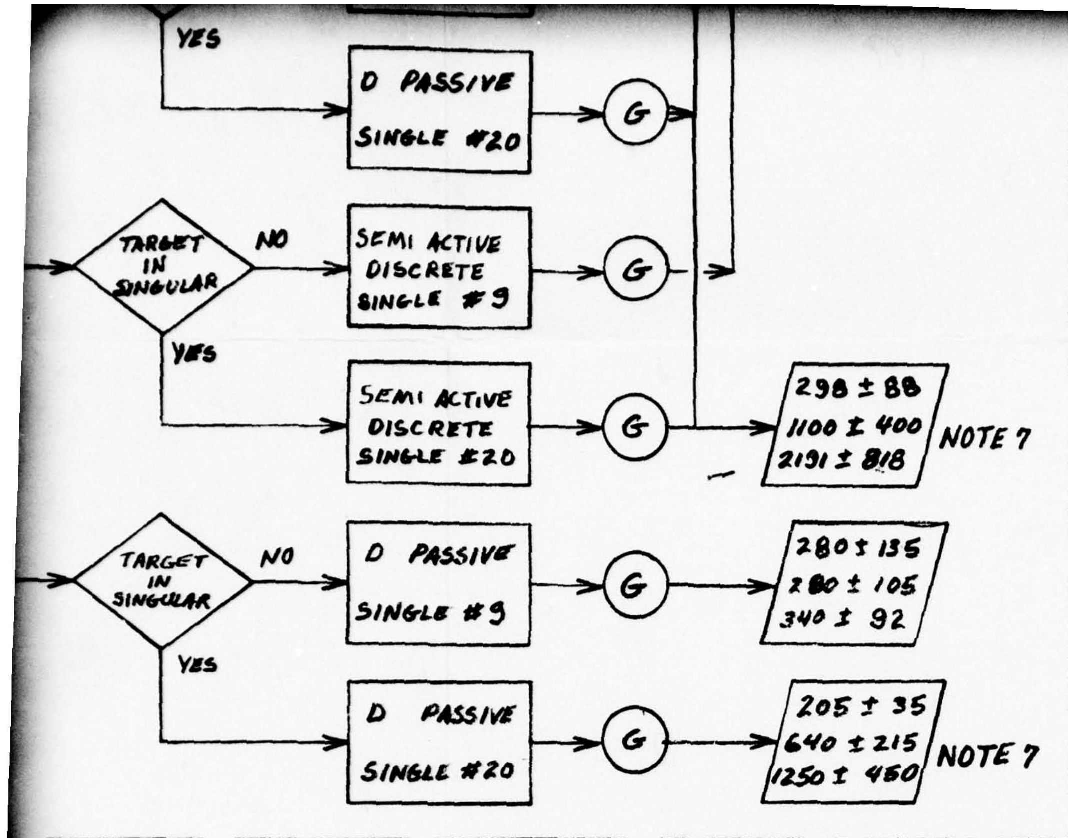
7: THIS GEOMETRIC RECONSTRUC

FIGURE 4-10

TITLE: BCAS MODE SELECTION AND CONTROL LOGIC PREFERRED EMBODIMENT

DATE: 3 APRIL, 1978 BY: PVH

REV #	REVISION DESCRIPTION	DATE



TE (1NM) AIRCRAFT
CANNOT BE PROVIDED IN
AL ANTENNA
EMENT IN THE SINGLE SITE DABS
. ECHO IS REQUIRED WHENEVER
T IN DABS
ACTIVE OMNI MODES WILL
AND NO PROTECTION IS
ENNA IS AVAILABLE

4: THE DIRECTIONAL ANTENNA CAN BE USED TO REDUCE PASSIVE GARBLE
5: AN RBX IS NOT REQ'D AT DABS IF RANGE & AZ. ARE BROADCAST BY DABS
6: R-PASSIVE REQUIRES LOW PRF INTERROGATION OF THE RBX
7: THIS GEOMETRIC RECONSTRUCTION DOES NOT MEET REQ'D ACCURACY

ND CONTROL LOGIC
ENT

BY : PVH

DATE

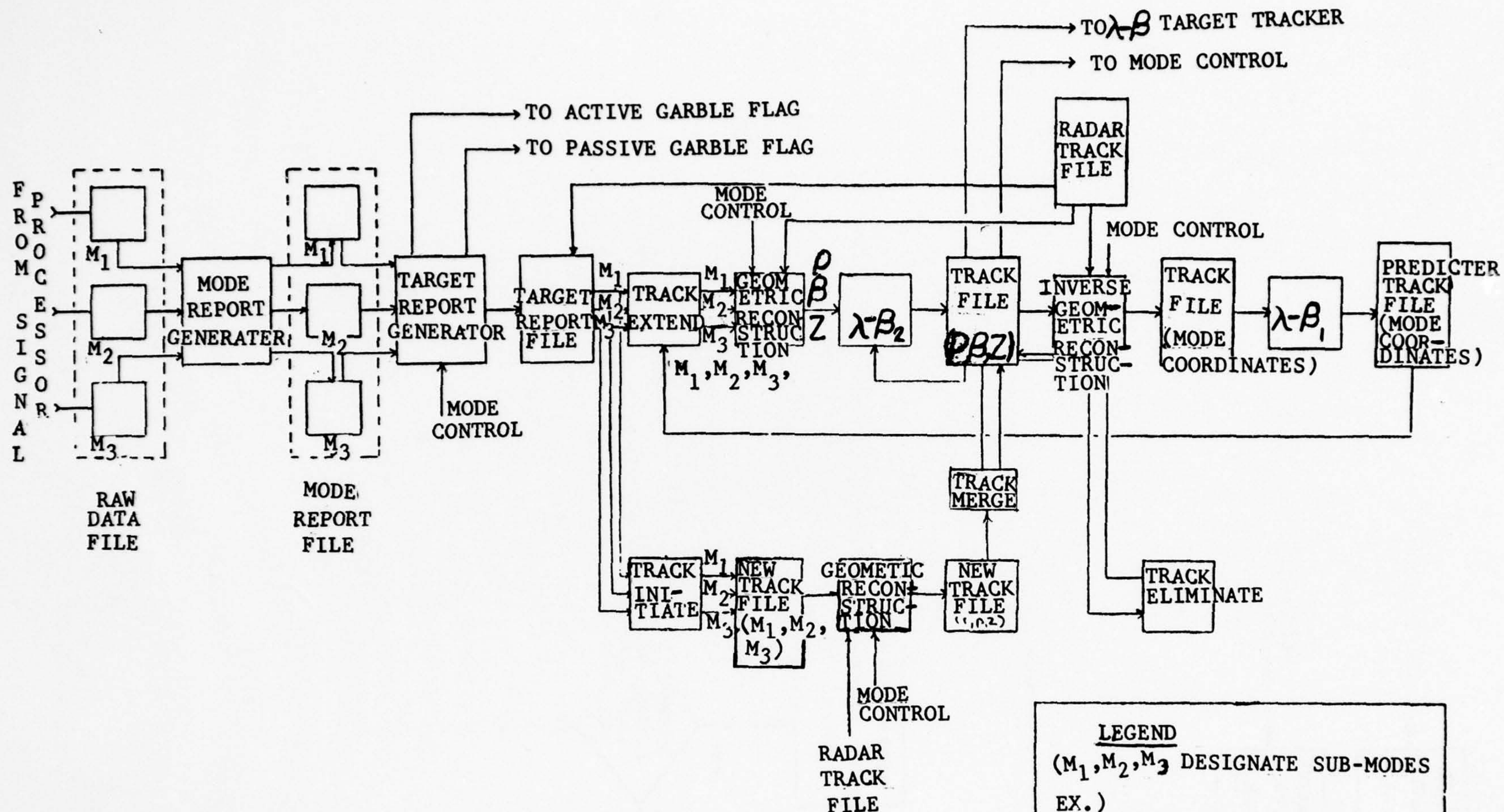


FIGURE 4-11

REPLY PROCESSOR

LEGEND

(M_1, M_2, M_3 DESIGNATE SUB-MODES EX.)

M_1=RBX SITE #1 DATA
M_2=RBX SITE #2 DATA
M_3=ACTIVE MODE DATA

Appendix J contains detailed description of the reply processor for the two BCAS modes: (i) Active Mode, and (ii) Single-Site Semi-Active (ATCRBS targets).

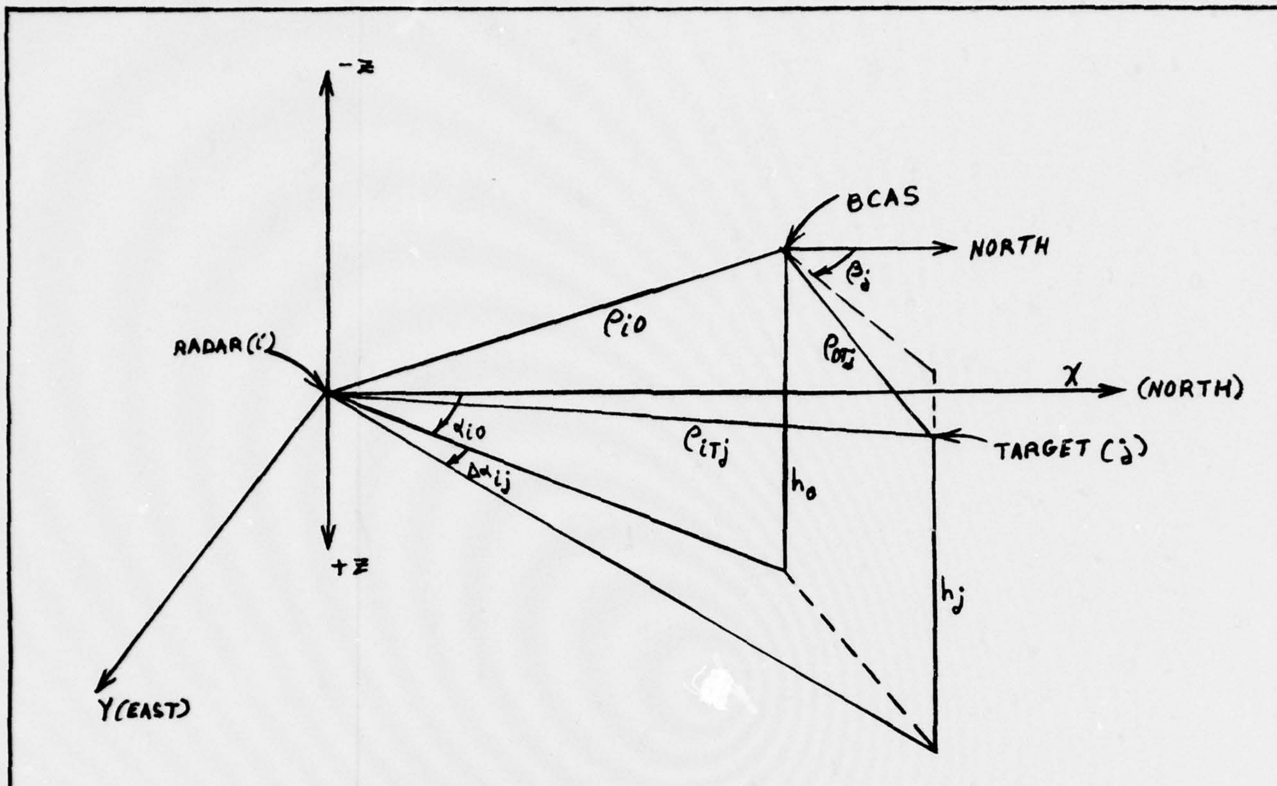
There are at most three sources of data from which a target report is obtained and from which a target track is generated. That is, BCAS will at most use two ground sites (2 passive sites) and will actively interrogate targets everywhere or in areas of passive singularities. Thus three raw data files are formed as shown in Figure 4-11.

The Mode Report Generator takes each mode raw data file and compresses the data in each mode and forms individual mode-target reports. Thus, for example, the 12 to 16 target sweep replies per ground interrogator scan are combined to one mode report. The outputs of the Mode Report Generator are then placed in the mode report file.

The next step is to associate the mode reports from several different modes (up to three) with the same target. This is done in the Target Report Generator. The Target Report Generator knows approximately, on the basis of its inputs from the radar track file and mode control when a given region of airspace has been interrogated by a given ground site. It also knows this information from the active mode. Thus, correlations between target reports based on this information, ID and altitude are made to associate the several modes with a given target. The result of this process is a target report file where for each target we have three uncombined mode reports each providing track parameters in their original measurement and data detected coordinates. Thus, a passive report will contain TOA's, differential azimuths, ID, altitude, etc., while an active mode report will contain range to target, bearing, altitude, ID, etc.

The target report file is used as the basic input for Track Extension and for Track Initiation. Track Extension is done in mode coordinates and for each mode so that target report is correlated with a track parameter extension on a mode by mode basis. Once a track has been extended on a multimodal basis it is passed on to Geometric Reconstruction.

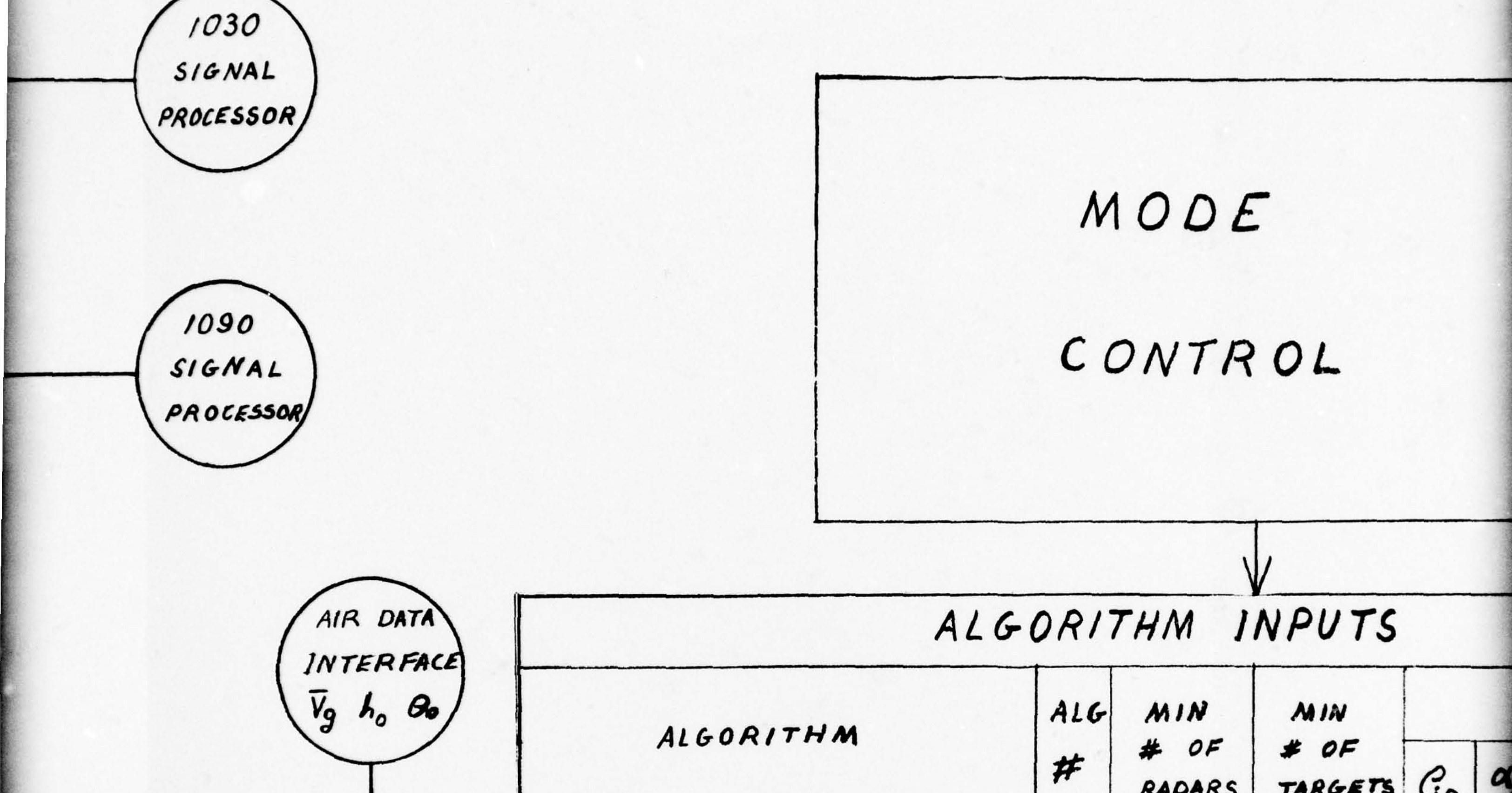
Geometric Reconstruction takes the extend track prediction and with inputs from the Radar Track File and Mode Control selects the best data from each mode to extend the target. The geometric reconstruction procedure is described in Figure 4-12.



BCAS GEOMETRY

BASIC MEASUREMENTS	MEASUREMENT SOURCE	1σ MEAS ACCURACY
BCAS RANGE TO RADAR (i)	ATCRBS - RBX DABS	100′
BCAS AZIMUTH TO RADAR (i)	CENTERMARK MAIN BEAM SYNCHRO-DABS AZ. ECHO	$0.25°/\sqrt{2}$ 0.1°
BCAS TO TARGET (j) DIFFERENTIAL AZIMUTH MEASURED FROM RADAR (i)	CENTERMARK MAIN BEAM SYNCHRO-DABS AZ. ECHO	0.25° $\sqrt{2} \times 0.1°$
DIFFERENTIAL TIME OF ARRIVAL OF TARGET (j) REPLY TO RADAR (i) MEASURED AT BCAS	TIME BETWEEN BCAS KNOWLEDGE OF RADAR INTERROGATION & RECEIPT OF TARGET REPLY	100 ns.
BCAS RANGE TO TARGET (j)	CALCULATED SYNCHRO-DABS RANGING ACTIVE RANGING	NA 100′ 100′

7



MEAS ...URACY	SYMBOL
...0′	ρ_{io}
...5°/√2 ...1°	α_{io}
...25° ...x 0.1°	$\Delta\alpha_{ij}$
...ns.)	τ_{ij}
...0′ ...	ρ_{OTi}

ALGORITHM INPUTS

ALGORITHM	ALG #	MIN # OF RADARS	MIN # OF TARGETS	ρ_{io}	α...
SINGLE #7	1	1	1	X	X
SINGLE #9	2	1	1	X	X
SINGLE #15	3	1	1		X
SINGLE #20	4	1	1	X	X
PASSIVE DUAL #13	5	2	1	X	X
SEMI-DUAL #13	6	2	1	X	X
SEMI-DUAL #26	7	2	1		X
PASSIVE DUAL #32	8	2	1	X	X
PASSIVE DUAL ATCRBS	9	2	2		
SEMI DUAL ATCRBS	10	2	2	—	
ACTIVE DIRECTIONAL	11	Ø	1		

3

ALGORITHM OUTP

ρ_{OTj} β_j FOR ALL ALGORITHMS

α_{io} FOR PASSIVE DUAL #32

INPUTS							
ρ_{io}	α_{io}	$\Delta\alpha_{io}$	τ_{ij}	ρ_{OTj}	β_j	h_o	h_j
X	X	X	X			X	X
X	X		X	X		X	X
	X	X	X	X		X	X
X	X	X	X	X		X	X
X	X		X			X	X
X	X		X	X		X	X
	X	X	X	X		X	X
X	X		X	X		X	X
		X	X			X	X
		X	X	X		X	X
				X	X	X	X

BASIC EQUATIONS (ALL ALGO

$$d_{io} = (\rho_{io}^2 - h_o^2)^{1/2}$$

$$d_{iTj} = (\rho_{iTj}^2 - h_j^2)^{1/2}$$

$$d_{OTj} = (\rho_{OTj}^2 - \Delta h_j^2)^{1/2}$$

$$\Delta h_j = (h_j - h_o)$$

$$\tau_{ij} = \rho_{iTj} + \rho_{OTj} - \rho_{io}$$

$$d_{iO} = d_{iTj} \cos \Delta\alpha_{ij} - d_{OTj} \cos ($$

$$d_{iTj} \sin \Delta\alpha_{ij} = d_{OTj} \sin (\beta_j -$$

4

h_j
X
X
X
X
X
X
X
X
X
X
X
X
X

ALGORITHM OUTPUTS

ρ_{OTj} β_j FOR ALL ALGORITHMS EXCEPT #32

α_{io} FOR PASSIVE DUAL #32 (RADAR #2)

↑

BASIC EQUATIONS (ALL ALGORITHMS)

$$d_{io} = (\rho_{io}^2 - h_o^2)^{1/2}$$

$$d_{iTj} = (\rho_{iTj}^2 - h_j^2)^{1/2}$$

$$d_{OTj} = (\rho_{OTj}^2 - \Delta h_j^2)^{1/2}$$

$$\Delta h_j = (h_j - h_o)$$

$$\tau_{ij} = \rho_{iTj} + \rho_{OTj} - \rho_{io}$$

$$d_{io} = d_{iTj} \cos \Delta\alpha_{ij} - d_{OTj} \cos(\beta_j - \alpha_{io})$$

$$d_{iTj} \sin \Delta\alpha_{ij} = d_{OTj} \sin(\beta_j - \alpha_{io})$$

$$\beta_{oj} = \beta_j - \theta_o$$

BCAS AZIMUTH TO RADAR (i)	CENTERMARK MAIN BEAM SYNCHRO-DABS AZ. ECHO	$0.25/\sqrt{2}$ 0.1°	α_i
BCAS TO TARGET (j) DIFFERENTIAL AZIMUTH MEASURED FROM RADAR (i)	CENTERMARK MAIN BEAM SYNCHRO-DABS AZ. ECHO	0.25° $\sqrt{2} \times 0.1^\circ$	$\Delta\alpha$
DIFFERENTIAL TIME OF ARRIVAL OF TARGET (j) REPLY TO RADAR (i) MEASURED AT BCAS	TIME BETWEEN BCAS KNOWLEDGE OF RADAR INTERROGATION & RECEIPT OF TARGET REPLY	100 ns.	τ_i
BCAS RANGE TO TARGET (j)	CALCULATED SYNCHRO-DABS RANGING ACTIVE RANGING - DISCRETE - DIRECTIONAL - OMNI	NA 100' 100'	ρ_{OT}
BCAS BEARING TO TARGET (j) (RELATIVE TO NORTH)	CALCULATED DIRECTIONAL ANTENNA	NA ± 5°	β_j
ALTITUDE	TRANSPONDER ENCODER	50' QUANTIZATION 10' (1σ)	h_0

NOTES

5

SINGLE #20	4	1	1	X	X	X	X	X		X	X
PASSIVE DUAL #13	5	2	1	X	X		X			X	X
SEMI - DUAL #13	6	2	1	X	X		X	X		X	X
SEMI - DUAL #26	7	2	1		X	X	X	X		X	X
PASSIVE DUAL #32	8	2	1	X	X		X	X		X	X
PASSIVE DUAL ATCRBS	9	2	2			X	X			X	X
SEMI DUAL ATCRBS	10	2	2			X	X	X		X	X
ACTIVE DIRECTIONAL	11	Ø	1					X	X	X	X
PASSIVE - DUAL #26	12	2	1		X	X	X			X	X
PASSIVE DUAL #15	13	2	1	X	X	X	X			X	X
SEMI ACTIVE DUAL #15	14	2	1	X	X	X	X	X		X	X

NOMENCLATURE

ρ_{io}	BCAS RANGE TO RADAR (i)
α_{io}	BCAS AZIMUTH TO RADAR (i)
$\Delta\alpha_{ij}$	BCAS TO TARGET (j) DIFFERENTIAL AZIMUTH MEASURED FROM RADAR (i)
h_o	BCAS ALTITUDE
h_j	TARGET (j) ALTITUDE
τ_{ij}	DIFFERENTIAL TIME OF ARRIVAL OF TARGET (j) RELATIVE TO RADAR (i)
ρ_{oTj}	BCAS RANGE TO TARGET (j)
ρ_{iTj}	RADAR (i) RANGE TO TARGET (j)
θ_o	BCAS HEADING RELATIVE TO NORTH
β_j	BCAS AZIMUTH TO TARGET (j) RELATIVE TO NORTH
β_{oj}	BCAS BEARING TO TARGET (j) RELATIVE TO AIRCRAFT
ρ_{ij}	RANGE BETWEEN RADARS (i) AND (j)

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THE FAA CONCEPT FOR A BEACON COLLISION AVOIDANCE SYSTEM (BCAS).--ETC(U)
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UNCLASSIFIED FAA-EM-78-5-2 NL

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END
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-12-78
DDC

cont

$$d_{OTj} = (\rho_{OTj}^2 - \Delta h_j^2)^{1/2}$$

$$\Delta h_j = (h_j - h_o)$$

$$\tau_{ij} = \rho_{iTj} + \rho_{OTj} - \rho_{iO}$$

$$d_{iO} = d_{iTj} \cos \Delta\alpha_{ij} - d_{OTj} \cos(\beta_j - \alpha_{iO})$$

$$d_{iTj} \sin \Delta\alpha_{ij} = d_{OTj} \sin(\beta_j - \alpha_{iO})$$

$$\beta_{Oj} = \beta_j - \theta_O$$

FIGURE 4-12

TITLE: GEOMETRIC RECONSTRUCTION

DATE: 17 MARCH, 1978

REV #	REVISION DESCRIPTION		DATE
1	ALGORITHM INPUT # 12, 13, 14	PVH	29 MAR 78

DRAWN BY PVH, 17 MARCH, 1978

7

The most recent entries to the Target Report File are next examined for the purpose of Track Extension. Track Extension begins by selecting a track from the Track File and examining a subset of the new target reports to see if any of them constitute a suitable extension to the track. The comparison of the track and the target report is based on a prediction of the next track point made by the Track Extender. The prediction uses the mode track coordinates and their first derivatives which are stored in the mode coordinate Track File. The tracking is done by an α-β filter whose parameters are individually chosen for each coordinate. The predicted coordinate is compared to the corresponding coordinate and if they are "close enough" a matching extension is made. Often the tests for closeness involve consideration of more than one component at a time, particularly when garble resolution measures are employed in the extension procedures.

Once a track has been extended on a multimodal basis it is passed on to Geometric Reconstruction. Geometric Reconstruction takes the extended track in mode coordinates for its several modes, with inputs from the Radar Track File and Mode Control, and selects the best data from each mode to make a coordinate transformation. The result of this transformation is a target track extension in range, bearing and altitude.

This positional data is then smoothed by an track in each of its three coordinates and placed into the Track File.

If a matching extension is not found, there are two other possible outcomes. One is that a point just slightly outside the allowable window is found and it is slewed into the window edge. Slew rate limiting of this sort is common in tracking systems which deal with occasional anomalous errors due to interference. Or, it may be the case that no matching extension is found, in which case the track is "coasted," i.e., linearly extended by feeding the predicted value back into the α,β track as though it were the actual measured value. Coasting permits maintenance of track continuity through periods where either the actual reply is badly distorted by interference or no reply was received. Occasionally multiple extensions are possible, and in such cases a new track is formed for each.

As part of the track extension procedure, the track confidence is updated to reflect the results of the most recent extension. When a track is first entered into the track file, it is assigned a confidence index equal to zero. As the track is extended, the confidence index will be permitted to build up as a function of various parameters of the extension process. A maximum value of the confidence index is stipulated, and when the confidence count reaches that value, the track is said to be established. The rules for incrementing and decrementing confidence are such that a track normally will be established within 30 seconds of the first reception.

When an established track has a succession of poor extensions (e.g., coasts rather than data-based extensions), confidence will decrement, and when it reaches a low enough level, the track will be declared invalid and dropped (see discussion of Track Elimination).

If a new track is created within the Track File because of multiple extension, the new track is assigned confidence equal to that of the old track.

When track extension is complete, the track file is updated accordingly. A track file entry contains all the positional parameters being tracked plus a few additional items such as an age index (time tag of start of track), track confidence index, establishment bit, etc.

Before we return to the target report file and see how new tracks are initiated, we note that in order for track extension to have taken place in mode coordinates, a second track file must exist on each target in terms of its mode coordinates. To obtain this second track file an inverse geometric reconstruction is performed as shown in Figure 4-11.

The Track Initiation function associates a group of target reports in mode coordinates from a number of consecutive replies to form tentative tracks. A number of searches and tests over the reports are required to do this. Track Initiation only operates when the Target Report File contains entries over a sufficient time span to make the correlation of replies into a tentative track meaningful (e.g., three consecutive replies).

The result of Track Initiation is a New Track File in mode coordinates which is transformed by geometric reconstruction to a New Track File in r, θ and z coordinates.

Once new tracks are formed and old tracks extended, the Track Merge procedure is invoked. It operates in two phases; in the first, new tracks and tracks in the old Track File are compared to determine if any new track is duplicate of an already existing track, and if so the new track is eliminated from the New Track Buffer. The standards for retaining the new track are not very stringent here since newly initiated tracks do not have the benefit of much smoothing.

After the New Track Buffer has been purged of redundant tracks, a second round of merge tests is performed, this time upon pairs of tracks within the newly updated Track File. In this case the standards for declaring track duplication can be more strict since established tracks have a certain amount of credibility associated with them. When duplicates are found, a rule which takes into account factors such as track age and confidence index determines which tracks is to be dropped.

To conclude the merge, all tracks in the New Track Buffer which have survived the merge are entered into the Track File where they are assigned an age tag corresponding to the current interrogation/reply number and an initial confidence level of zero. The New Track Buffer is cleared for the next reply round.

Not all track pairs in the file need be compared for merge, since some of them can be easily determined to be non-duplicates on the basis of data other than the track points themselves. For example, in the active mode, track pairs which lie in wholly distinct antenna beams can be determined from their beam indices and require no further comparison. Single-site Passive Mode tracks are tagged with a quantized ACP count which is a general indication of target azimuth relative to the site, and comparisons based on widely disparate ACP counts can be avoided. This point is important because the number of comparisons will be proportional to N^2, where N is the number of tracks, if no pre-editing of tracks to be compared is done. Dividing direction of arrival in active mode into nine sectors can cut the number of comparisons down by a factor approaching 81.

Completion of Track Merge leads to Track Elimination. Tracks may be eliminated from the file for various reasons. The first is lack of confidence in the track; this is determined by having the confidence index of the track drop below a minimum acceptable value. Factors which contribute to deteriorated track confidence are primarily excessive numbers of adjustments to the measured data via coasts, slews and altitude corrections.

A second reason is that the track corresponds to a target which is no longer of interest to BCAS because it does not represent a potential collision threat. Such targets are determined on the basis of excessive range from BCAS, diverging range rate, large differential altitude, etc. Based on the detection of one or more such factors, a track may be eliminated.

A third reason may be that the track has been determined to be a false track. False tracks can be generated in a garble environment by a coincidental sequence of false target reports. These may persist and even escape elimination in the merge test, and may last until they are eliminated because of poor extension. A class of false targets which arises in the active mode is the phantom target class. These are generated when garbled replies from aircraft on the ground persistently indicate a target at non-zero altitude. Phantoms can be detected in active mode by calculating various velocity components of the target. Observation of these components over a short period can indicate that the track cannot possibly correspond to a moving airborne target, and hence the track can be dropped.

When Track Elimination is finished, the reply processor/tracker cycle for one reply set has been completed and the housekeeping initializations for the next reply set can be performed.

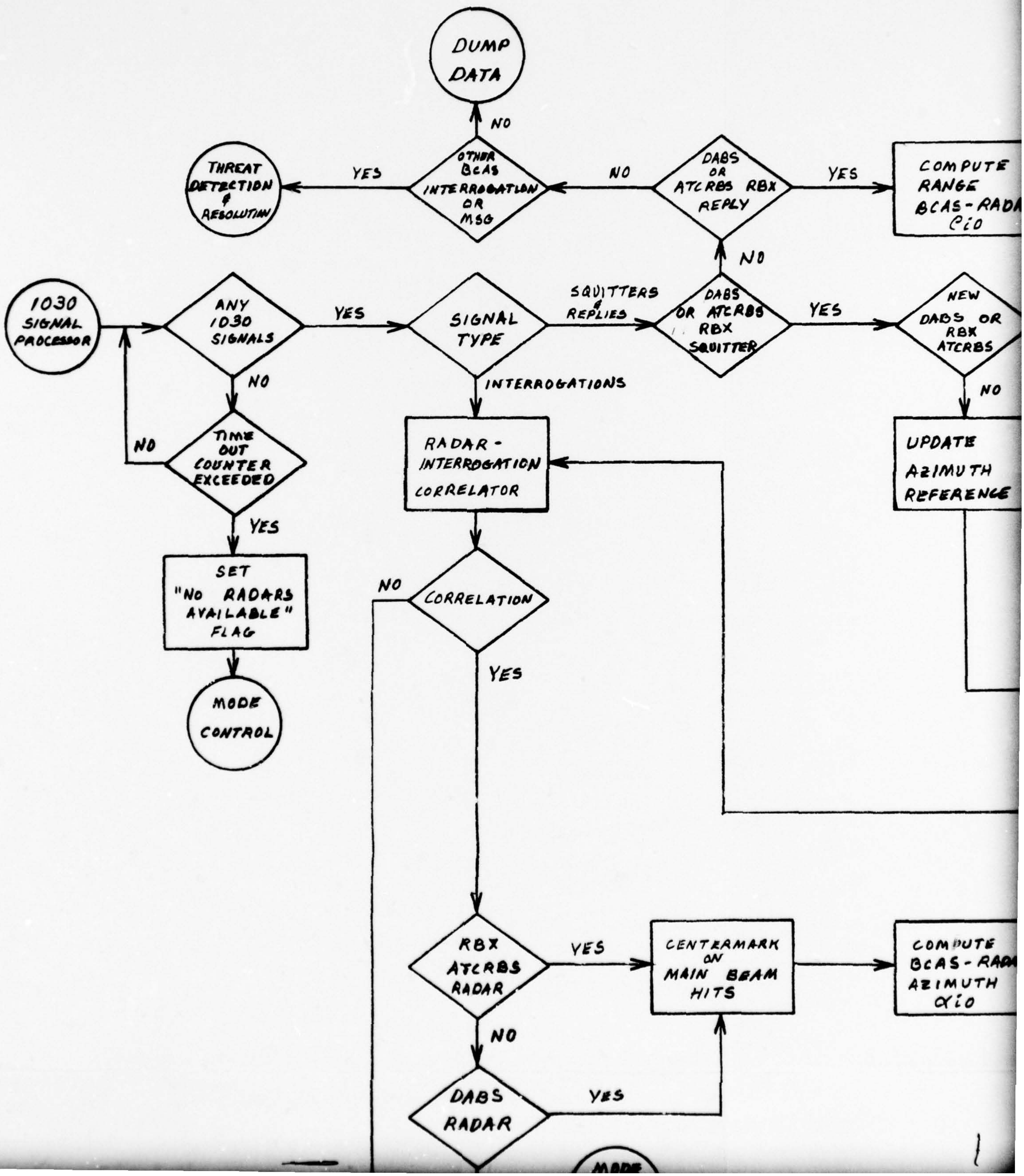
This concludes the overall description of the BCAS reply processor.

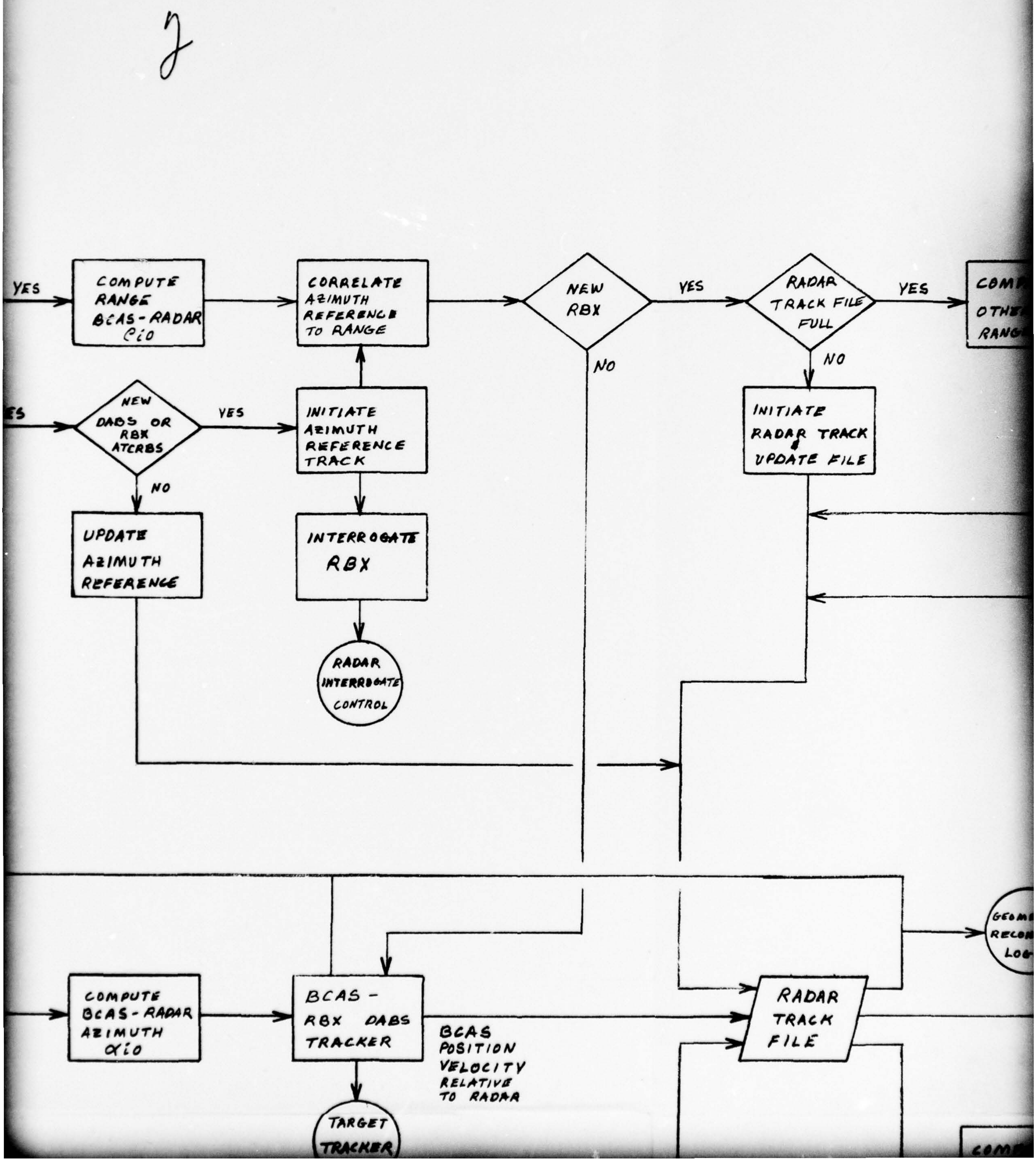
4.2.5 The Radar Selector and Tracker

The radar selector and tracker performs the functions of selecting the best ground sites to track and actually tracking the position of their main beams, together with other information such as distance to site when such information is available.

The radar selector and tracker receives information from the 1030 MHz signal processor and from message control in case RBX squitters are received.

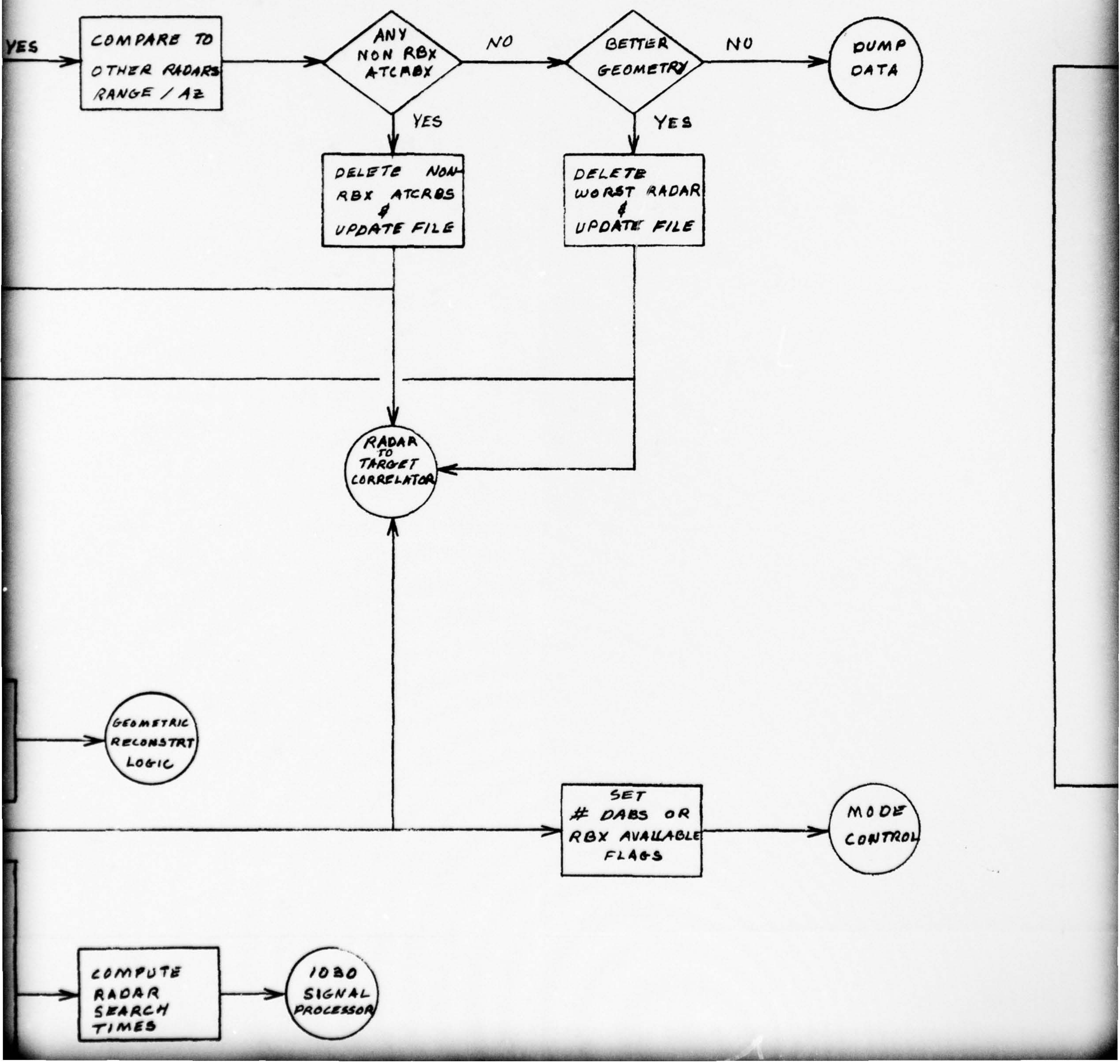
If no 1030 MHz interrogations are picked up, BCAS will go active. When BCAS picks up 1030 MHz interrogations, it either uses this information to extend existing radar track file data or if no correlation occurs, it uses this information to start a new track. Since the radar selector is dealing with several different types of ground interrogations, it must identify the types and start a hierarchy of sites it wants to track based upon site types and BCAS/ground site geometry. BCAS would rather track a DABS site than an RBX and would rather track an RBX than an ATCRBS site. Since BCAS will use, at most, only two sites in any target position solution, it will only need to track, at most, 4 ground sites. The radar selection and tracking logic is presented in Figure 4-13.

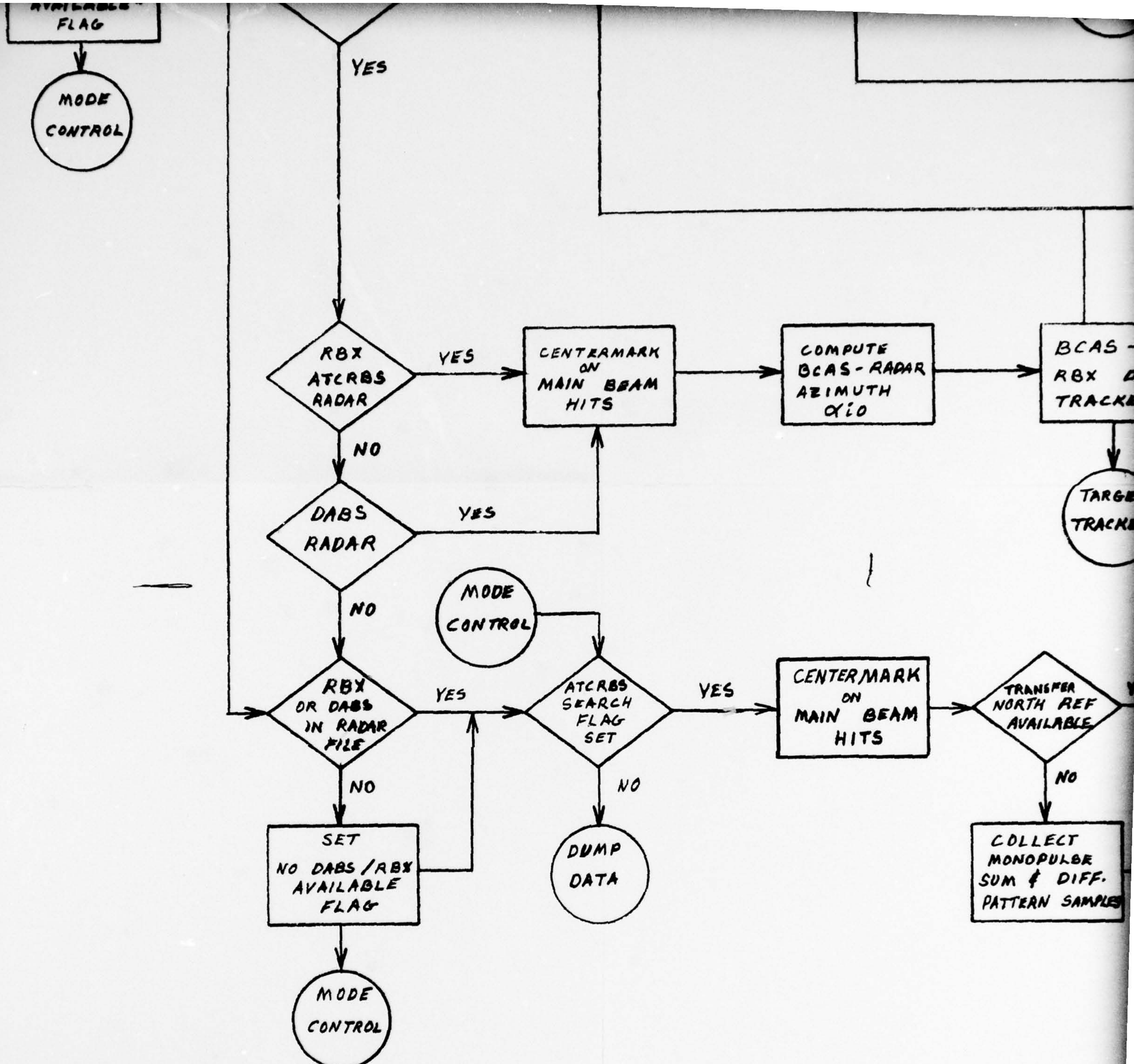

DUMP DATA
NO
THREAT DETECTION & RESOLUTION
YES
OTHER BCAS INTERROGATION OR MSG
NO
DABS OR ATCRBS RBX REPLY
YES
COMPUTE RANGE BCAS-RADA
NO
1030 SIGNAL PROCESSOR
ANY 1030 SIGNALS
YES
SIGNAL TYPE
SQUITTERS & REPLIES
DABS OR ATCRBS RBX SQUITTER
YES
NEW DABS OR RBX ATCRBS
NO
INTERROGATIONS
NO
TIME OUT COUNTER EXCEEDED
NO
RADAR-INTERROGATION CORRELATOR
UPDATE AZIMUTH REFERENCE
YES
SET "NO RADARS AVAILABLE" FLAG
NO
CORRELATION
YES
MODE CONTROL
RBX ATCRBS RADAR
YES
CENTERMARK ON MAIN BEAM HITS
COMPUTE BCAS-RADA AZIMUTH
NO
DABS RADAR
YES



7
YES
COMPUTE RANGE BCAS-RADAR
CORRELATE AZIMUTH REFERENCE TO RANGE
NEW RBX
YES
RADAR TRACK FILE FULL
YES
NO
NO
NEW DABS OR RBX ATCRBS
YES
INITIATE AZIMUTH REFERENCE TRACK
INITIATE RADAR TRACK & UPDATE FILE
NO
UPDATE AZIMUTH REFERENCE
INTERROGATE RBX
RADAR INTERROGATE CONTROL
COMPUTE BCAS-RADAR AZIMUTH
BCAS - RBX DABS TRACKER
BCAS POSITION VELOCITY RELATIVE TO RADAR
RADAR TRACK FILE
TARGET TRACKER

3


YES
COMPARE TO OTHER RADARS RANGE / AZ
ANY NON RBX ATCRBX
NO
YES
BETTER GEOMETRY
NO
YES
DUMP DATA
DELETE NON RBX ATCRBS & UPDATE FILE
DELETE WORST RADAR & UPDATE FILE
RADAR TO TARGET CORRELATOR
GEOMETRIC RECONSTRT LOGIC
SET # DABS OR RBX AVAILABLE FLAGS
MODE CONTROL
COMPUTE RADAR SEARCH TIMES
1030 SIGNAL PROCESSOR



FLAG
MODE CONTROL
YES
RBX ATCRBS RADAR
YES
CENTERMARK ON MAIN BEAM HITS
COMPUTE BCAS-RADAR AZIMUTH αio
BCAS - RBX
TRACK
NO
DABS RADAR
YES
TARGE TRACK
NO
MODE CONTROL
RBX OR DABS IN RADAR FILE
YES
ATCRBS SEARCH FLAG SET
YES
CENTERMARK ON MAIN BEAM HITS
TRANSFER NORTH REF AVAILABLE
NO
NO
NO
SET NO DABS / RBX AVAILABLE FLAG
DUMP DATA
COLLECT MONOPULSE SUM & DIFF. PATTERN SAMPLES
MODE CONTROL

4

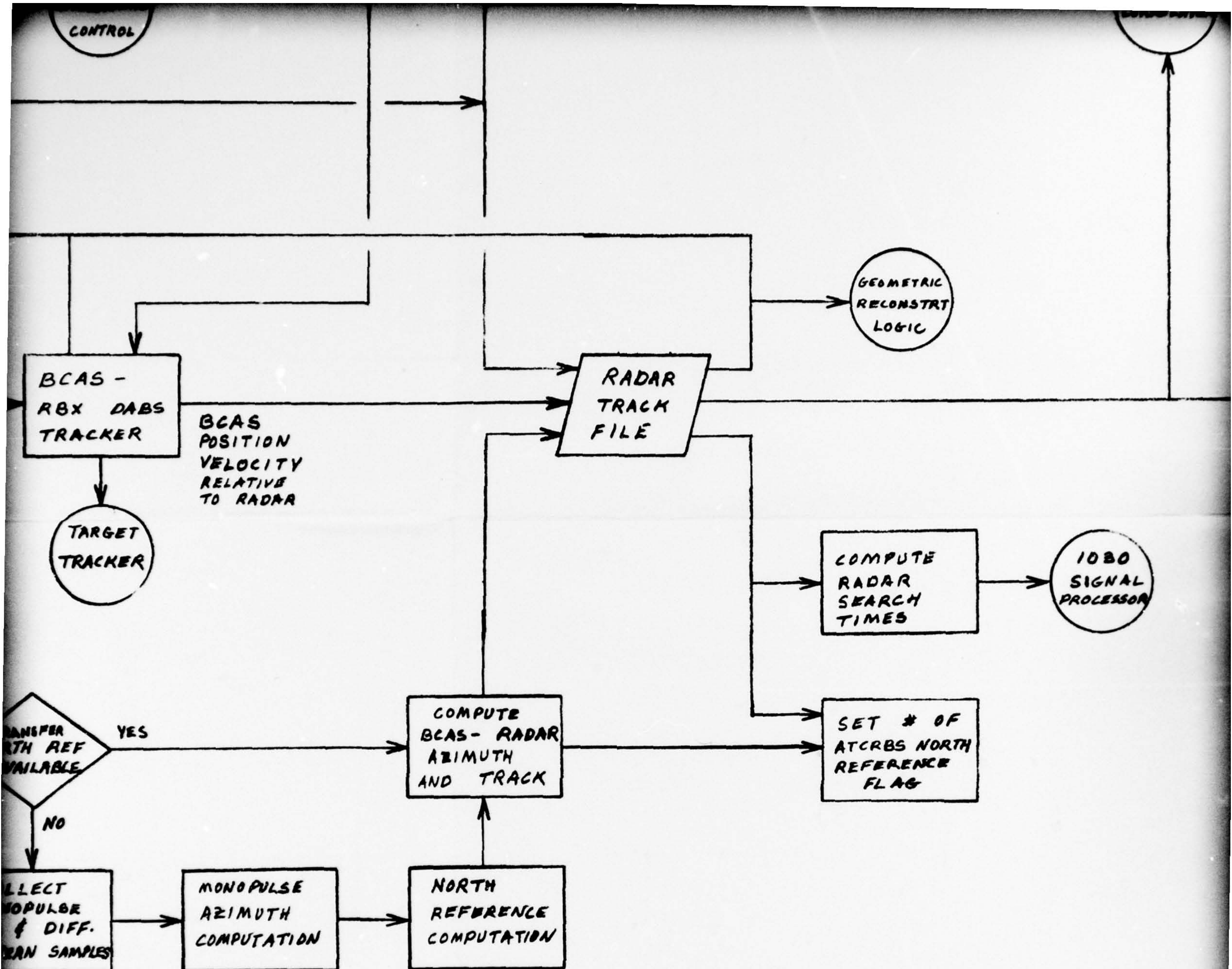

CONTROL
GEOMETRIC RECONSTRT LOGIC
BCAS - RBX DABS TRACKER
RADAR TRACK FILE
BCAS POSITION VELOCITY RELATIVE TO RADAR
TARGET TRACKER
COMPUTE RADAR SEARCH TIMES
1030 SIGNAL PROCESSOR
YES
COMPUTE BCAS- RADAR AZIMUTH AND TRACK
SET # OF ATCRBS NORTH REFERENCE FLAG
NO
MONOPULSE AZIMUTH COMPUTATION
NORTH REFERENCE COMPUTATION

FIGURE 4-13

TITLE: RADAR SELECTION AND TRACKING LOGIC

DATE: 20 MARCH, 1978

REV #	REVISION DESCRIPTION	DATE
1	NORTH REFERENCE TRANSFER & CENTERMARK DETAIL PVH	3-30-78
	DRAWN BY: PVH	

4.2.6 Message Controller

The message controller receives both 1030 MHz and 1090 MHz data and demodulates all messages. The 1090 MHz message list consists of target BCAS replies to BCAS interrogations, DABS squitter and DABS replies to BCAS interrogations and ATARS messages to BCAS.

The 1030 MHz message list includes ATARS message, ATC messages, target BCAS aircraft interrogations and RBX squitters.

The routing of messages is shown in Figure 4-14.

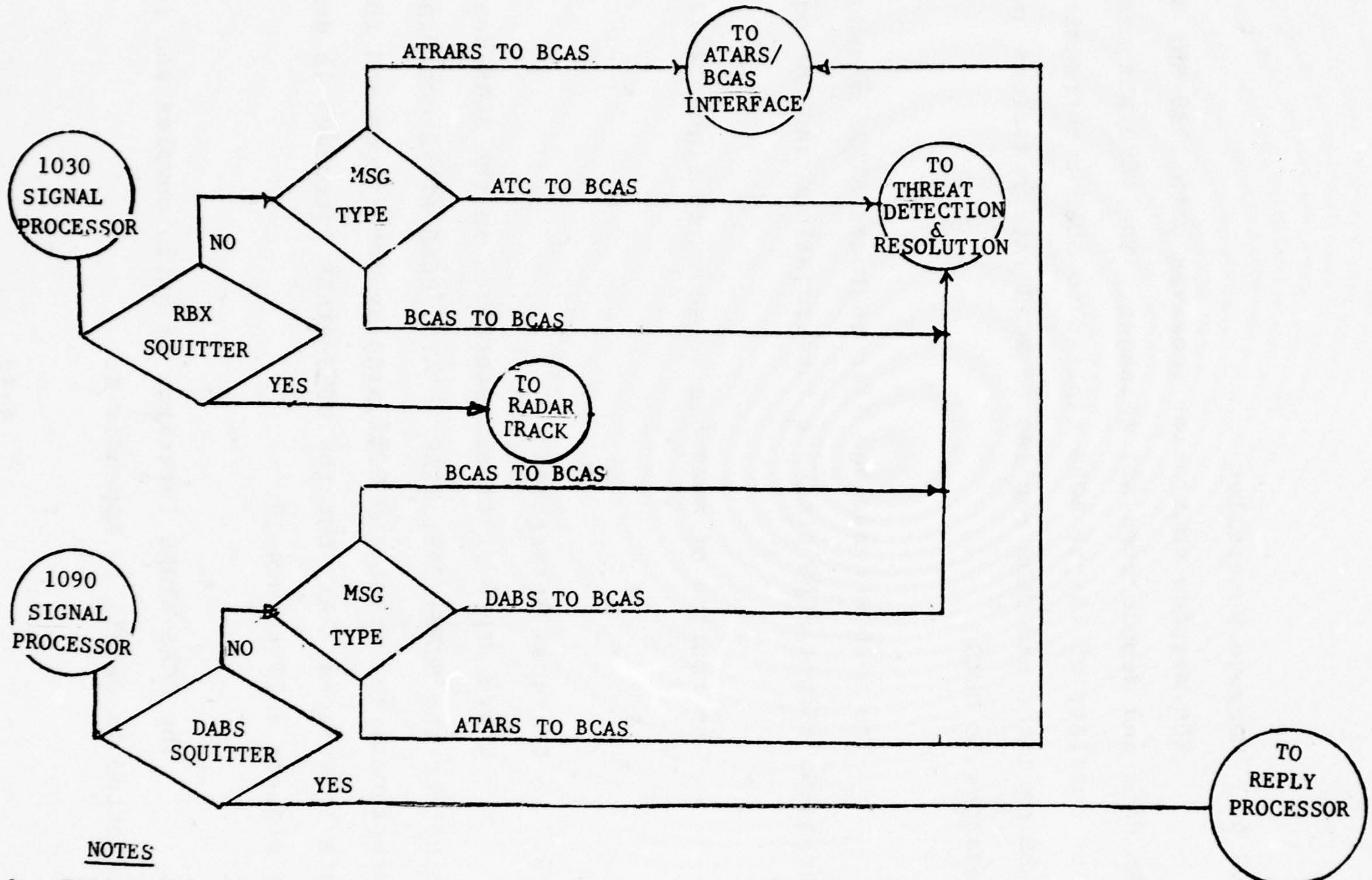
4.2.7 Critical Interfaces

There are 6 critical interfaces in the BCAS design which are the BCAS-BCAS, BCAS to ATC, BCAS-ATARS coordination interfaces, the pilot and CDTI display interfaces and the air data interfaces. All but the BCAS-ATARS interface is described in Figures 4-15 thru 4-19.

The BCAS-ATARS interface is quite complex and is presented in detail in Appendix K.

FIGURE 4-14

MESSAGE CONTROL



NOTES

1. ATARS TO BCAS CAN BE GROUND OR AIR DERIVED ON BOTH 1030 & 1090

FIGURE 4-15

BCAS-BCAS INTERFACE

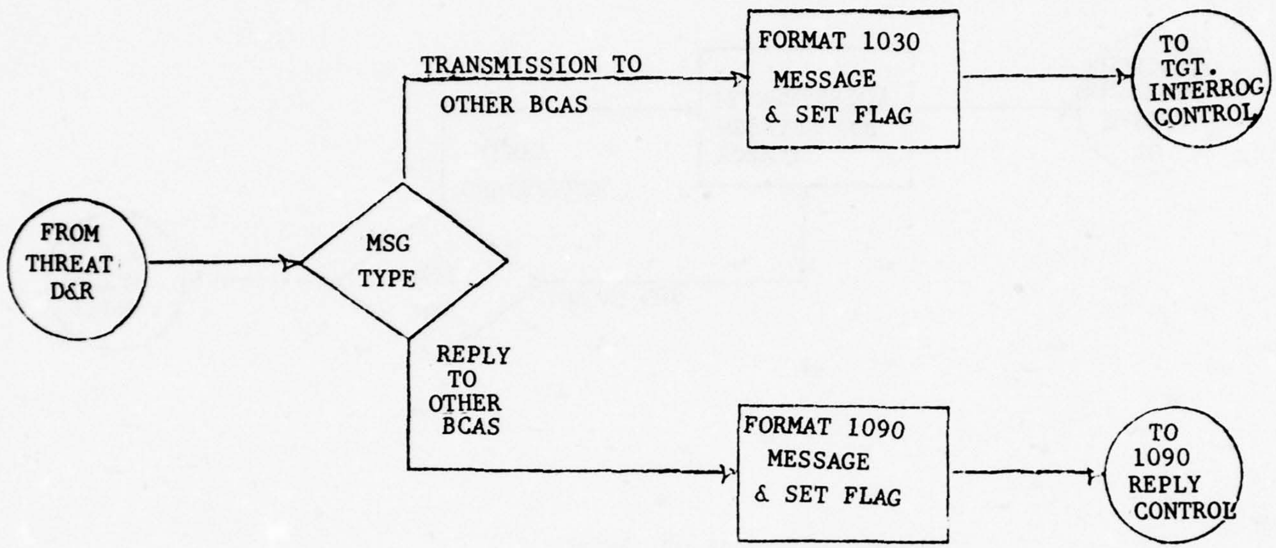
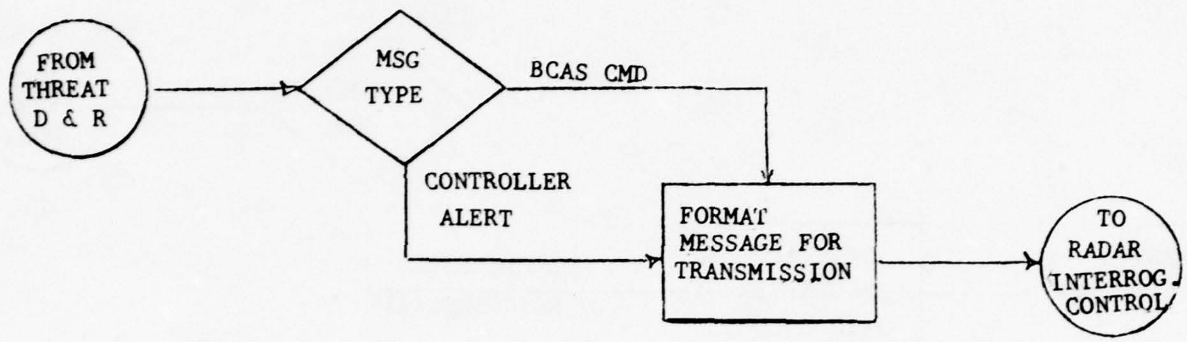


FIGURE 4-16

BCAS TO ATC INTERFACE



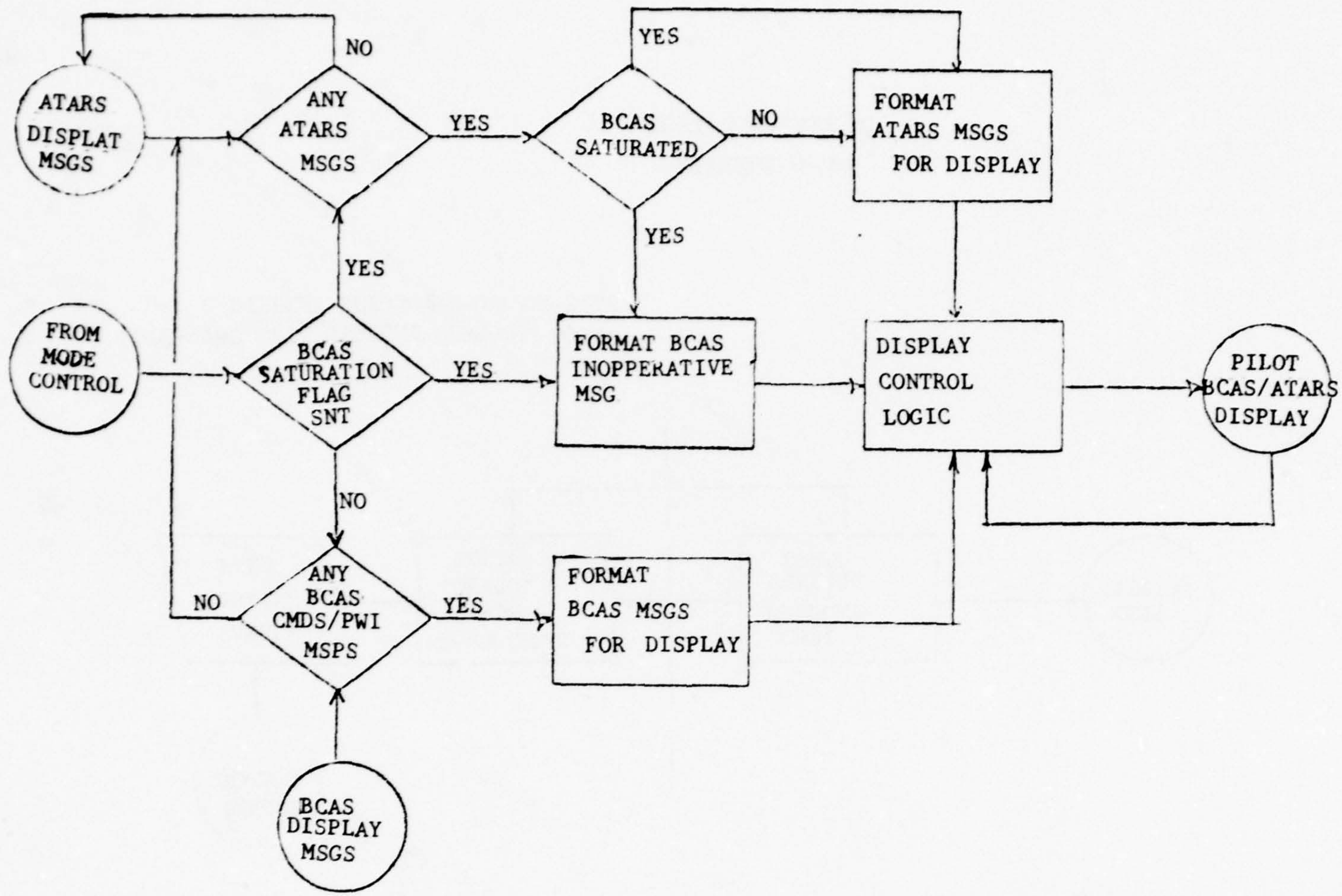
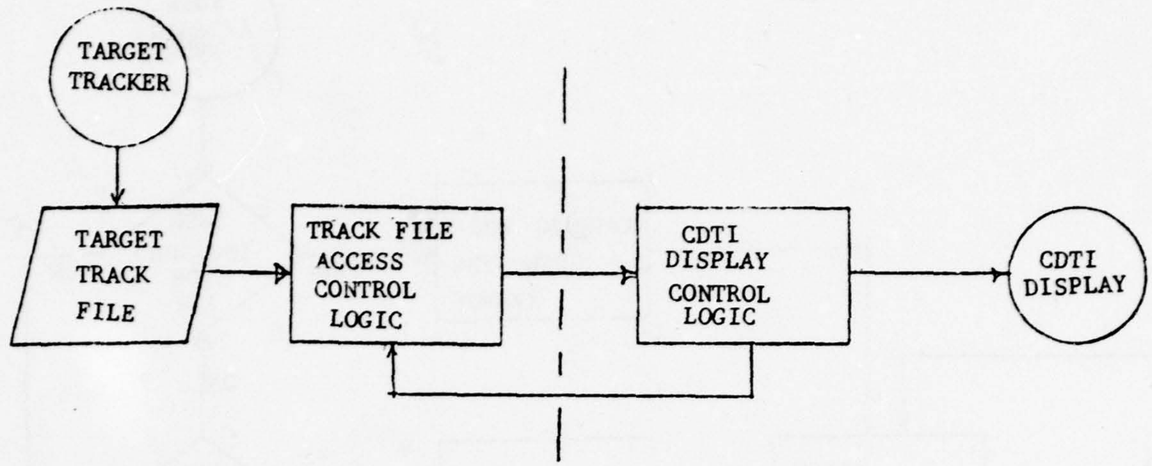


FIGURE 4-17

PILOT DISPLAY INTERFACE

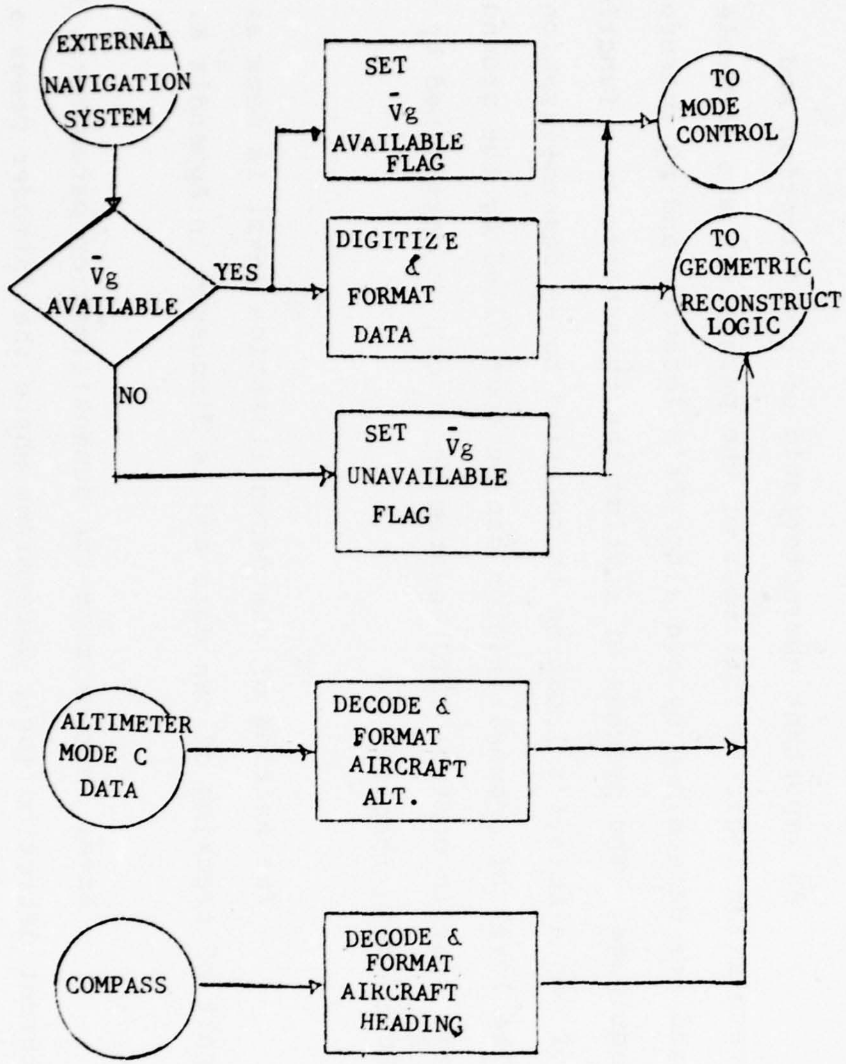


NOTE: THE CDTI DISPLAY CONTROL LOGIC & DISPLAY ARE NOT PART OF BCAS.

FIGURE 4-18
CDTI INTERFACE

FIGURE 4-19

AIR DATA INTERFACE



4.2.8 Conflict Detection and Resolution Algorithm

This section illustrates the threat detection and resolution logic by discussing the logic required to give positive and negative commands in the passive mode. The active mode logic is largely a subset of the passive mode logic. For this reason, the passive mode logic is presented and is described in some detail. Complete logic for all modes and all commands is given in Appendix K.

An important characteristic of the detection and resolution logic is that most of the parameters are variable and are determined by own aircraft's location and by intruder's equipage. The process of setting the thresholds as a function of own aircraft's location is referred to as desensitization. The level of desensitization can be controlled by the ground air traffic control (ATC) system or it can be determined by the BCAS logic itself.

The setting of the desensitization level is done as a part of tracking of own data and is discussed in Appendix K.

After initializing the desensitization parameters, the threat detection logic determines where the intruder poses a threat warrranting either a positive command request or a negative command request. If such a request is warranted, the logic also determines whether the maneuver should be vertical or horizontal.

Figures 4-20 and 4-21 show the protection afforded by the logic in the relative range--relative range rate plane and in the relative altitude--relative altitude rate plane, respectively.

A command is requested by the logic when the following three conditions are satisfied simultaneously:

1. the relative range and relative range rate are such that the point defined by the pair lies within the protected area in the R-RDOT plane,
2. the relative altitude and relative altitude rate are such that the point defined by the pair lies within the protected area in the A-ADOT plane, and
3. the projected horizontal miss distance is less than a certain threshold.

The first condition involves either a modified range-tau test or an immediate range test. The second condition involves either a vertical-tau test or an immediate altitude test. Finally, the third condition is tested by comparing the horizontal miss distance to a threshold.

If all three conditions are satisfied, the logic proceeds to determine the type of command to be requested. This

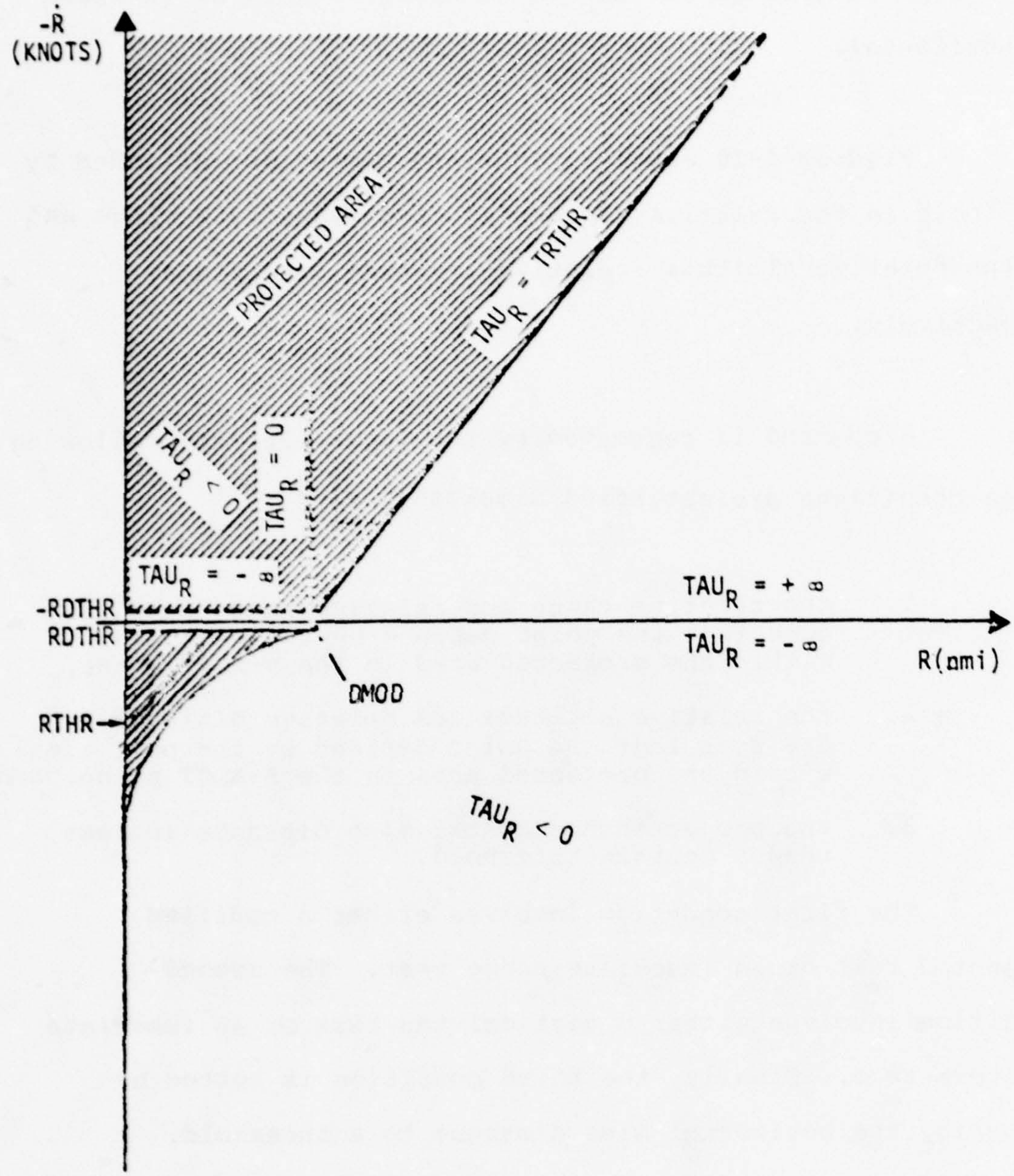


FIGURE 4-20

PROTECTION AFFORDED BY THE DETECTION LOGIC IN THE RELATIVE RANGE – RELATIVE RANGE RATE (R-$\dot{R}$) PLANE

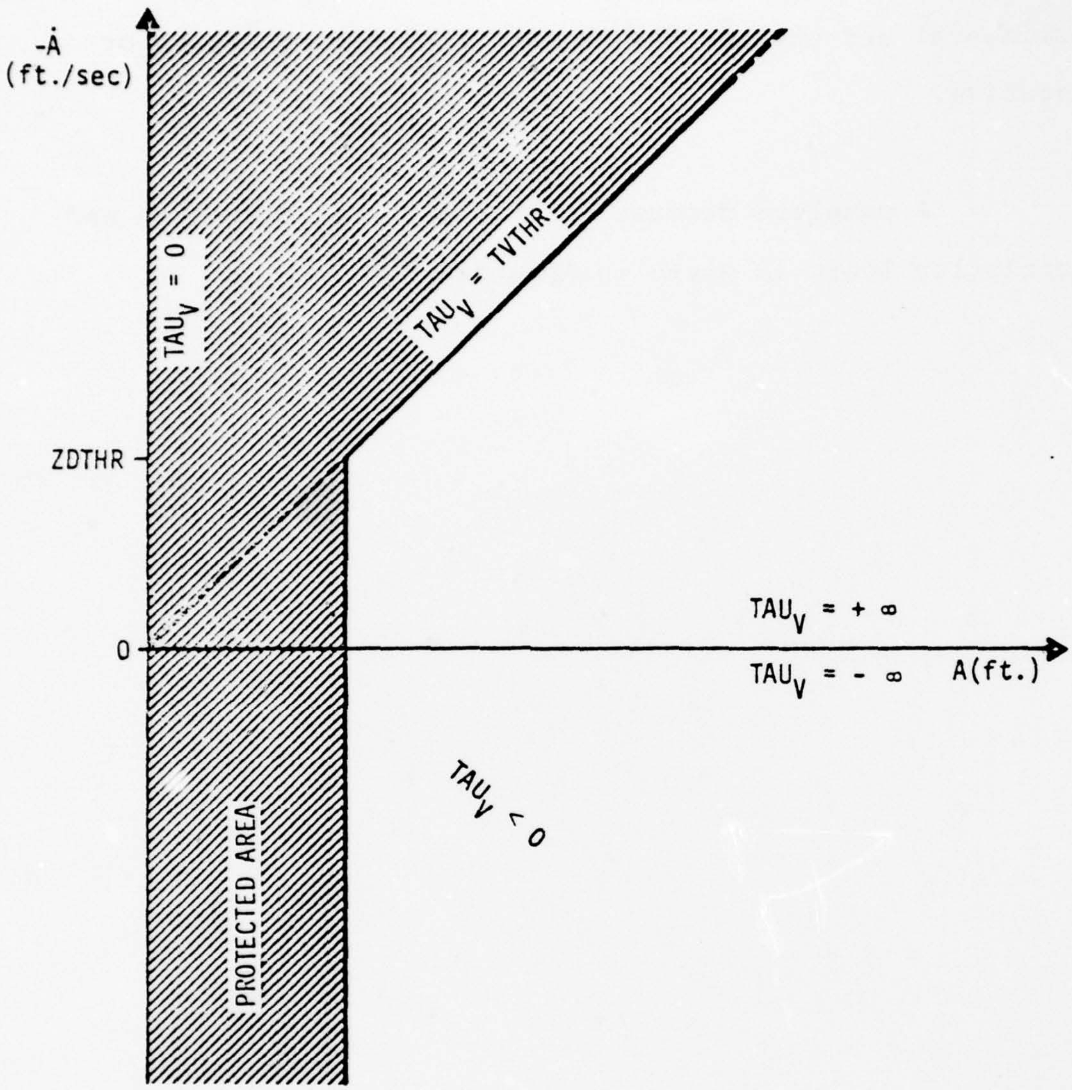


FIGURE 4-21

PROTECTION AFFORDED BY THE DETECTION LOGIC IN THE RELATIVE ALTITUDE – RELATIVE ALTITUDE RATE (A-Ȧ) PLANE involves deciding whether the maneuver should be vertical or horizontal and whether the command should be positive or negative.

A complete discussion of the threat detection and resolution logic is given in Appendix K.

5. BCAS/RBX Data Link

The radar beacon transponder (RBX) will squitter information and reply to range measurement interrogations and air/ground data link messages made by the BCAS aircraft. This section is concerned with the design of the RBX-BCAS aircraft data link.

All transmissions between RBX and BCAS will occur on the 1030 MHz frequency. This allows transmissions to take advantage of the 6 dB DPSK modulation gain and avoids saturation problems associated with 1090 MHz RBX transmissions feeding back into the colocated 1090 MHz ATCRBS ground receiver. More importantly, and as will be shown, the BCAS receiver sensitivity will have to be increased substantially. If this were done at 1090 MHz, fruit would trigger the receiver at an unacceptably high rate. The 1030 MHz frequency channel is "cleaner" (has a lower signal load) so that the effect of increasing the sensitivity of the receiver at this frequency is less detrimental to performance.

We will first describe the RBX squitter and then the BCAS-RBX interrogation and reply signalling sequence.

All RBX squitters will be transmitted via the RBX antenna and will be received on the BCAS omni antenna. However, as will be shown, the link is sufficiently strong that the RBX squitter can be transmitted in a normal DABS format. Table 5-1 describes the RBX squitter characteristics.

The RBX antenna is assumed to provide upper hemispherical coverage and is thus assumed to have 3 dB of gain. Between the transceiver and the antenna there is a 2 dB cable loss and there is a propagation loss of 138 dB at 1030 MHz for a 100 mile range. The BCAS antenna gain is taken to be 0 dB and with a 3 dB cable loss the received power is -109 dBW. Since a 7 dB noise figure front end is relatively inexpensive today at 1030 MHz we have assumed a receiver noise power density of -197 dBJ. The resultant post processing signal to noise (E/N_o) ratio is a healthy 25 dB. One final comment pertains to the receiver sensitivity. A DABS receiver is specified to have a 77 dBm receiver sensitivity, ± 3 dB. Thus, the BCAS-DABS receiver is at least 5 to 8 dB more sensitive than a normal DABS receiver. A -88 dBm sensitivity is suggested for enroute flights to enable BCAS to operate semi-actively 200 miles from an ATCRBS interrogator.

The RBX squitters will use the DABS Broadcast format (DABS/COM-A) for its transmissions. As shown in Table 5-2, RBX squitters once per second, with a complete data cycle once every two seconds. The COM-A format can only accommodate 56

Table 5-1

RBX Data Link Characteristics

	1030 MHz squitter	1030 MHz All other transmissions
Transmitter Power	31 dBW	31 dBW
Antenna Gain RBX	+3 dB	+3 dB
RBX cable loss	-2 dB	-2 dB
Path loss (100 miles)	-138 dB	-138 dB
Antenna Gain	0 dB	+8 dB
Cable loss aircraft	-3 dB	-3 dB
Received Power	-109 dBW	-101 dBW
Received Energy ($\frac{1}{2}\mu s$ bits)	-172 dBJ	-164 dBJ
Receiver Noise Power Density	-197 dBJ (7 dB NF)	-197 DBJ (7 dB NF)
Signal Energy to Noise Spectral Density E/N_o	25 dB	33 dB
E/N_o required for a 10^{-6} error rate (DPSK)	11 dB	11 dB
Margin	14 dB	22 dB
Receiver threshold setting	-85 to -88 dBM	

Table 5-2

Squitter Characteristics

Squitter rate: once per second

Squitter cycle rate: once every 2 seconds

Message format DABS COM-A - (2 successive squitters)

Message content

Squitter 1

	bits	
RBX address	10	
ACP count	12	
PRF	9	
Altitude	12	
Squitter type	2	(DABS Aircraft, RBX squitter 1, RBX Squitter 2)
Total bits	45	

Squitter 2

RBX address	10
Squitter type	2
Latitude	17
Longitude	17
WR	6
Total bits	52

bits in its field and with a 97 bit requirement, two successive COM-A transmissions are sent at a rate of one per second.

The BCAS-RBX interrogation/reply sequences are both sent at 1030 MHz. The BCAS interrogation is normally once every 4 seconds and contains RBX and BCAS discrete addresses as shown in Figure 5-1. This link is "healthier" than that of the squitter since the interrogator's directive antenna can be utilized (see Table 5-1). Twenty four bits are available in the interrogation/reply format and can be used for transmitting information of BCAS intent to ground control.

Finally, we note that the ground omni will experience multipath problems and RBX transmissions will have to be time sequenced with normal ATCRBS/DABS interrogations. The timing interface and the multipath problems are now under investigation.

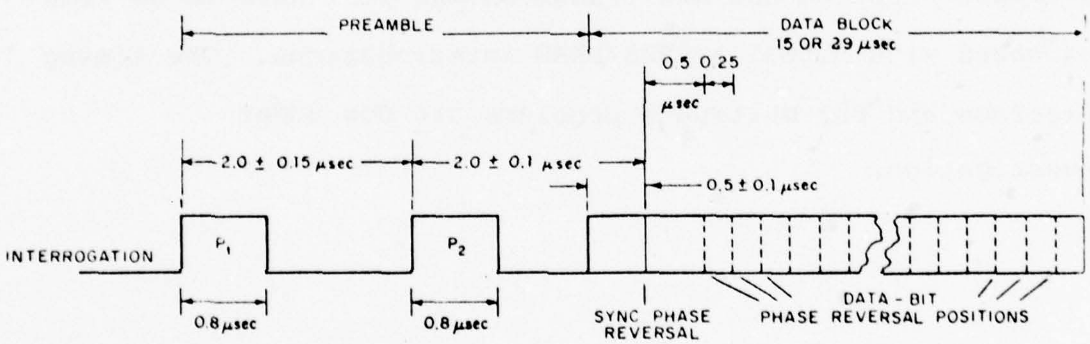
Figure 5-1: BCAS-RBX

BCAS-RBX Interrogation

RBX ID	10
BCAS ID	24
Message (option)	22

RBX-BCAS Reply

RBX ID	10
BCAS ID	24
Message (option)	22



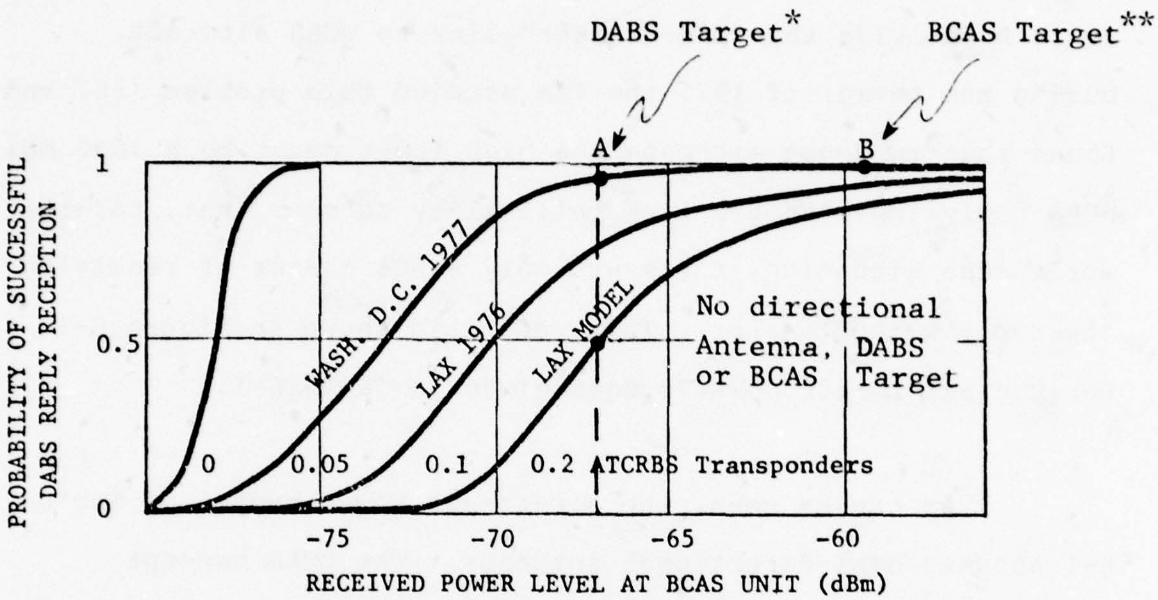
16 Bits	16 Bits	56 Bits	24 Bits
Link Control Field	Surveillance Data Field	Standard Message Field (Optional)	Address/Parity Field

Section 6

AIR-TO-AIR DATA LINK

The air-to-air data link must be extremely reliable if it is to provide the "tie-breaker" link to BCAS aircraft. During the summer of 1977 the FAA studied this problem (16) and found that in dense airspace the high fruit count on a 1090 MHz BCAS reply impacted the link reliability so much that, for the worst case situation, there was only a 50% chance of receiving the reply without error. This result is shown in Figure 6-1 for the air-to-air power budget given in Table 6-1.

As can be seen, the air-to-air power budget of Table 6-1 assumes omni-directional antennas. The BCAS concept utilizes directionality in both its transmit and receive modes for BCAS aircraft. Thus, the effect of receiver directionality is to reduce the fruit density. Assuming a fruit reduction of 4 for a 40^{o} directive beam, we will then be performing at point A in Figure 6-1. This is equivalent to operating in Washington, D. C. environment with an omni antenna. As can be seen, the link reliability is better than 90%. This link could represent the data link between a BCAS aircraft and a DABS aircraft. The 1030 MHz interrogation is essentially free from fruit so that the directional antenna capability reduces fruit only on reception of the 1090 MHz DABS target reply.



(b) DABS

Figure 6-1: DABS REPLY PROCESSOR PERFORMANCE IN A FRUIT ENVIRONMENT (OMNI-ANTENNA)

Taken from Reference [16]

* Assumes directional antenna receive

** Assumes directional antenna transmit and receive

TABLE 6-1: AIR-TO-AIR POWER BUDGET
(1090 MHz, 5 nmi, Nominal Conditions)

1.	Transmitter Power	dBm	57	Nominal
2.	Transmitter Cabling Loss	dB	3	Nominal
3.	Transmitter Antenna Gain	dB	0	Nominal
4.	Free Space Path Loss (5 nmi)	dB	112	
5.	Receiving Antenna Gain	dB	0	Nominal
6.	Receiving Cabling Loss	dB	3	Nominal
7.	Received Power	dBm	-61	Nominal
8.	Power Deviation Allowance	dB	6	
9.	Worst Case Received Power	dBm	-67	

Taken from Reference [16]

If a BCAS aircraft was communicating with a BCAS target aircraft, then in addition to the reduced fruit due to the directivity of the antenna's signal reception, an 8 dB further improvement is possible because of the antenna's transmission gain. This combined effect provides the link reliability equivalent to point B in Figure 6-1. This BCAS-to-BCAS link is thus seen to be extremely reliable. Therefore, the addition of the directive antennas has a significant impact on the reliability of the air-to-air data link.

Section 7

ENVIRONMENTAL AND PERFORMANCE SUMMARY

7.1 ENVIRONMENTAL SUMMARY

The BCAS environment of interest is characterized by the number of aircraft that need to be tracked and the signal environment from which BCAS must extract reliable track information. In this section the BCAS aircraft environment and the active and passive signal environments will be summarized.

Normally, BCAS is required to acquire targets at a 10 to 20 nm radial distance. It takes about 30 seconds for the system to establish a confident track so that when targets are 5 nm and/or within a 60 second tau region, BCAS has a reliable target track.

Table 7-1 describes the number of aircraft that BCAS sees within a 10 nm radius in the L.A. Basin. The tabulated results are based on a 1982-85 traffic simulation of the L.A. Basin. It can be seen that BCAS sees 116 targets on the average with a maximum of 140 targets. Assuming that half the targets are flying away from the BCAS aircraft, BCAS will have to track between 58 and 70 targets in the L.A. Basin, the airspace of greatest density in the world.

Model Density (Relative to LA 82/85)	BASIN	BCAS	ABS. MAX
FULL	743	116	140
HALF	382	66	80
QUARTER	177	29	35

Table 7-1: NUMBER OF AIRCRAFT WITHIN 10 nm RADIUS OF BCAS

Based on the work presented in Appendix C, Tables 7-2 and 7-3 compare the L.A. Basin environment (0.095 aircraft density per square nautical mile in 1985 from Table 7-2) with 59 other high and medium density hub areas. As can be seen, the projected densities will increase significantly so that by 1995 over 8 hub areas will have aircraft densities greater than that found in L.A. in 1985 and over 19 hub areas will have aircraft densities greater than that which is found in the L.A. Basin today.

As described in Section 3, garbled interrogation replies cause BCAS to generate many more tracks than actually exist in order to insure that no information is lost. With time, false tracks will have an associated low confidence factor and will be eliminated from the track file. The number of tracks so formed and the reliability of the track will be a function of the garble environment.

The active mode garble environment for the 1982 L.A. Basin is described by Table 7-4. It can be seen that the average number of garbles received by an omni-BCAS on a given reply is 77. This assumes the BCAS aircraft to be in the most dense region of the L.A. Basin (see Appendix A for details). If aircraft can be interrogated in an effective beam width of $22\text{-}1/2^{o}$, then the maximum number of targets that is received

HUB	1975	1980	1985	1990	1995	
OKC	0.029	0.041	0.057	0.081	0.113	SYNCHRO-DABS
SAN	0.027	0.039	0.054	0.076	0.107	REQUIRED
TUL	0.026	0.036	0.051	0.071	0.100	
RIV	0.025	0.035	0.050	0.071	0.099	
SJC	0.025	0.035	0.049	0.069	0.096	
PDX	0.024	0.034	0.047	0.067	0.093	
IND	0.024	0.033	0.046	0.065	0.091	
TPA	0.023	0.032	0.045	0.063	0.088	
MKE	0.022	0.031	0.043	0.060	0.084	
PHX	0.021	0.029	0.041	0.057	0.080	
SAC	0.018	0.028	0.036	0.051	0.072	
CMH	0.018	0.026	0.036	0.050	0.070	
LOU	0.018	0.025	0.035	0.049	0.068	
MEM	0.016	0.022	0.031	0.044	0.061	
BDL	0.015	0.020	0.029	0.040	0.056	
BUF	0.014	0.020	0.028	0.040	0.056	
OMA	0.014	0.019	0.027	0.038	0.053	DIRECTIONAL ANTENNA
ABQ	0.013	0.018	0.025	0.036	0.050	REQUIRED
CIN	0.012	0.017	0.024	0.034	0.047	
JAX	0.012	0.017	0.024	0.034	0.047	
ORL	0.011	0.015	0.021	0.030	0.042	
TUS	0.010	0.014	0.020	0.028	0.040	
SAT	0.010	0.014	0.020	0.028	0.039	
GSO	0.010	0.014	0.019	0.027	0.038	
DAY	0.009	0.013	0.018	0.026	0.036	
PBI	0.009	0.013	0.018	0.025	0.036	
GEG	0.008	0.012	0.017	0.023	0.033	
SLC	0.008	0.011	0.015	0.021	0.030	
ORF	0.008	0.011	0.015	0.021	0.030	
ROC	0.007	0.009	0.013	0.018	0.026	
ELP	0.006	0.008	0.012	0.016	0.023	
RIC	0.006	0.008	0.012	0.016	0.023	
RNO	0.005	0.008	0.011	0.015	0.021	
BNA	0.005	0.007	0.010	0.014	0.020	
SYR	0.005	0.007	0.010	0.014	0.020	
CLT	0.005	0.007	0.010	0.013	0.019	OMNI *
RDU	0.004	0.006	0.009	0.012	0.017	

Table 7-1:

BCAS COMPLEXITY vs. DENSITY AT THE
37 MEDIUM DENSITY HUBS (30 nm radius)

* Does not provide all capabilities desired of BCAS
(i.e., no protection against Mode A equipped targets)

HUB	1975	1980	1985	1990	1995	
LAX	0.048	0.068	0.095	0.133	0.128	SYNCHRO-DABS
CHI	0.028	0.040	0.056	0.079	0.110	REQUIRED
MIA	0.025	0.038	0.050	0.070	0.098	
SFO	0.022	0.031	0.043	0.061	0.085	
NYC	0.020	0.029	0.040	0.057	0.079	
DFW	0.020	0.028	0.039	0.055	0.078	
WAS	0.017	0.023	0.033	0.046	0.064	
DET	0.018	0.023	0.032	0.046	0.064	
MSP	0.016	0.022	0.031	0.044	0.061	
EWR	0.014	0.019	0.027	0.038	0.053	DIRECTIONAL ANTENNA
IAH	0.013	0.019	0.026	0.037	0.051	REQUIRED
SEA	0.013	0.018	0.025	0.036	0.049	
ATL	0.012	0.017	0.024	0.034	0.048	
BOS	0.011	0.016	0.022	0.031	0.044	
MKC	0.009	0.013	0.018	0.026	0.036	
PHL	0.009	0.013	0.018	0.025	0.035	
DEN	0.009	0.013	0.018	0.025	0.035	
CLE	0.009	0.012	0.017	0.024	0.034	
PIT	0.009	0.012	0.017	0.024	0.034	
STL	0.007	0.010	0.014	0.020	0.028	
MSY	0.006	0.008	0.011	0.016	0.022	
LAS	0.004	0.006	0.008	0.011	0.016	OMNI *
BAL	0.003	0.004	0.005	0.009	0.012	

Table 7-2:

BCAS COMPLEXITY vs. DENSITY AT THE
23 HIGH DENSITY HUBS (50 nm radius)

* Does not provide all capabilities desired of BCAS (i.e., no protection against Mode A equipped targets)

ABQ	Albuquerque	MSP	Minneapolis-St. Paul
ATL	Atlanta	MSY	New Orleans
BAL	Baltimore	OKC	Oklahoma City
BDL	Hartford	OMA	Omaha
BNA	Nashville	ORD	Chicago
BOS	Boston	ORF	Norfolk
BUF	Buffalo	ORL	Orlando
CIN	Cincinnati	PBI	West Palm Beach
CLE	Cleveland	PDX	Portland
CLT	Charlotte	PHL	Philadelphia
CMH	Columbus	PHX	Phoenix
DAY	Dayton	PIT	Pittsburgh
DCA	(WAS) National	RDU	Raleigh-Durham
DEN	Denver	RIC	Richmond
DFW	Dallas-Ft. Worth	RIV	Riverside
DTW	Detroit	RNO	Reno
ELP	El Paso	ROC	Rochester
EWR	Newark	SAC	Sacramento
GEG	Spokane	SAN	San Diego
GSO	Greensboro	SAT	San Antonio
IAH	Houston	SDF	Louisville
IND	Indianapolis	SEA	Seattle
JAX	Jacksonville	SFO	San Francisco
JFK	New York	SJC	San Jose
LAS	Las Vegas	SLC	Salt Lake City
LAX	Los Angeles	STL	St. Louis
MEM	Memphis	SYR	Syracuse
MIA	Miami	TPA	Tampa
MKC	Kansas City	TUL	Tulsa
MKE	Milwaukee	TUS	Tucson

	MEAN	1 SIGMA	MAX	MIN	
OMNI ANTENNA	77	—	77	—	100%
	38	—	38	—	50% OF 82 MODEL
	16		16	—	25%
15° WEDGE 1 24:1	3.22	2.49	13	0	100% 4:1 peak
	1.58	1.61	9	0	50%
	.67	.77	3	0	
22½° WEDGER 16:1	4.83	3.31	16	0	100 3:1 peak
	2.40	2.07	10	0	50%
	1.03	0.95	3	0	25%
30° WEDGE 12:1	6.43	4.01	18	1	100% 3:1 peak
	3.18	2.48	11	0	50%
	1.33	1.10	4	0	25%

Table 7-4: ACTIVE GARBLE (DIRECTIONAL ANTENNA)

on a given reply is 16. If we then add 6 to 8 levels of whisper/shout we can expect to get the peak garble on any one reply down to less than 7, a number which can be handled by the BCAS reply processor.

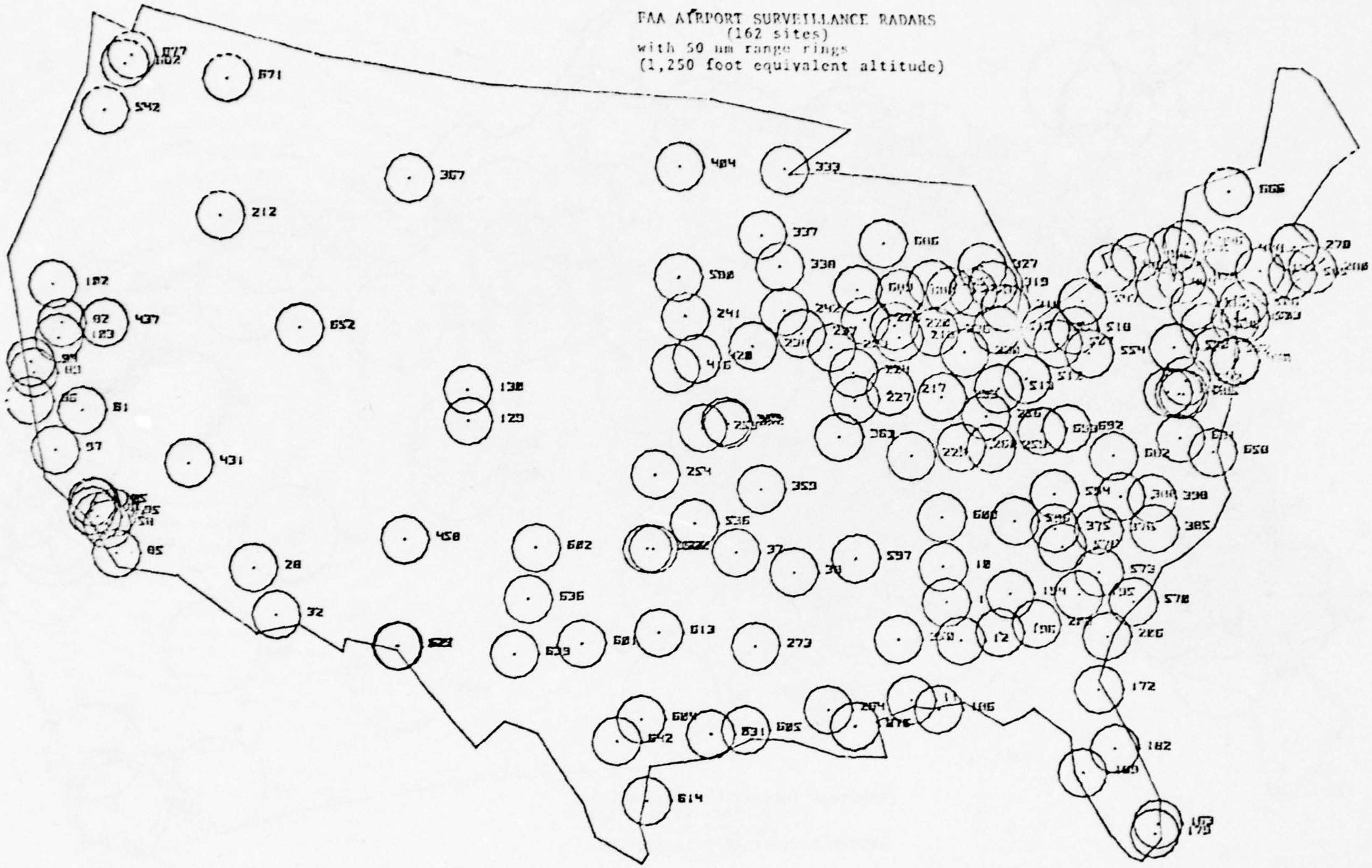
There are two major characteristics of the passive environment which impact the design and performance of BCAS. The first defines the ATCRBS coverage regions while the second describes the passive BCAS garble environment.

The ATCRBS coverage regions are described by Figures 7-1 through 7-4. Several interesting facts can be stated based on a study of these figures which are:

- Above 5,000 ft, FAA airport and enroute radars provide coverage nearly everywhere in CONUS.
- The FAA airport surveillance radars (four second scan rates) are located where nearly all of the aircraft are.
- The enroute radars (ten second scan rates) fill in areas not covered by airport radars and, therefore, provide coverage in less dense airspace.*
- For low-flying BCAS aircraft (1200 ft), there are many "holes" in passive coverage. Coverage is better than described by Figures 7-1 through 7-4 if one includes coverage from non-FAA interrogators.

*/Enroute radars are less desireable than airport radars for BCAS performance because of their low scan rate. However, enroute radars can be used as part of a semi-active mode when garble is not significant. (7)

Figure 7-1



FAA AIRPORT SURVEILLANCE RADARS
(162 sites)
with 50 nm range rings
(1,250 foot equivalent altitude)

Figure 7-2

FAA AIRPORT SURVEILLANCE RADARS
(162 sites)
with 100 nm range rings
(5,000 foot equivalent altitude)

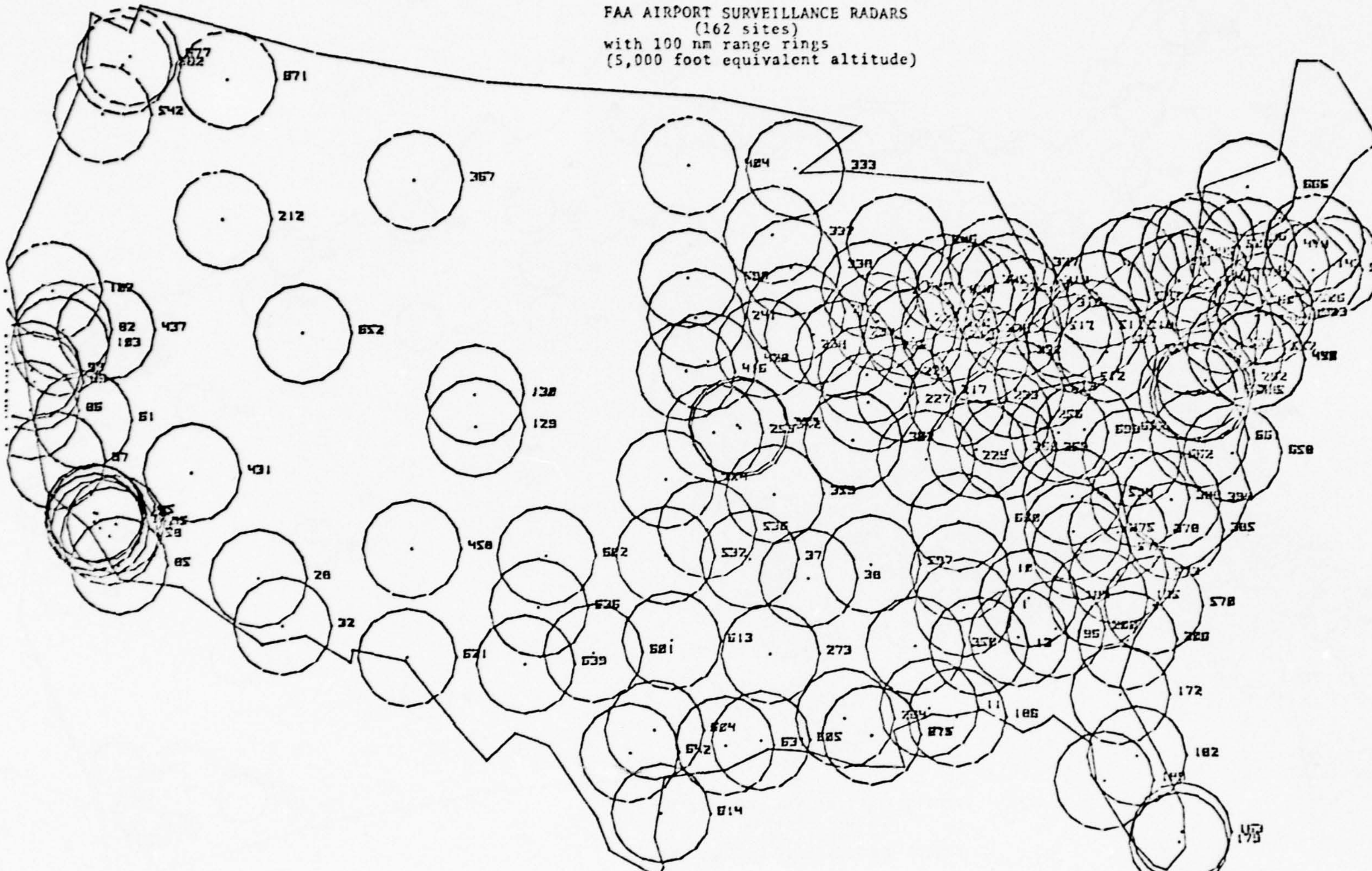


Figure 7-3

FAA ENROUTE RADARS (88 sites)
with 100 nm range rings
(5,000 foot equivalent altitude)

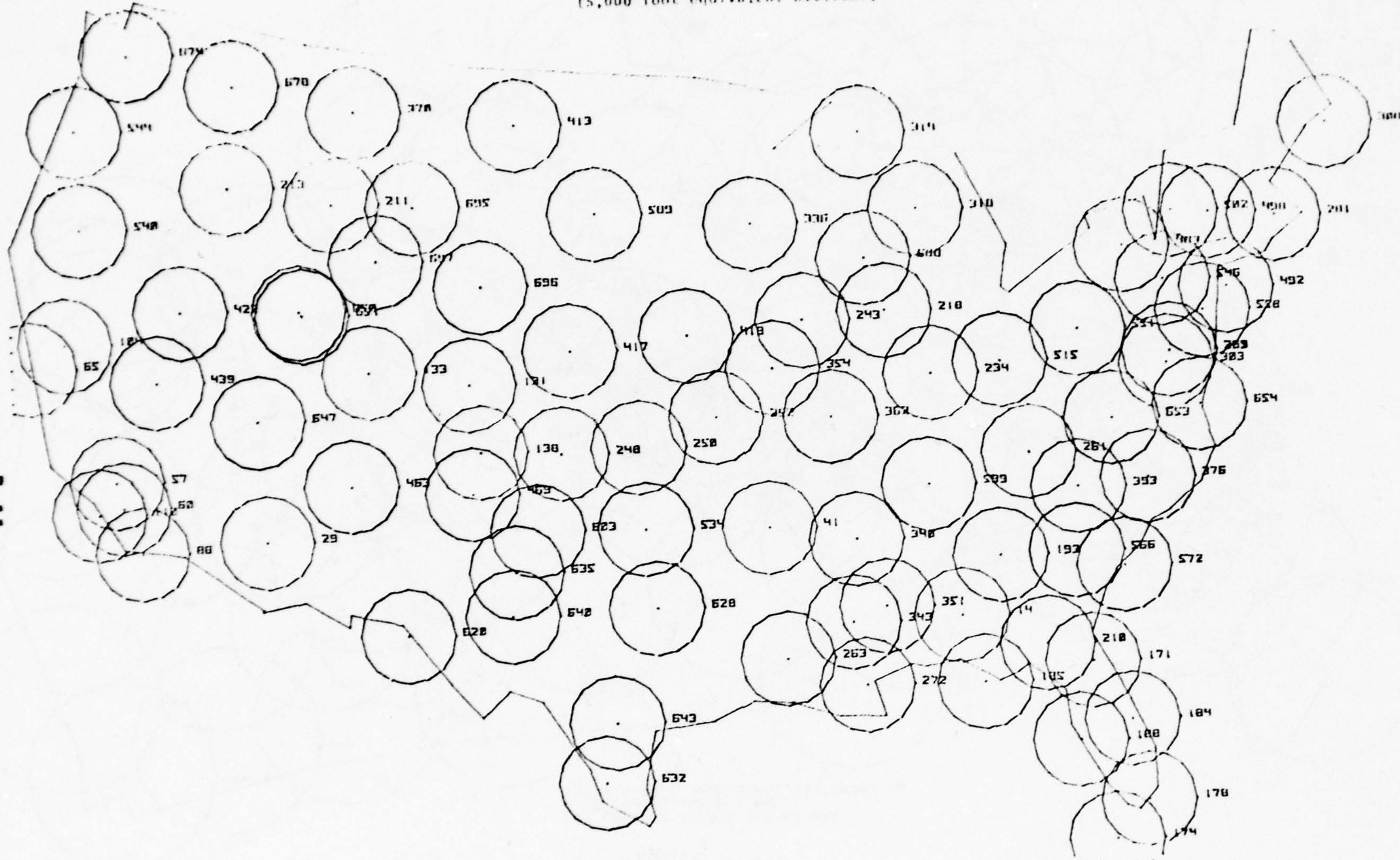
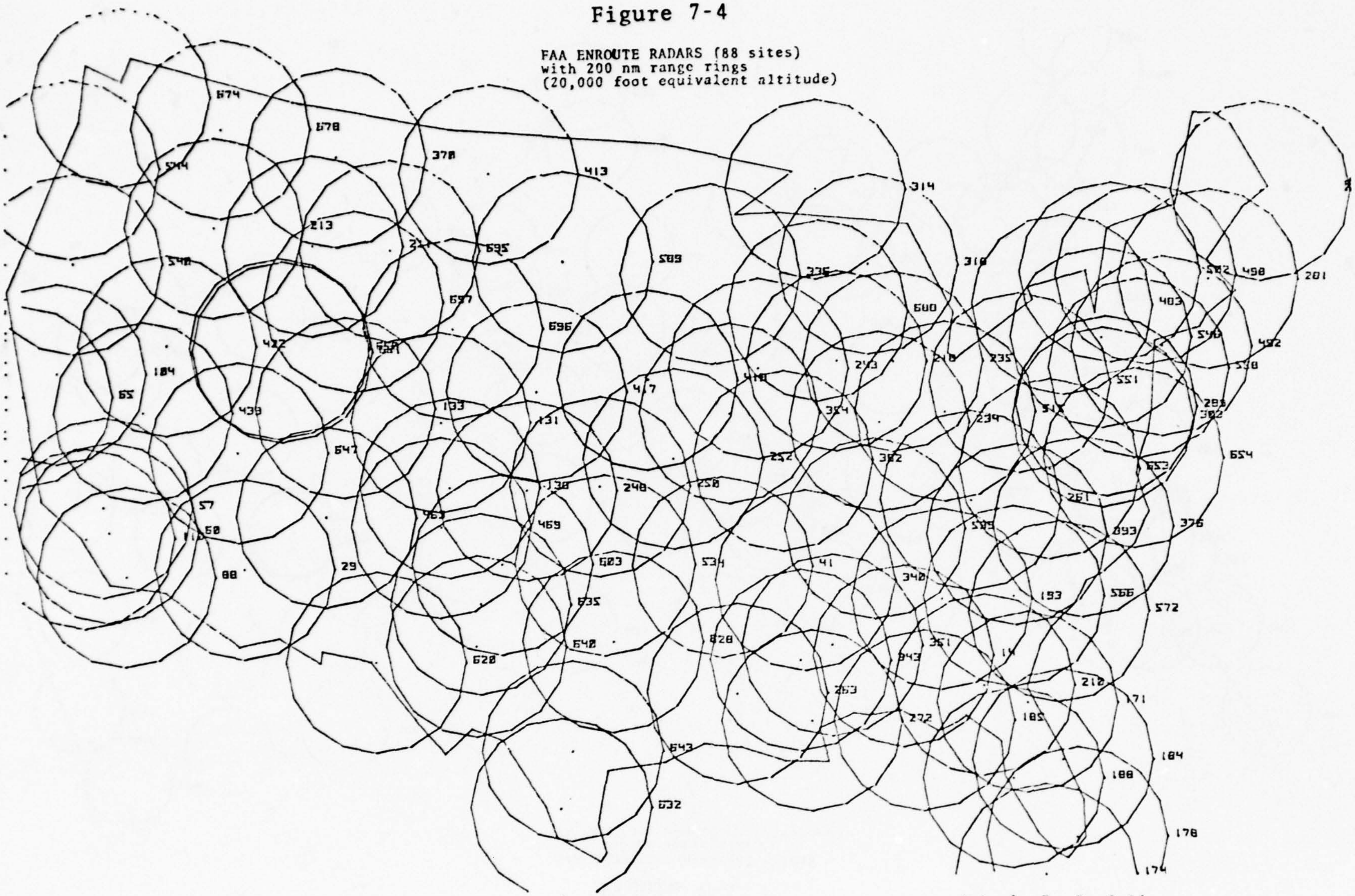


Figure 7-4

FAA ENROUTE RADARS (88 sites)
with 200 nm range rings
(20,000 foot equivalent altitude)



Worst case passive garble as found in the L.A. Basin of 1982 is described by Table 7-5. It can be seen that garble rates are excessive except for the garble associated with interrogations closest to the BCAS aircraft (less than 20 nm away). These findings have led to the conclusion that a multi-mode passive solution will not work in dense airspace and that a single site RBX passive/semi-active solution would be best.

7.2 PERFORMANCE SUMMARY

The parameter used in this report to measure performance is the rms position error σ_ρ . The threshold value for σ_ρ is 825 ft. Initially the multi-modal analysis, given in Appendix E, is summarized to show when and where each of the modes of BCAS satisfy the threshold value. In the latter part of this section the reasons for selecting the threshold value at 825 ft to indirectly measure BCAS performance will be provided quantitatively.

The multi-modal performance of BCAS is summarized in Figures 7-5 and 7-6. For the single radar BCAS modes, it can be seen that as the range increases, σ_ρ increases for all modes. However, these single site radars corresponding to the ATCRBS, RBX and DABS environments, each have acceptable

	LAX	MAR	BUR	LGB*	OUT	ELT	NOR	SP	SA
Full L.A. Density	20	34	36	6	22	21	45	13	13
Half the L.A. Density	13	17	20	3	11	8	27	8	8
A Quarter of the L.S. Density	7	6	11	1	5	5	11	5	4

* Site closest to BCAS aircraft

Table 7-5: GARBLE ANALYSIS SUMMARY

Figure 7-5: **SINGLE RADAR BCAS MODES**

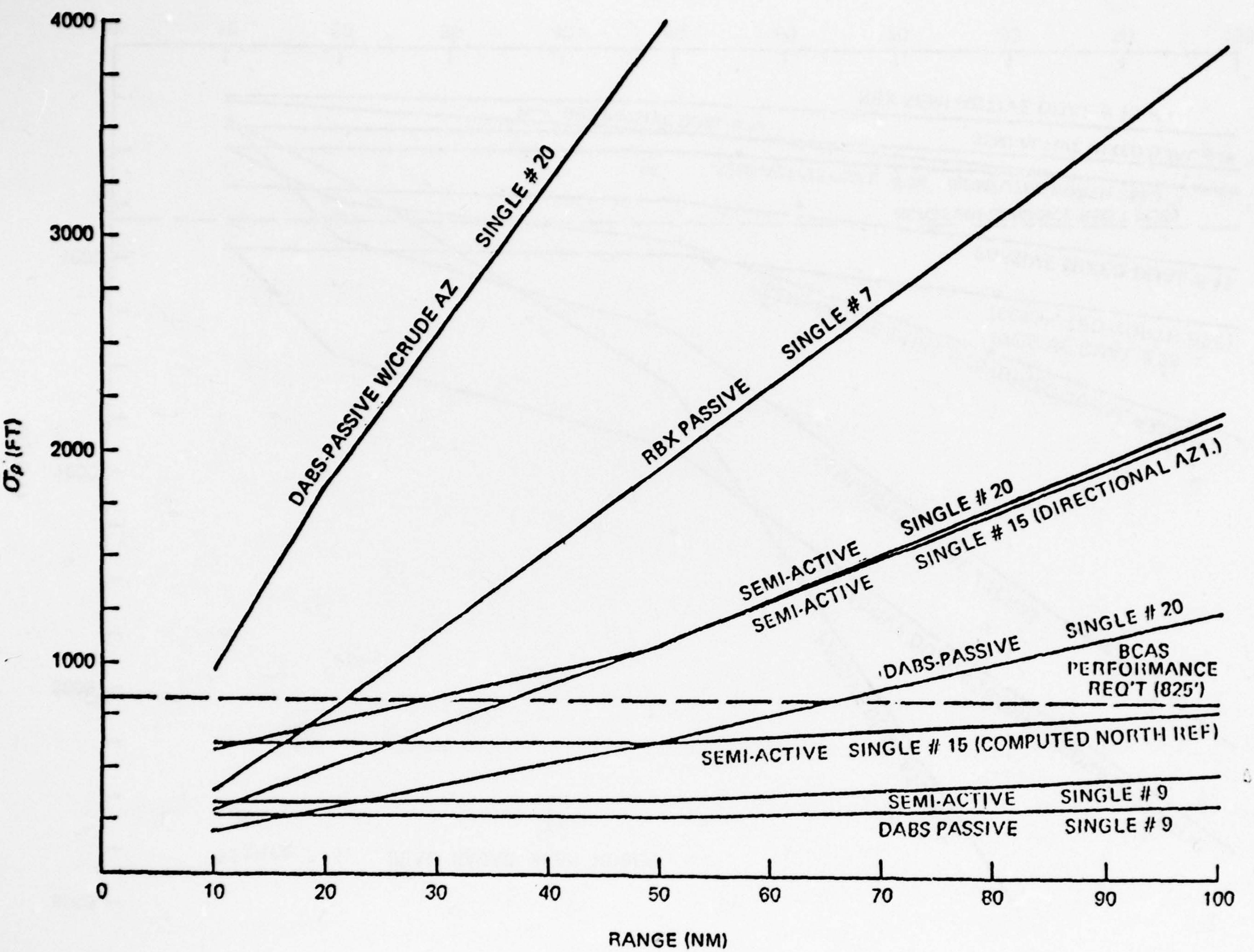
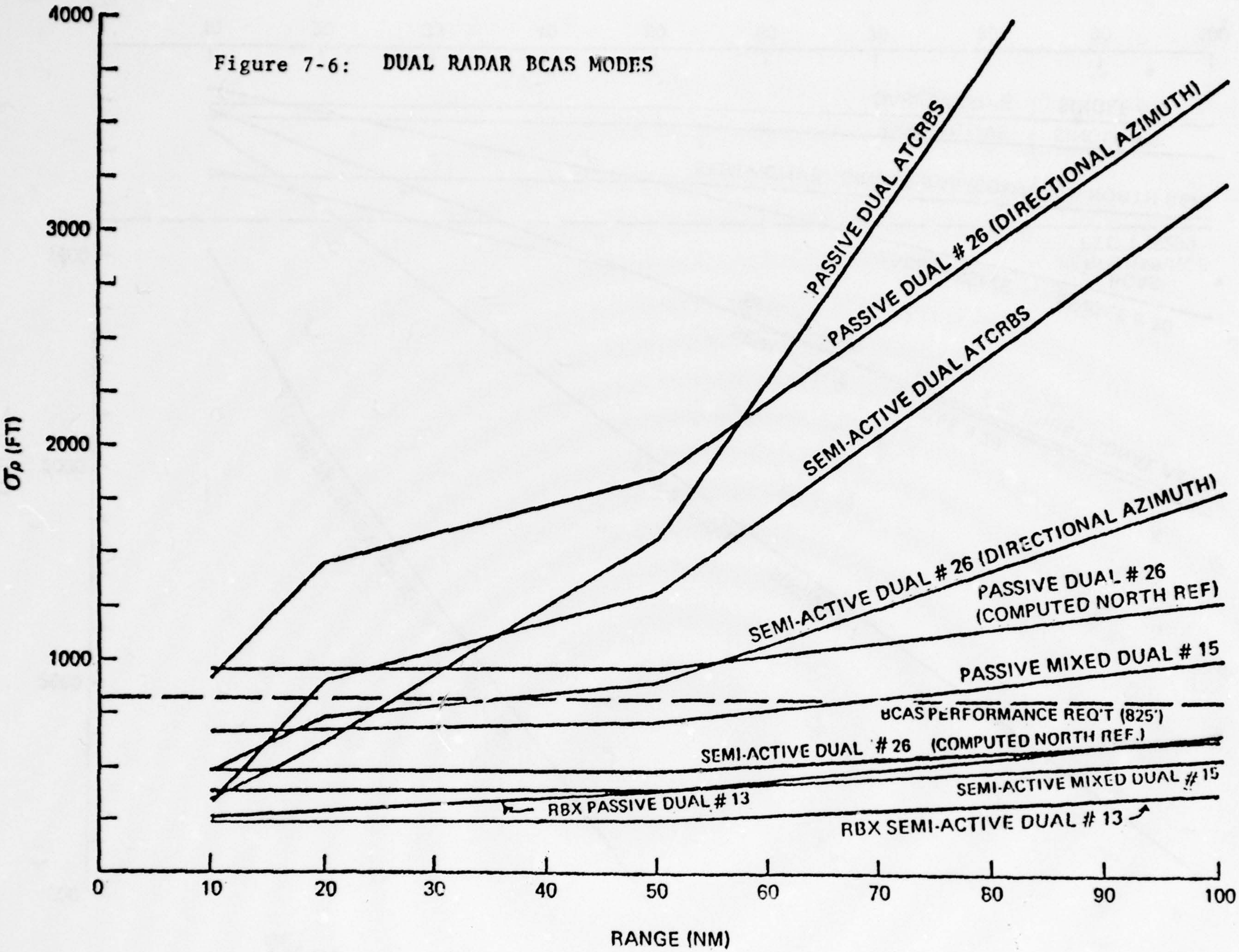


Figure 7-6: DUAL RADAR BCAS MODES



performance (σ_ρ 825 ft) out to 100 nm.* In addition, it should be noted that only synchro-DABS can remain totally passive with a single site and provide acceptable performance everywhere.

For dual site solutions it can be seen that two RBX sites can remain passive everywhere while a solution with but one RBX and one ATCRBS can allow BCAS to remain passive out to a range of 70 nm.

The BCAS performance is summarized in Figure 7-7 and Table 7-6. It can be seen that, for the specified value of (825 feet) the false alarm probability for a miss of one nm for a non-turning target or a turning target is 0%, and the missed alarm probability (failure) given a close proximity turn to a collision for a non-turning (straight) aircraft is 0%. However, it can be seen that the missed alarm probability given a close proximity collision for a turning aircraft is 90%. That is, targets in close proximity that are being accurately tracked by a BCAS aircraft, pose real threats if they suddenly

---

*/ Note that ATCRBS computed North reference is not independent of the RBX.

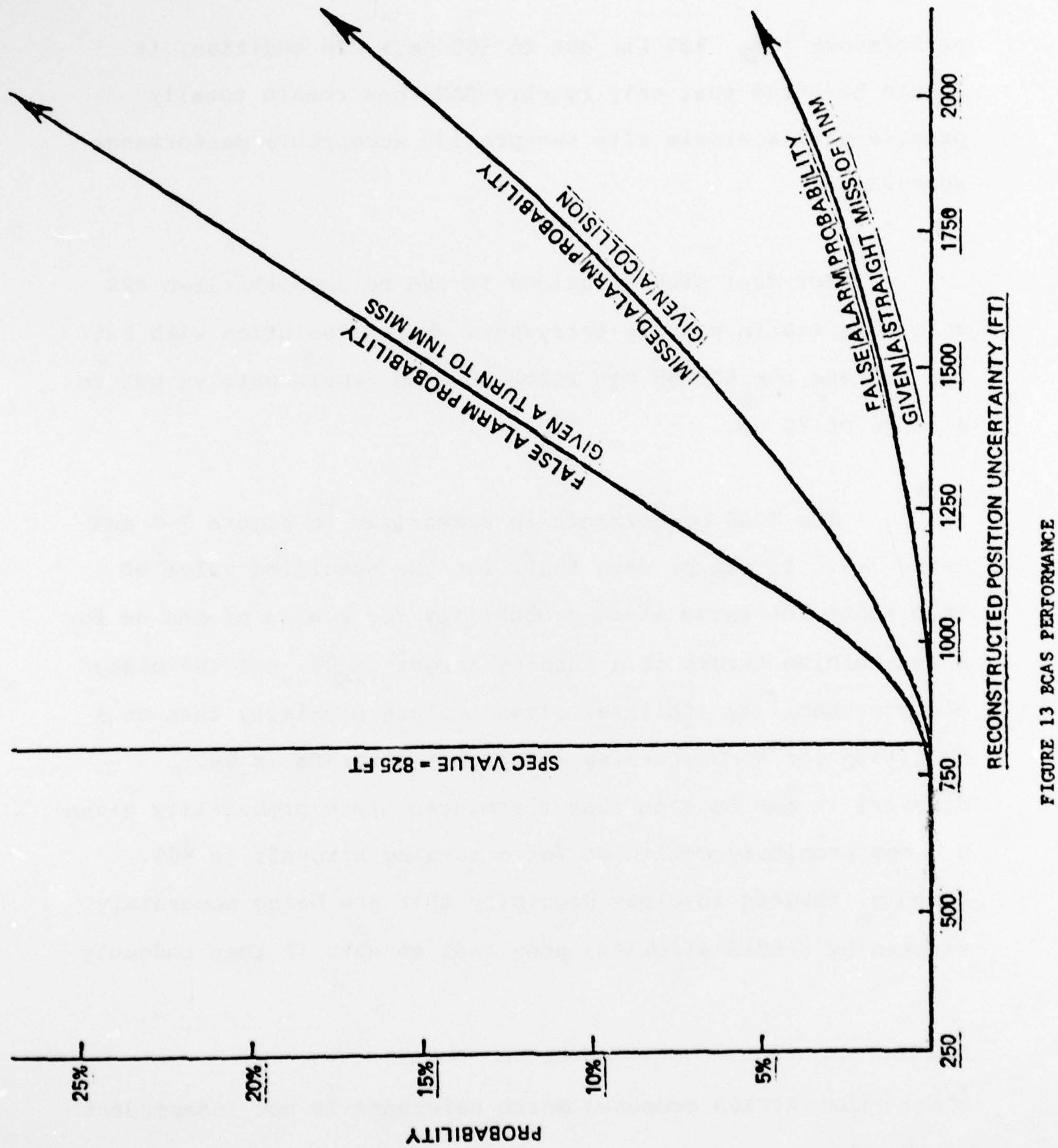


Figure 7-7: BCAS Performance

Table 7-6: BCAS PERFORMANCE VERSUS σ_p

		FAILURES(%)		FALSE ALARMS(%)		TRACK ACCURACY	
σ_p (FT)	MANEUVER LOGIC	STRAIGHT	TURNS*	STRAIGHT	TURNS	POSITION	VELOCITY
						ft	kts
250	H	0%	100%	0%	0%	150	7.5
	V	0%	100%	0%	0%		
750	H	0%	90%	0%	0%	450	22.5
	V	0%	90%	0%	0%		
825 Spec value	H	0%	90%	0%	0%	500	25
1000	H	5%	90%	0%	0%	600	30.0
	V	1%	90%	0%	2.5%		
2000	H	20%	90%	3.5%	25%	1200	60.0
	V	15%	65%	3.7%	30%		

SAFETY ZONE: 1000 FT HORIZONTAL
200 FT VERTICAL

FAILURE : DOES NOT PROVIDE ADEQUATE SEPARATION GIVEN AN EXACT COLLISION

FALSE ALARM: PROVIDES A POSITIVE COMMAND GIVEN AN EXACT MISS OF 6000'

* PWI (Directional Antenna) Required to provide protection against close proximity turns.

turn toward that aircraft. No automated collision avoidance algorithm can react fast enough and still keep the other three probabilities of interest acceptably low.

The above is one more reason that PWI is extremely important. That is, PWI provides the pilot with a visual siting of the target. If a close proximity target is sited and visually tracked, the pilot will be able to react to any sudden and dangerous maneuvers of the target aircraft.

There is one additional aspect of BCAS performance which must be addressed. All the BCAS aircraft in a given area will cause an impact on a target ATCRBS' round reliability. The requirement is to see that BCAS does not reduce round reliability by more than 2%.

Table 7-7 presents a worst case computation for a target in the densest part of the L.A. Basin. It can be seen that the target's round reliability will not be reduced by more than 1.73%.

Table 7-7

IMPACT OF BCAS ON ATCRBS
ROUND RELIABILITY

$$\left[\left(\frac{30\ \mu s \times A \times B \times C \times D \times E \times F}{G} \right)_{\text{Top Antenna}} + \left(\frac{30\ \mu s \times A \times B \times C \times D \times E \times F}{G} \right)_{\text{Bottom Antenna}} \right] \times 100\% = \Delta R$$

Top Antenna		Bottom Antenna	
A	= 2	A	= 2
B	= 6	B	= 1
C	= 2	C	= 2
D	= 100	D	= 100
E	= $\frac{7}{8}$	E	= $\frac{1}{2}$
F	= $\frac{1}{2}$	F	= $\frac{1}{2}$
G	= 2	G	= 2

$\Delta R = 1.73\%$

where

R = Worst case percent reduction in ATCRBS Round Reliability caused by BCAS

30 us is the suppression time due to a P_1P_2 reception or the dual time due to a P_1P_3 reply

A = Number of 20° azimuth sectors in which BCAS goes active

B = Number of levels of whisper/shout

C = Number of interrogation modes per cycle (mode A and Mode C)

D = Number of BCAS aircraft

E = Fraction of BCAS aircraft that could possibly be seen by given antenna

F = Fraction of BCAS aircraft that could be possibly seen that are actually seen (function of interrogation antenna pattern - see Appendix I)

G = Interrogation cycle time

Section 8

ISSUES IN PROCESS OF RESOLUTION

The BCAS concept will ultimately be verified by flight testing a BCAS engineering model. However, before advancing to a "cut metal" stage there are still several outstanding issues which have to be resolved for an analytic proof of concept. These issues are briefly described in this section.

8.1 ANTENNA DESIGN

The phased array antenna has been sized and its capabilities and applications described. A second iteration is required to determine the following:

- How small can the antenna be made
- How can antenna drag be minimized
- What is the proper antenna pattern for obtaining an effective 20° transmit pattern
- What is the best way of obtaining an effective 20° transmit pattern
- What is the minimum number of dipole elements that can be used

8.2 REPLY PROCESSOR

The reply processor is, in reality, a set of processors which vary as a function of the mode in which BCAS is operating.

Thus, the active mode and the several passive and semi-active modes have to be defined in a compact software package.

More importantly, the reply processor design has to be completed and tested via simulation to prove that it can perform as well as has been predicted in this paper.

8.3 SETTING THE GARBLE FLAG

In the multi-modal logic descriptions, garble flags have been shown. The understanding is that if passive or active garble gets excessive, a garble flag will be set. The criteria for setting each of the garble flags has to be defined. This is a non-trivial task since the flags cannot be set instantaneously nor dropped instantaneously. The time period over which reply information is observed and utilized for decision making becomes a parameter which has to be chosen very carefully.

8.4 IMPACT OF ACCURACY ANALYSIS ON MODE SOLUTION

The accuracy analysis of Section 5.2.3 did not include the effects of garble in the modal solution.

Several modes of BCAS may be affected by garble more than others, and several pieces of data from which the best solution is selected may be affected differently by garble. It then follows that the "best" solution may differ once garble is included into the analysis.

8.5 COMPARISON OF BCAS PERFORMANCE WITH DABS, AND BCAS PERFORMANCE WITH ATCRBS/RBX

As discussed earlier BCAS passive performance in the presence of garble with a DABS site which is not in a synchronous mode has not been evaluated. Here, our concern is with the increased garble caused by the longer DABS All-Call reply (3 times as long). On the other hand, the DABS squitter information will prove extremely helpful in degarbling the All-Call replies.

8.6 MODE CONTROL LOGIC

The mode control logic is the brain of the BCAS software logic. As has been shown it determines the solution set that is to be used and controls the key elements such as transmit control, antenna switching matrixes, signal processor, reply processor, etc. It is, therefore, important that a second and more in depth look be given to this critical BCAS element.

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Report No. FAA-EM-78-5, II

FAA BCAS Concept
Concept Description

E. J. Koneke, et al

April 1978

Page 2-1, Section 2.1, Line 5 should read: "...BCAS provide Proximity Warning Indicator (PWI)..."

Page 2-1, Section 2.1.1, Line 2 should read: "...pilot which if executed..."

Page 2-2, Section 2.1.1, Line 2 should read: "...flight tests of Intermittant Positive Control (IPC)..."

Page 2-2, Section 2.1.2, Line 7 should read: "...tests have shown..."

Page 2-4, Section 2.1.2, Paragraph 3, Line 2 should read: "...an ATCRBS transponder..."

Page 2-4, Section 2.1.2, Paragraph 3, Line 8 should read: "...airframe shields its bottom..."

Page 2-5, Section 2.2.1, Paragraph 1, Line 5 should read: "...existing or planned..."

Page 2-5, Section 2.2.1, Paragraph 1, Line 9 should read: "...planned or given by BCAS..."

Page 2-6, Section 2.2.4, Line 3 should read: "...MHz replies to 1030 MHz..."

Page 2-6, Section 2.2.4, Line 4 should read: "...1090 MHz replies..."

Page 2-6, Section 2.2.4, Line 5 should read: "...1090 MHz replies to 1030 MHz..."

Page 2-7, Section 2.3.1, Line 4 should read: "...ATC and ATARS separation"

Page 2-8, Paragraph 1, Line 2 should read: "...where no DABS ground..."

Page 2-9, Section 2.3.4, Line 4 should read: "...such as RNAV..."

Page 2-9, Section 2.4, Line 8 should read: "ground surveillance."

Page 3-1, Section 3.1, Paragraph 2, Line 2 should read: "...in Section 1 and..."

Page 3-3, Figure 3-1 insert arrow toward "BRG ANTENNA AVAIL" block on line from "SET RADAR TRACK MODE FLAG" block.

Page 3-9, Paragraph 2, Line 4 should read: "...future Cockpit Display of Traffic Information (CDT) is"

Page 3-13, Paragraph 1, Line 5 should read: "Mode 4 is used..."

Page 3-13, Paragraph 3, Line 8 should read: "...a proximity warning..."

Page 3-16, Figure 3-4, new wording in the mid-area to the left of figure, "PWI lights are around o'clock display; CAS commands are in center."

Page 3-17, Paragraph 1, Line 1 should read: "...of the modal"

Page 3-17, Paragraph 1, Line 2 should read: "...modal solution degrades"

Page 3-17, Paragraph 1, Line 3 should read: "beyond a certain...", ...air space (generally because of extremely poor geometry), the..."

Page 3-17, Paragraph 1, Line 4 should read: "...unacceptable. A..."

Page 3-17, Paragraph 1, Line 5 should read: "...error in these regions."

Page 3-17, Paragraph 2, Line 5 should read: "...maneuver, whether...", ...horizontal, to avoid..."

Page 3-17, Paragraph 2, Line 7 should read: "...geometry."

Page 3-25, Paragraph 2, Line 2 delete "...in a narrow vertical volume below"

Page 3-25, Paragraph 2, Line 3 delete "the aircraft...bottom mounted" and insert "...which are in the null of the interrogating aircraft's top-mounted..."

Page 3-25, Paragraph 2, Line 4 should read: "...such nearby aircraft..."

Page 3-25, Paragraph 2, Line 6 should read: "...suppression pulse pair from the top antenna at the next..."

Page 3-25, Paragraph 2, Line 6 should read. "...(2nd level)."

Page 3-25, Paragraph 2, Line 7 delete "since...aircraft."

Page 3-25, Paragraph 2, Line 8 should read: "...period, a Mode C (or A)..."

Page 3-25, Paragraph 2, Line 9 should read: "...transmitted (at the 2nd power level) via..."

Page 3-39 Paragraph 1, (a), Line 5 should read: "... ρ_{10} (ρ_{10}) = c(1/2) (δt_1) where

Page 3-40, Paragraph 1, (c), Line 3 should read: "...determines $\angle \alpha_1$..."

Page 3-41, Paragraph 1, (d), Line 6 should read: "...N_{12} and Σ_{12} are..."

Page 3-41, Paragraph 1, (d), Line 13 should read: "...part Σ_{12} is proportional"

Page 3-41, Paragraph 1, (d), Line 14 should read: "...arrival ΔTOA which..."

Page 3-41, Paragraph 1, (d), Line 21 should read: "...obtaining Δ TOA does not..."

Page 3-42, Paragraph 2, Line 1 should read: "To get ρ_{OT}, compute"

Page 3-42, Paragraph 2, Line 3 should read: " ρ_{IT} =..."

Page 3-42, Paragraph 2, Line 4 should read: " $\rho_{OT} = \Delta\rho + \rho_{IO} - \rho_{IT}$

Page 3-43, Paragraph (h), Line 2 should read: "...projection of ρ_{10} and..."

Page 3-43, Paragraph (h), Line 3 should read: " ρ_{OT} (d_1 and d_2,..."

Page 3-43, Paragraph (h), Line 7 should read: "3-10, the ground-plane..."

Page 3-44, Paragraph 1, Line 2 should read: "... $\left[\frac{E_T - E_O}{N_T - N_O}\right]$ "

Page 3-47, Section 3.2.2.1.2, Paragraph 2, Line 6 should read: "second or two. However,..."

Page 3-52, Paragraph 1, Line 5 should read: "...value of ΔTOA. In..."

Page 3-54, Pargraph 2, Line 3 should read: "...are equiprobable and independent."

Page 3-54, Paragraph 2, Line 7 should read: "...overlaps is..."

Page 3-54, Paragraph 2, Line 8 should read: "These statistics for..."

Page 3-54, Paragraph 2, Line 9 should read: "superimposing "l's"..."

Page 3-54, Paragraph 2, Line 11 should read: "...returns when the number of overlapping bits/reply is"

Page 3-59, Paragraph 1, Line 3 should read: "...range ρ_{OT} can be"

Page 3-60, Section 3.2.2.1.3, Line 5 should read: "...ATCRBS/RBX site as shown in Figure 3-16. To..."

Page 3-60, Section 3.2.2.1.3, Line 7 delete the last sentence of this paragraph.

Page 3-61, Figure 3-16 (revision is attached)

Page 3-67, Paragraph 2, Line 2 should read: "...measurements than..."

Page 3-67, Paragraph 2, Line 3 should read: "performed (Appendix E) to...

Page 3-95, Paragraph 3, Line 6 should read: "...reply ($L_r = cT_r$,...

Page 3-118, Paragraph 1, Line 2 should read: "...DABS scheduled time blocks and..."

Page 3-118, Paragraph 1, Line 4 should read: "...out; both azimuth and Δ TOA..."

Page 3-118, Paragraph 1, Line 5 should read: "...targets." and delete the rest of the paragraph.

Page 4-4, Paragraph 4, Line 3 should read: "...first, if the target..."

Page 4-4, Paragraph 4, Line 5 should read: "have to be..."

Page 4-5, Paragraph 1, Line 2 should read: "...the singular or non-singular solu-"

Page 4-5, Paragraph 1, Line 3 should read: "...is dependent"

Page 4-5, Paragraph 1, Line 4 delete "upon actual ...positions but"

Page 4-11, Paragraph 2, Line 3 should read: "...transmitted on the sum"

Page 4-11, Paragraph 2, Line 4 should read: "...on the Δ beam..."

Page 4-11, Paragraph 3, Line 3 delete "Half beamwidth"

Page 4-11, Paragraph 3, Line 4 should read: "Sectors of one half beamwidth appear..." and change "40^{o}3dB" to "a half power"

Page 4-11, Paragraph 3, Line 5 should read: "beamwidth of 40^{o}.

Page 4-11, Paragraph 4, Line 2 should read: "...null of the Δ beam..."

Page 4-16, Figure 4-6 change "NOWNCONVERTER" to "DOWNCONVERTER"

Page 4-17, Paragraph 2, Line 2 should read: "lar, except the PAM..."

Page 4-18, Figure 4-7 (revision attached)

Page 4-20, Section 4.2.2, Line 4 should read: "...altitude and ID, TOA"

Page 4-21, Paragraph 1, Line 2 should read: "...the simpler of the"

Page 4-23, Paragraph 2, Line 8 should read: "once timing sync..."

Page 4-25, Figure 4-9 (revision attached)

Page 4-28, Section 4.2.4, Line 4 should read: "...the micro-processor complex"

Page 4-30, Figure 4-11 (revision attached)

Page 4-35, Paragraph 1, Line 1 should read: "...by an $\alpha-\beta$ track in each of"

Page 4-38, Paragraph 1, Line 8 should read: "...tracks are to be dropped."

Page 4-40, Paragraph 2 , Line 1 delete reply

Page 4-40, Paragraph 2, Line 3 should read: "and the timing (housekeeping)..."

Page 4-44, Figure 4-14 (revision attached)

Page 4-50, Paragraph 2, Line 4 should read: "...intruder's replies as determined by his equipment. The process..."

Date Issued: June 1979
Attachments

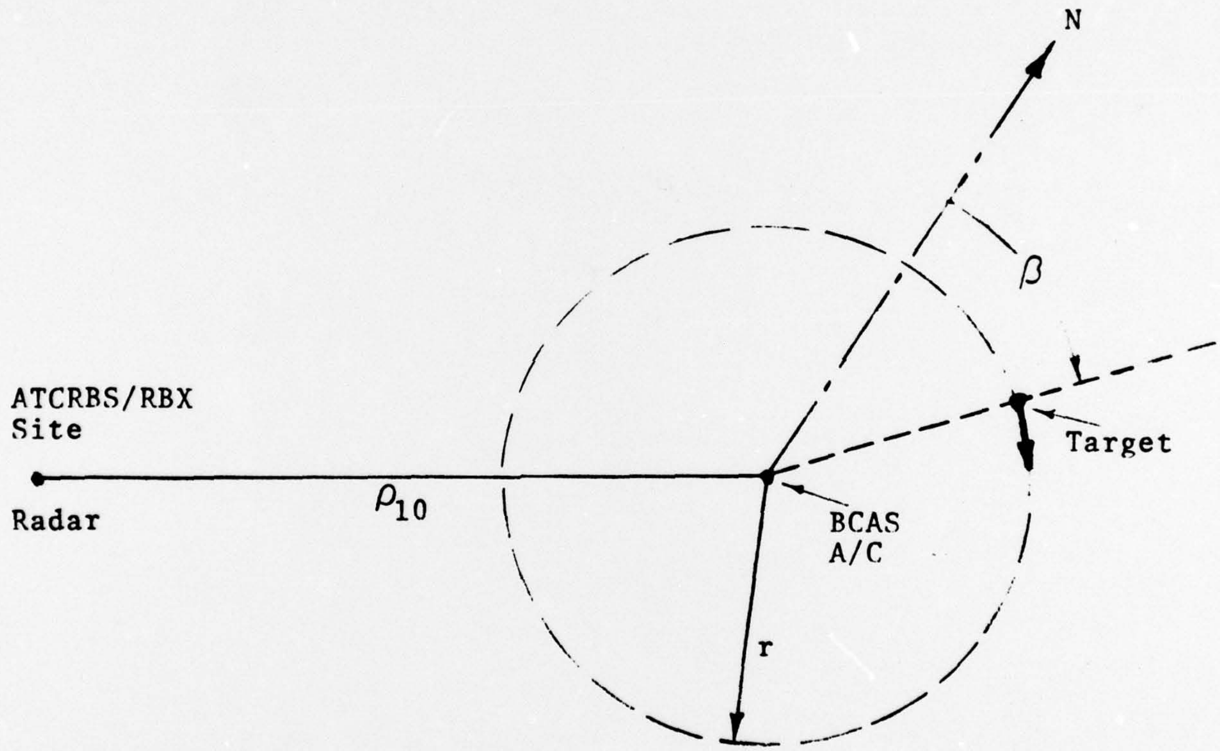


Figure 3-16
Revised

Geometry for σ_ρ Analysis - ATCRBS/RBX Site

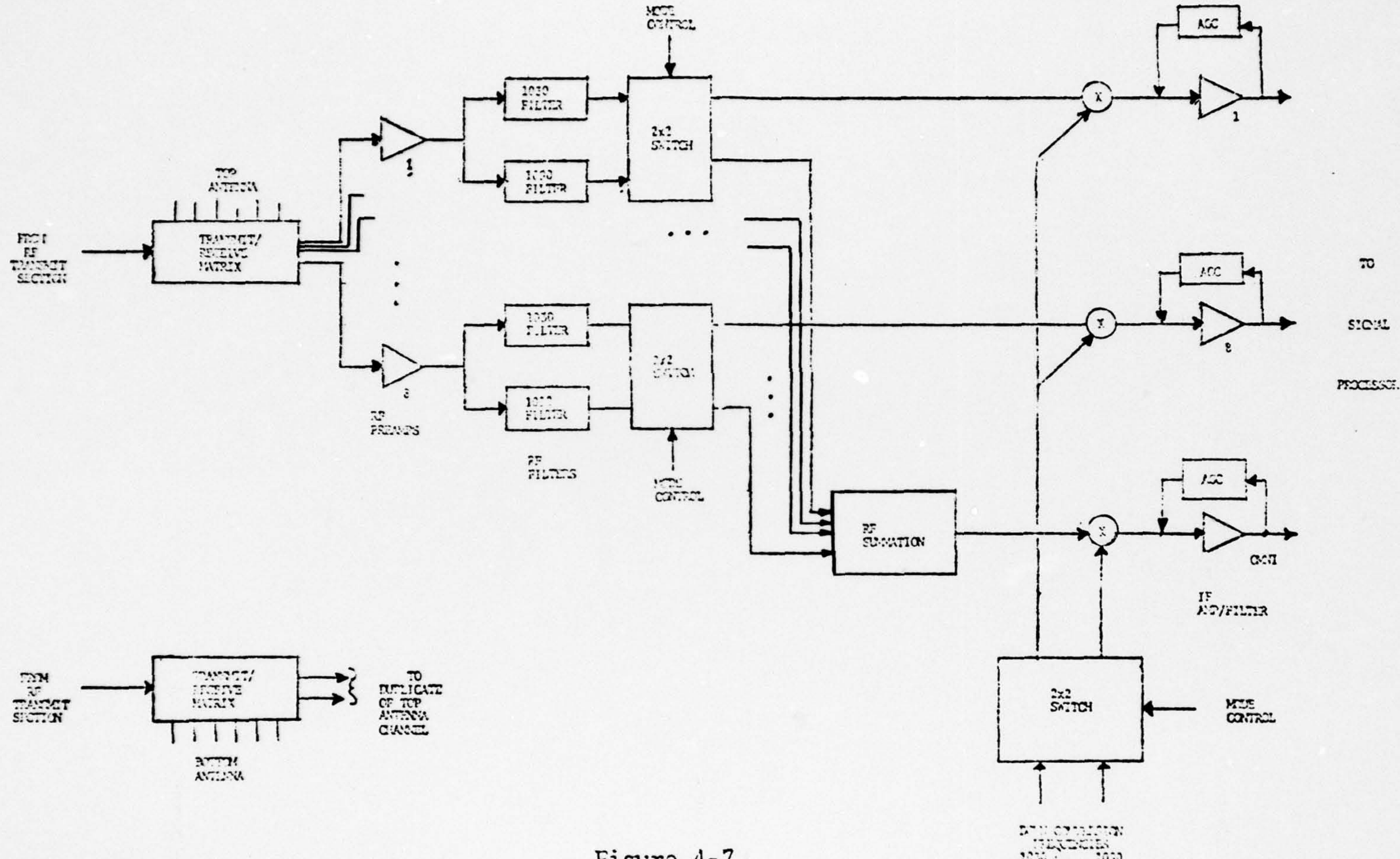


Figure 4-7

RF RECEIVER SYSTEM
(REVISED)

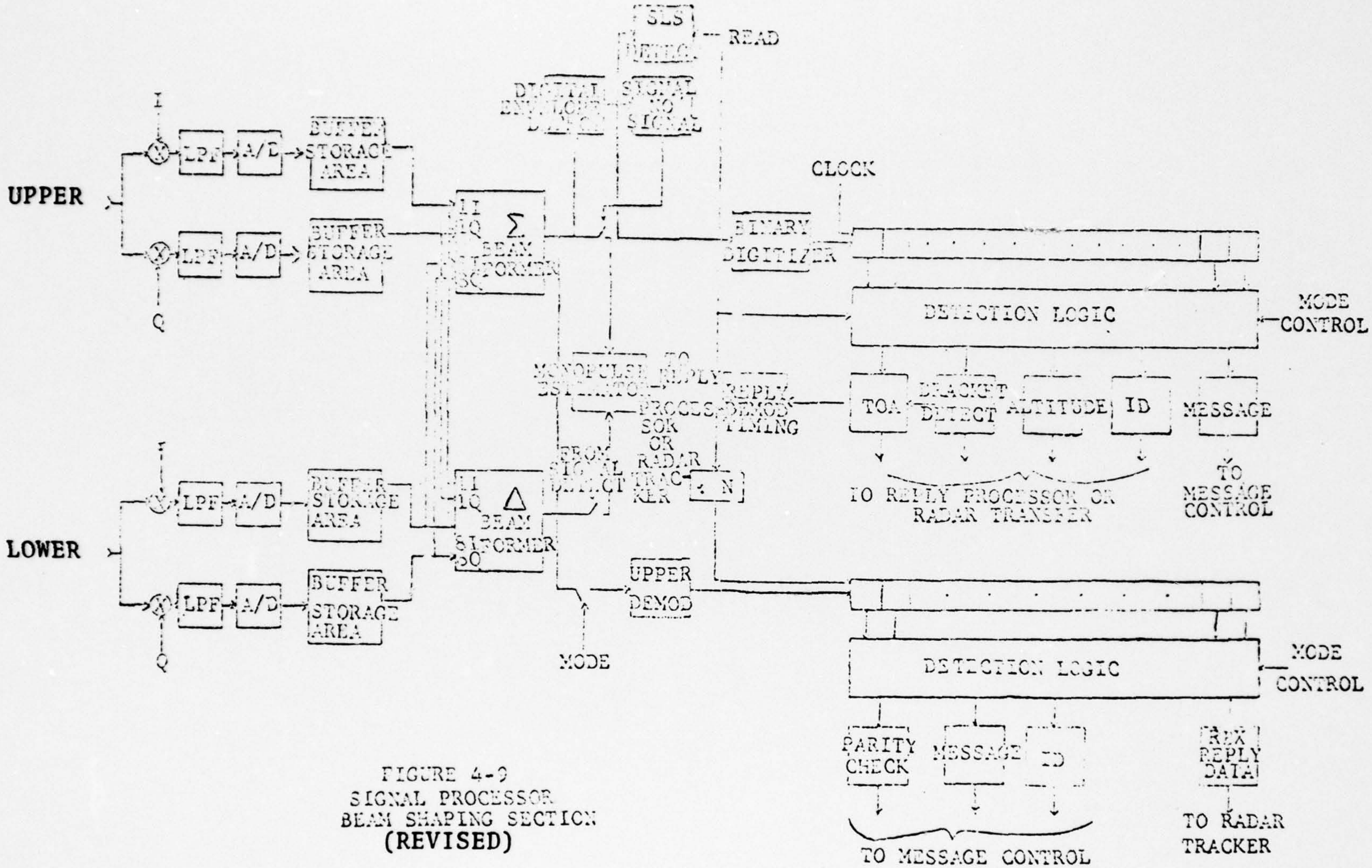


FIGURE 4-9
SIGNAL PROCESSOR
BEAM SHAPING SECTION
(REVISED)

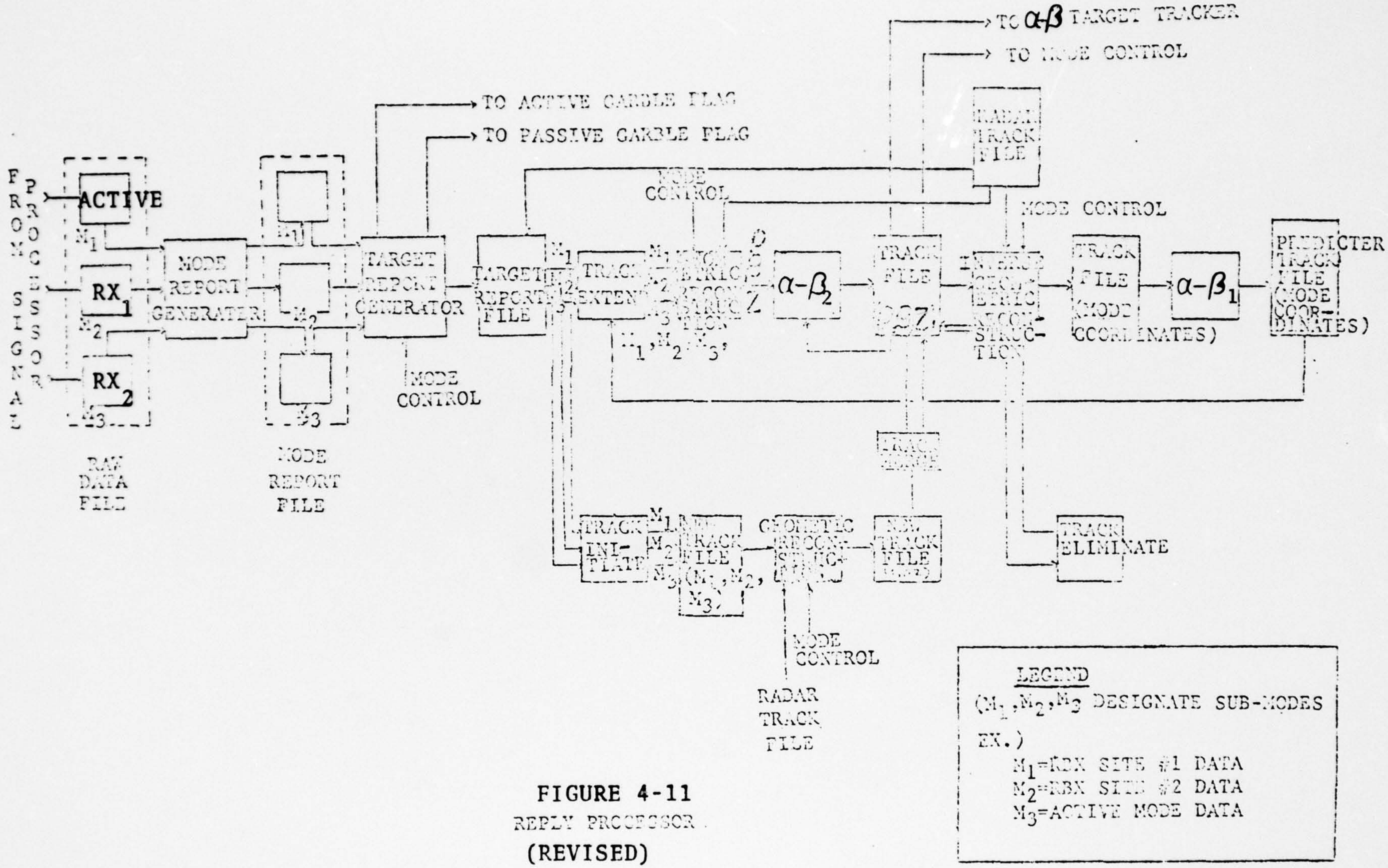
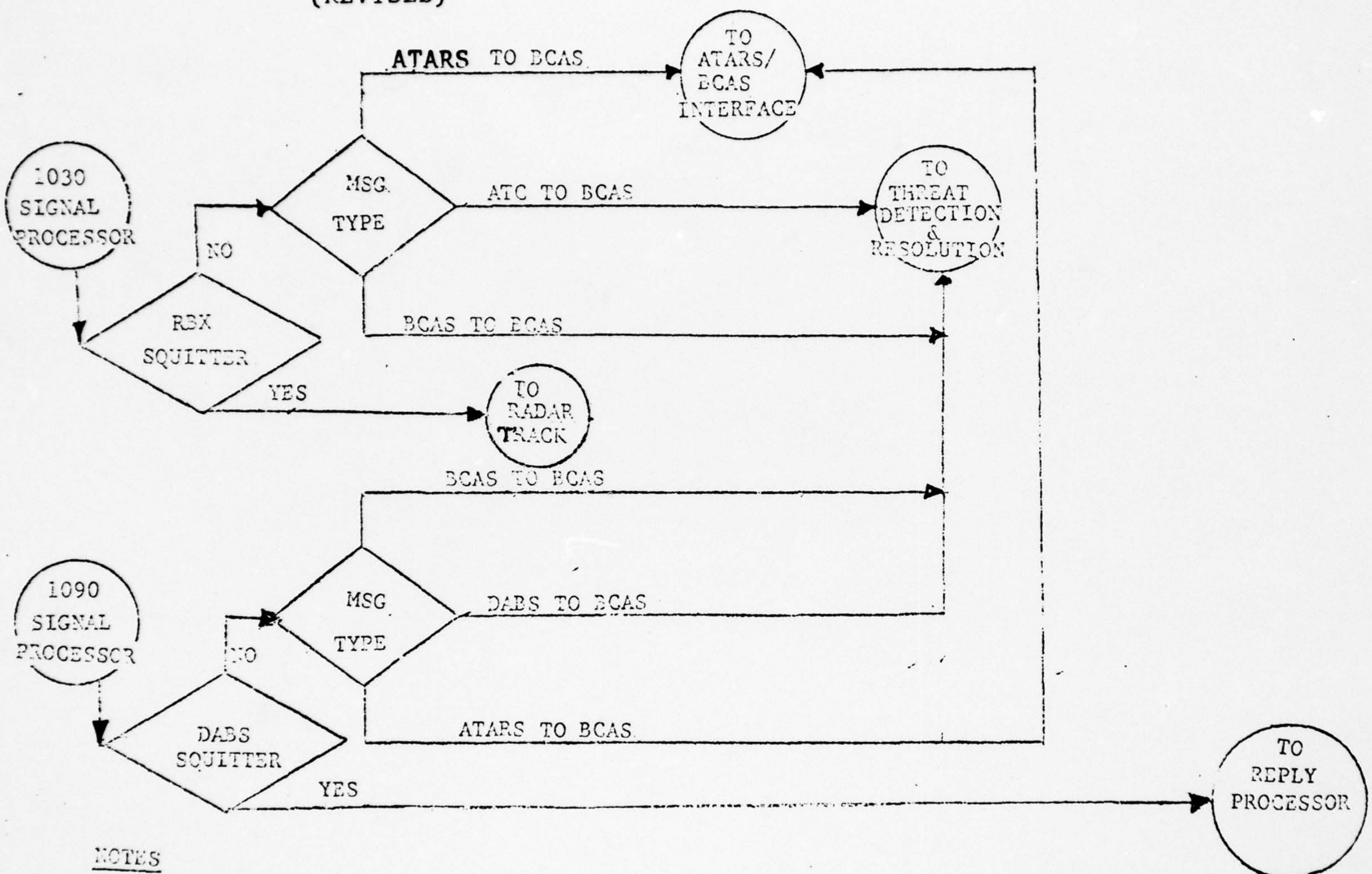


FIGURE 4-11
REPLY PROCESSOR
(REVISED)

FIGURE 4-14

MESSAGE CONTROL

(REVISED)



NOTES

1. ATARS TO BCAS CAN BE GROUND OR AIR DERIVED ON BOTH 1030 & 1090