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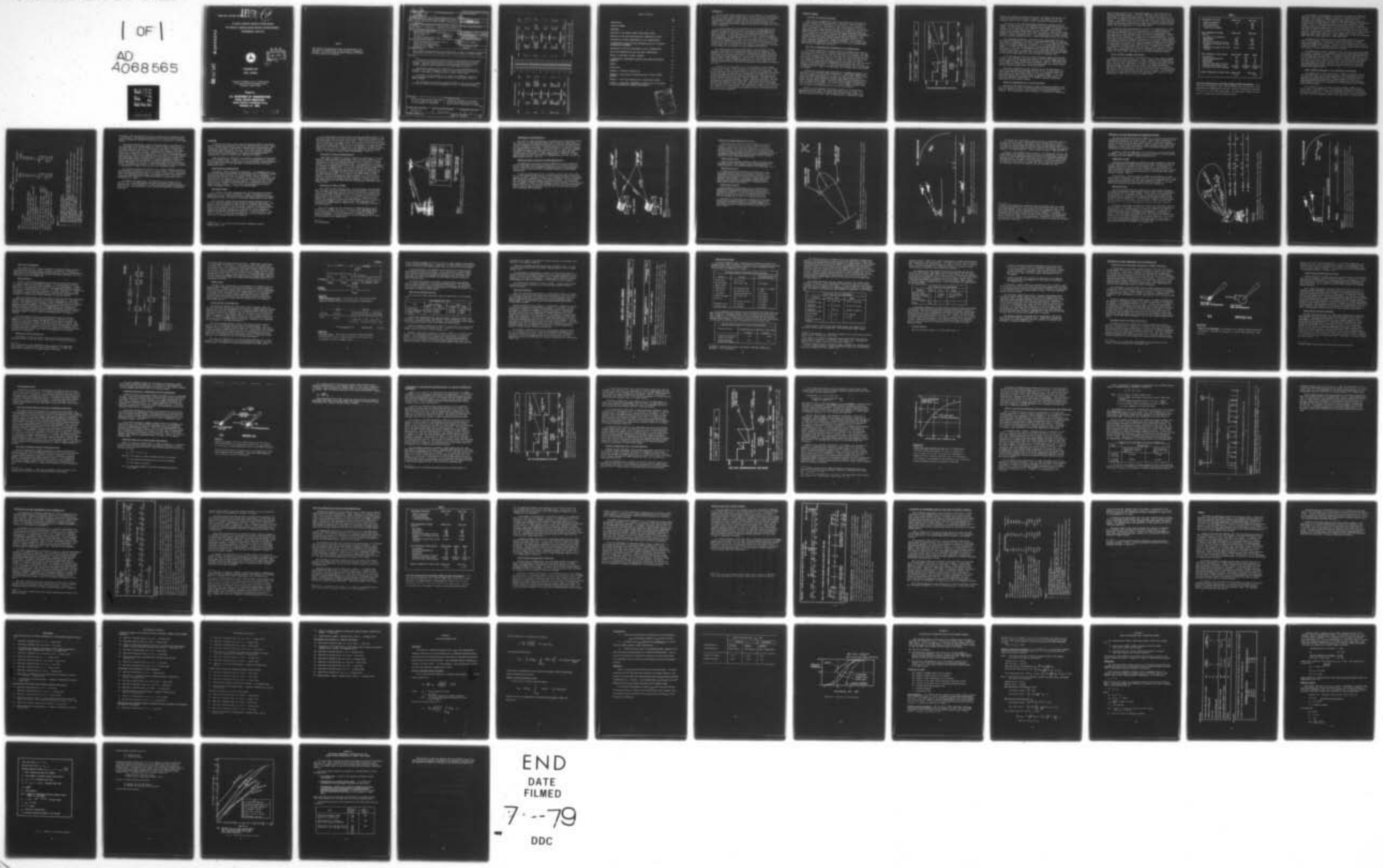

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DISCRETE ADDRESS BEACON SYSTEM (DABS)
AIR TRAFFIC CONTROL RADAR BEACON SYSTEM (ATCRBS)
INTERFERENCE ANALYSIS

NOVEMBER 1978

FINAL REPORT

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J.D. Welch, W.H. Harman, V.A. Orlando, R.R. LaFrey

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Lincoln Laboratory
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16. Abstract

The FAA is currently developing the Discrete Address Beacon System (DABS) as an evolutionary upgrading of the Air Traffic Control Radar Beacon System (ATCRBS). DABS will provide improved surveillance and data link service to suitably equipped aircraft operating on the same ATCRBS frequencies.

Questions in response to the publication of the proposed DABS National Standard in the Federal Register in March 1978 have been raised regarding the potential interference to ATCRBS because of common channel usage.

The purpose of this document is to present the assumptions, models and system operation necessary to assess the potential interference effects of DABS on ATCRBS.

The conclusion of the analysis presented herein is that the current ATCRBS surveillance ability will not be degraded as a result of implementing DABS.

17. Key Words
Discrete Address Beacon System (DABS)
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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INTRODUCTION

The Air Traffic Control Radar Beacon System (ATCRBS) is the principal source of aircraft position information in today's air traffic control system. The Discrete Address Beacon System (DABS) has been designed as an evolutionary upgrading of ATCRBS to achieve improved surveillance quality in the higher traffic densities predicted for the next 20-30 year period, and to provide a ground-air-ground data communications channel to support air traffic control automation.

In a recent response to the publication of the Proposed DABS National Standard the question has been raised as to whether the implementation of DABS will degrade the performance of neighboring unmodified ATCRBS sites during the period of transition from an all-ATCRBS environment to an all-DABS environment. The analysis presented shows that, if properly managed, the implementation of DABS equipment will at no time result in a degradation of the ATCRBS performance. In fact, just the opposite will occur. The modification of an ATCRBS ground station to include DABS capability will not only provide better quality surveillance data to the users of the data from that ground station but, by reducing the total amount of interrogation in the area, it will enhance the performance of nearby ATCRBS ground stations.

The enhancement of the beacon environment by the deployment of DABS equipment can be predicted by relatively simple technical arguments. The purpose of this paper is to summarize the assumptions and models behind the DABS design and to present the technical and operational background required to support an informed judgment as to the potential interference effects of DABS on ATCRBS. Final experimental verification of these predictions using engineering test models of DABS equipment will occur in the near future at the FAA's National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, N.J.

It should also be noted that all of the predictions in this document concerning the effects of DABS transmissions on ATCRBS performance also apply to the effects of DABS on the performance of military beacon equipment. The major interference considerations (potential suppression of ATCRBS transponders by DABS interrogations and potential interference with ATCRBS receivers by asynchronous DABS replies) are virtually unchanged when considering military beacon equipment using secure IFF or "Mode-4" waveforms. The DABS design accounts for all possible DABS-Mode 4 mutual triggering mechanisms. The DABS interrogation waveform cannot trigger Mode 4 replies because different sync preambles and modulation formats are used. DABS replies should not trigger Mode 4 sensors since the pulse spacings, transmission lengths, and reply delays are different for the two systems. The compatibility of DABS and the secure IFF system will be investigated and documented in detail as the DABS test and evaluation effort progresses.

EXECUTIVE SUMMARY

Potential Interference Mechanisms

The selection of DABS signal formats was governed by the design goal of common channel ATCRBS/DABS operation. This goal is important since it allows the system to be implemented at much less cost than if separate channels were required. In selecting a DABS interrogation waveform to be used at 1030 MHz it was found that any form of data modulation, if sustained long enough, would trigger unwanted replies from a significant number of ATCRBS transponders. To avoid this, the DABS uplink waveform was designed with a preamble to intentionally suppress any ATCRBS transponder which detects the DABS interrogation. The remainder of the DABS transmission is then completed within the nominal 35-μsec ATCRBS suppression interval. As a result, the only residual uplink interference mechanism is the effect of these intentional suppressions on ATCRBS transponders. The principal interference mechanism identified on the downlink is the effect of asynchronous DABS replies on ATCRBS reply processors.

The Effect of DABS-generated Suppressions on the ATCRBS System

Intentional suppressions are widely used by the ATCRBS system itself to prevent unwanted replies due to sidelobe radiation and reflections. The DABS environment can be controlled so that the suppression rate generated by a DABS sensor always remains less than the suppression rate from the ATCRBS interrogator which that DABS sensor replaces. In addition because DABS suppressions are transmitted only on the directional antenna, the volume of airspace within which the DABS-generated suppressions are detectable will often be smaller than the corresponding volume for ATCRBS-generated suppressions which are transmitted omnidirectionally at sites using improved SLS. Thus, the deployment of DABS sensors will result in an improvement in the ATCRBS uplink interference environment.

Consider the suppression rate experienced by an ATCRBS transponder in the sidelobes of three terminal ATCRBS interrogators. DABS-ATCRBS compatibility can be illustrated by considering the effect of replacing these ATCRBS interrogators with DABS interrogators as the DABS transponder population grows. Assume that the initial deployment includes three ATCRBS interrogators with a mutual coverage overlap region. The mix of ATCRBS and DABS interrogators may then be changed from "no DABS" to "all DABS" and the changes in suppression rate observed as illustrated in Fig. 1. A "victim" ATCRBS transponder experiences improved SLS suppressions from all three interrogators.

Initially, the suppression rate remains constant as the transponder population increases, since the ATCRBS interrogation rate is fixed. If no DABS sensors were deployed, the suppression rate would remain constant at 1200 per second for all time. When an ATCRBS sensor is replaced by a DABS

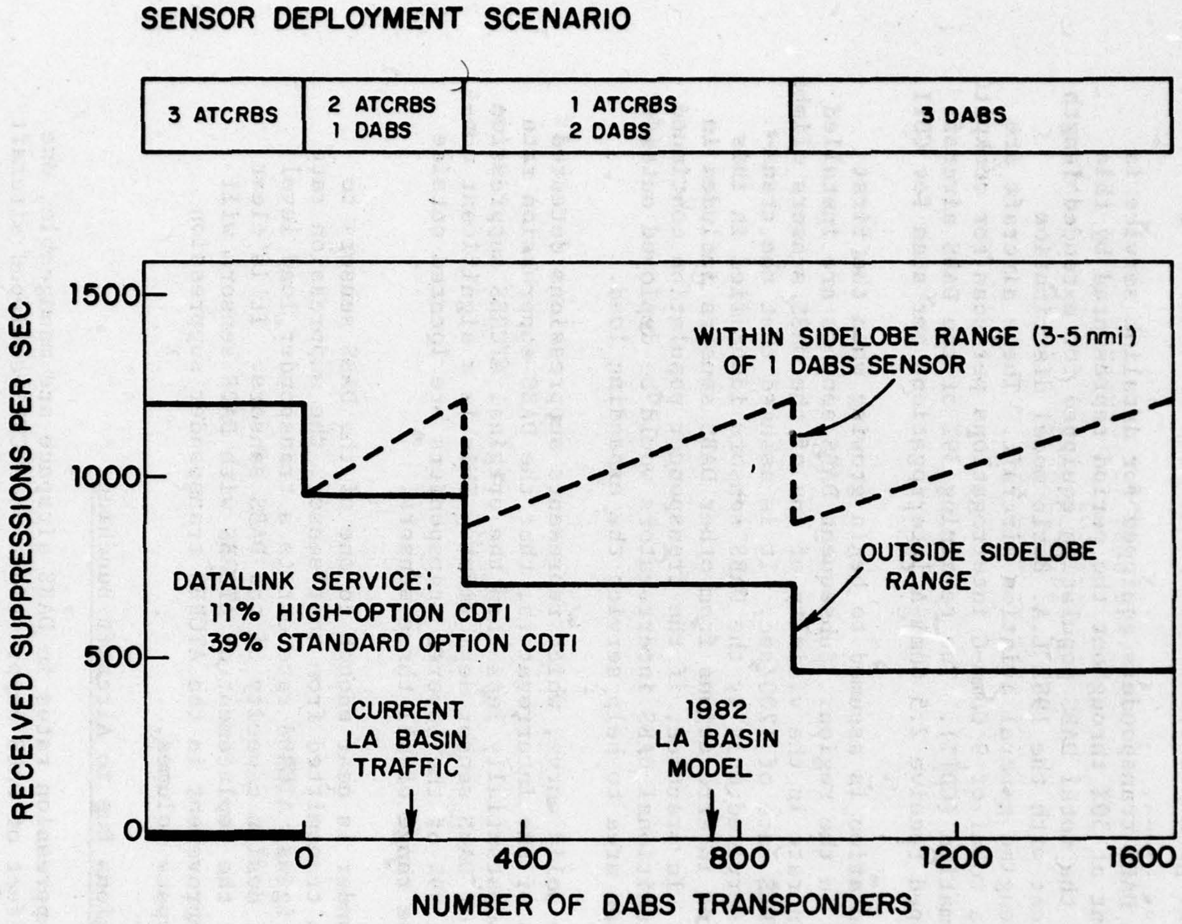

Figure 1

Comparison of Suppression Rates for ATCRBS and DABS Sensors. The suppression rate drops each time an ATCRBS sensor is replaced. By timing the replacement of ATCRBS sensors, the peak DABS suppression rate can be maintained below the original ATCRBS rate through all stages of DABS deployment. Furthermore less than 1% of the airspace served by these sensors experiences this peak suppression rate.

sensor, the suppression rate decreases because the ATCRBS interrogation rate from that site drops from 400/sec to 150/sec. The suppression rate then gradually builds up due to growth in DABS transponder and datalink usage.

The fraction of the DABS transponders equipped for datalink service is assumed to remain constant at 50% throughout the period represented by this figure. The fraction of the total DABS population equipped for extended length messages is 11%, consistent with the 1982 L.A. Basin model distribution of air carrier and twin-engine general aviation aircraft. These aircraft are assumed to each receive a total of 9 Comm-C interrogations per scan for cockpit display of traffic information (CDTI). The remaining 39% of the DABS aircraft which are datalink equipped receive 2.5 Comm-A interrogations per scan for CDTI.

The transponder population is assumed to begin growing when the first DABS sensor is installed in the region. Subsequent DABS sensors are installed each time the suppression rate in the vicinity of one of the DABS sensors climbs back to the original ATCRBS rate of 1200/sec. It is assumed that the transponders in the area are serviced only by the DABS sensors identified in this figure (i.e., there are no interrogations from other DABS sensors included in the suppression counts). In practice, if the transponder population continued to grow as shown here, additional DABS interrogators would be deployed outside of this mutual suppression area to help service the expanding load.

It is seen from the solid curve, which represents suppressions detected outside of the sidelobes of the interrogators, that the DABS suppression rate in this region will be substantially less than the original ATCRBS suppression rate through all stages of DABS sensor deployment. This is a significant conclusion, since more than 99% of the covered transponders are located outside of the effective sidelobe range of all three sensors.

Even when a transponder is near enough to one of the DABS sensors to detect every suppression transmitted from that sensor, the suppression rate can be kept below the original ATCRBS rate out to a transponder load level which exceeds the normal design capacity of the DABS sensors. It is clear from these figures, that the replacement of ATCRBS with DABS sensors will result in significant improvement in the ATCRBS transponder suppression environment in both airspace volumes.

Peaking of Suppressions Due to Aircraft Bunching

Although average suppression rates in DABS airspace are manageable, one must also examine the effect of DABS suppressions on ATCRBS-equipped aircraft flying in regions with locally high densities of DABS datalink-equipped aircraft. The interference in such a situation is controlled by limiting the peak interrogation rate from a single DABS sensor to a value which does not degrade nearby ATCRBS sensors. If needed, additional datalink capacity can be obtained by deploying more DABS sensors. The suppressions generated by a DABS sensor are sharply localized within the sidelobes of the DABS directional antenna. If the DABS sensors are more than about 5 nmi apart, their effective sidelobe ranges will not overlap and no region in the mutual airspace coverage volume will experience either peak or average suppression rates significantly greater than those generated by a single DABS sensor.

The specified peak interrogation rate which can be transmitted by a DABS sensor is 350 interrogations in a 125-ms interval. An ATCRBS transponder will remain suppressed 12.6% of the time while receiving interrogations at this rate and its reply probability will be reduced correspondingly. However, the probability of detecting this target does not drop proportionally to its reduction in round reliability. Evaluation of the ARTS III processor indicates that, when the detection parameters are properly set, the Mode-C target detection probability does not drop below 95% until the transponder reply probability has been reduced by at least 16%. This performance is achieved at the expense of considerable redundancy in the ATCRBS surveillance process and is likely to be representative of most ATCRBS reply processors. Because of the relative insensitivity of the ATCRBS reply detection algorithm to a reduction in transponder reply probability, there will be no observable degradation in the performance of nearby ATCRBS interrogators due to DABS interrogation peaking.

Effects of DABS on ATCRBS Interrogators

Asynchronous interference in the 1090 MHz band, or fruit, will be reduced significantly when DABS is introduced. Table 1 compares the probabilities of reply loss due to fruit generated by an ATCRBS interrogator and a DABS interrogator, where the DABS interrogator is assumed to provide surveillance and full datalink service to as many aircraft as seen by the ATCRBS interrogator. Although the DABS interrogator provides surveillance service for a total of 400 aircraft and datalink service for the half of those which are DABS equipped, the lower fruit rate generated by the DABS system is evident. Even though each DABS reply is longer than an ATCRBS reply, the DABS replies result in a lower probability of reply loss for the victim ATCRBS sensor.

TABLE 1

TRANSPONDER POPULATION	ATCRBS CASE		DABS CASE
ATCRBS Transponders	400		200
DABS Transponders	-		200
% Standard Datalink	-		78%
% High Option Datalink	-		22%
FRUIT GENERATED BY ATCRBS REPLIES	**ATCRBS CASE**		**DABS CASE**
Run Length (1.5 beamwidth)	16		6
Replies/Scan	6400		1200
Replies/Sec	1600		300
Fruit/Sec (Received by Victim)	160		30
Probability of Overlap (42 μsec Window)	0.672%		0.126%
Probability of Reply Loss (0.32/ Overlap)	0.215%		0.040%
FRUIT GENERATED BY DABS REPLIES	**SURVEILLANCE**	**COMM-B**	**COMM-D**
Transponders	200	200	44
Replies/Transponder/Scan	2	0.5	2
Replies/Scan	400	100	88
Replies/Sec	100	25	22
Fruit/Sec (Received by Victim)	10	2.5	2.2
ATCRBS Overlap Window (μsec)	64+21=85	120+21=141	120+21=141
Prob Reply Loss (=Prob Overlap)	0.084%	0.035%	0.032%
OVERALL PROBABILITY OF REPLY LOSS	**ATCRBS CASE**		**DABS CASE**
	0.22%		0.19%

Fruit Rate Comparisons For Individual ATCRBS and DABS Interrogators. It is seen that the probability that a desired ATCRBS reply is lost due to fruit generated by an ATCRBS sensor is greater than the corresponding probability of loss due to fruit from a DABS sensor. The DABS sensor handles the same number of targets and provides datalink service.

As the number of interrogators is increased in an area, the ATCRBS and DABS fruit rates are both increased. However, the ATCRBS fruit rate is proportional to the number of ATCRBS interrogators, whereas DABS fruit is relatively more independent of the number of DABS interrogators since only one DABS sensor provides datalink service to each DABS transponder and generally no more than 2 or 3 DABS sensors provide surveillance coverage in a given airspace. Thus, if 10 ATCRBS sensors have overlapping coverage in airspace containing 400 ATCRBS transponders, the fruit rate detected by a sensor in that area will be 1600 per second and the resulting probability of reply loss will be 2.15%. In comparison, the DABS fruit rate for the same set of targets within range of 10 DABS sensors would not increase beyond about 3 times the rate resulting from a single DABS sensor. Thus, ATCRBS reply loss due to overlapping DABS fruit will remain negligible as DABS usage grows.

Although loss of ATCRBS replies due to overlapping DABS fruit has been shown to be negligible, a DABS reply arriving in the clear at an ATCRBS sensor (operating without a defruiter) can be falsely decoded as a string of overlapping ATCRBS reply brackets. Strings of up to 50 such brackets could be decoded on receipt of a long DABS reply if the bracket detector were sufficiently tolerant of out-of-specification bracket spacings.

The ATCRBS reply processor intended for use in the ARTS-IIIa system (known as the SRAP-I processor) is an example of a processor using firmware degarbling and phantom elimination subsystems. Preliminary tests with this processor at the FAA NAFEC have indicated that it is capable of handling DABS fruit at rates of up to 250 fruit per second without significant reply processor degradation. This DABS fruit level is several times larger than would be ever experienced in an operational environment. Analysis of the existing ARTS processor and the Common Digitizer processor indicate that these processors, which both employ hardware-based bracket rejection schemes, would be less susceptible to DABS fruit than the SRAP-1.

DABS to ATCRBS Interference in Two High-Density Environments

The maximum level of DABS interference to ATCRBS is dependent upon the capacity limits built into the DABS equipment. These specification limits were based on traffic and datalink demand models and interference analyses generated during DABS system design. Table 2 compares the worst case assumptions which have guided the DABS system design with a set of assumptions suggested by one of the respondents to the publication of the Proposed DABS National Standard.

The respondent's model assumed an aircraft loading of 2000 aircraft within range of the DABS sensor. This assumption is within the theoretical surveillance capability of a DABS sensor provided the targets are relatively uniformly distributed in the air-space around the sensor. It was then assumed that 50% of these transponders require a very high rate of datalink service

TABLE 2

DABS INTERFERENCE TO ATCRBS - COMPARISON OF TWO SCENARIOS

Model	DABS Design Model (1995)	Respondent's Model
Total A/C in Model	1700	2000
% DABS Equipped	100%	100%
A/C in Mainbeam Range of Victim ATCRBS Sensor	700	2000
A/C Interrogated by Busiest DABS Sensor(1)	700	2000
Fraction of A/C with High-Option CDTI & Datalink(2)	0.22	0.5
High Option CDTI Transmissions Per Scan	10	30
DABS Interrogation Rate(3)	799/sec	8938/sec
% Suppressed Time for Victim with Range < 3 NMI(4)	4.27%	40.9%
% Suppressed Time for Victim with Range > 5 NMI(5)	0.75%	1.48%
Reply Rate of All Targets in Range of Mainbeam(6)	663/sec	2494/sec
DABS Fruit Rate Above MTL of ATCRBS Sensor(7)	66/sec	249/sec
Probability of ATCRBS Reply Loss Due to DABS Replies(8)	0.80%	2.99%

NOTES:

1. Assumes Adjacent Sensor Failure
2. Remainder Have Low-Option Service
3. Reinterrogation Rate is 10%
4. SLS is Used; All Transmissions are detected by ATCRBS Transponder; ATCRBS Interrog. Rate = 150/sec; Xponder Supp. Time = 45 μsec
5. Only Mainbeam DABS Interrogations are Detected; All SLS Pulses are Detected within Improved SLS Range (20 - 50 nmi)
6. Each Target Gets Dual Surveillance and Single Data Coverage; Link Failures Divide Equally Between Up & Downlink
7. Fixed Threshold at -79 dBm (S.T.C. would further reduce the Fruit Rate); BCAS Squitters Locked Out
8. ATCRBS Receiver Blanked for 120 μsec on Receipt of DABS Preambles; No ATCRBS or All-Call Fruit Included

to support a CDTI system with the ability to display up to 30 intruder tracks in the cockpit. The resulting interrogation rate is nearly 9000 per second, which far exceeds the theoretical interrogation rate capacity of a single DABS sensor.

The actual specified upper limits on the performance of the DABS link are represented in the column based on the 1995 L.A. Basin traffic model. In this model there are a total of 1700 aircraft in the Basin. Of these, 700 are within detection range of one of the sensor sites located in the highest density part of the area. Normally, a DABS sensor is required to provide surveillance coverage for up to 400 aircraft. In order to accommodate adjacent sensor failure, sensors can be expanded to handle a peak of up to 700 targets. The assumed upper bound on datalink service for this situation consists of high-option CDTI service (an average of 12 targets displayed) for 22% of the targets, mid-option CDTI (an average of 6 targets displayed) for 40%, and normal ATARS service for the rest. In the design model, the high-option CDTI service is handled by an average of 9 Comm-C transmissions per scan as opposed to approximately 30 Comm-C's per scan as in the respondent's model.

The resulting suppression probability for a victim transponder outside of the interrogator sidelobes is 0.75% for the design model. If the victim flies within the effective sidelobe range of the sensor, it experiences a suppression rate of 949 suppressions per second. This suppression rate is less than the suppression rate experienced by ATCRBS transponders in large areas of the Northeastern U.S. today.

According to the design model, the DABS fruit rate resulting from the replies of all of the DABS targets within DABS interrogator range is 66/sec detected above a fixed threshold of -79 dBm, assuming a standard ATCRBS interrogator antenna. The probability of reply loss due to DABS fruit is completely negligible.

BACKGROUND

In 1969 the Air Traffic Control Advisory Committee (ATCAC) of the Department of Transportation examined in detail the then-existing air traffic control system, with the purpose of developing recommendations for modifications and enhancements which would permit the air traffic control system to meet the anticipated demands through the year 2000. One of the principal recommendations of ATCAC was the development of a combined surveillance/datalink communications system to overcome known limitations of ATCRBS.

ATCAC recognized the importance of the ability to implement the new system in an evolutionary fashion. However, it was also recognized that it might be difficult to provide these new services on the same frequency channels presently used by ATCRBS because of the high level of interference which the current ATCRBS would cause.

ATCAC Frequency Recommendations

Consequently, ATCAC considered two approaches: the recommended one, of providing the improved surveillance and communications as an extension of ATCRBS "which would operate nationally on a single channel"; and an alternative of providing these services on new frequencies, in the vicinity of 1600 MHz -- the latter option to be taken only if it proved impossible to realize the required capabilities on the existing frequency channels. It should be noted in this regard that the "strawman" design presented in the ATCAC Report did use the ATCRBS frequency channels as noted in the final paragraph of the section "System Improvement Options ... Use of the 1600 MHz Band".*

DABS Signal Design

As a result of the ATCAC recommendations, the FAA sponsored a multiyear program at the M.I.T. Lincoln Laboratory to design a new surveillance and communication system, following the general guidelines presented in the Report. This system has come to be known as the Discrete Address Beacon System (DABS).

One of the major design issues confronting Lincoln Laboratory was the choice of frequency channels for DABS uplink and downlink transmissions. The simplest technical design would have resulted if a separate unused channel could have been selected for the DABS system. However, in the initial design effort, great attention was given to the realization of the improved surveillance and datalink communications capability as a direct extension of ATCRBS on the 1030 MHz and 1090 MHz frequencies. It was clear that, if this could be achieved, it would make implementation of the new system far less costly than if separate channels were required.

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*"Report of D.O.T. Air Traffic Control Advisory Committee, Volume 1, December 1969, p. 66.

Cost considerations require not only that DABS and ATCRBS designs be compatible but that there be as much specification commonality as possible so that the same hardware can be used for both systems. This is particularly crucial in the air since it is of utmost concern that the general aviation population be able to afford DABS transponders and not be required to pay for dual transponder and antenna installations. Since the area most amenable to ATCRBS/DABS commonality is in the RF and IF subsystems, it was important to attempt to develop a new system whose RF and IF design could also support the existing ATCRBS signals. This approach required common RF frequencies. (Fig. 2).

Advantages of Common Frequency Approach

Using common frequencies it will be possible for transponders to be built which use common receivers, IF amplifiers, video processors, modulators and transmitters for both the ATCRBS and DABS functions. In addition, a common antenna may be used for both ATCRBS and DABS. In view of the fact that LSI circuits are now available which perform all of the ATCRBS digital processing, the inclusion of ATCRBS capability in a DABS transponder can be accomplished at negligible incremental cost. Contrast this with the situation which would prevail if different frequency channels were used for ATCRBS and DABS. Two receivers, two transmitters and two beacon antennas would be needed in all DABS-equipped aircraft. It is unlikely that common ATCRBS and DABS functions could be incorporated in a single package. As a result the cost burden of providing both ATCRBS and DABS capability could prove excessive to a large portion of the general aviation community. A major part of the DABS link design effort was therefore spent investigating ATCRBS/DABS interference issues.

Coexistence of DABS and ATCRBS

As a result of these investigations, it was determined that DABS equipment (including sensors with mechanically rotating antennas) could perform all of the DABS and ATCRBS functions required for handling the densest surveillance and traffic loads predicted for this century on the identical frequency channels used by ATCRBS. It was also concluded that this could be achieved with a net reduction in channel occupancy as compared with the channel time required by conventional ATCRBS equipment. Thus the operation of the existing ATCRBS would be improved rather than degraded by the replacement of ATCRBS sensors by DABS sensors, even though DABS operated on the same channels.

Once it was clear that the introduction of DABS would reduce the RF interference to ATCRBS, the focus of the design effort centered on means for assuring that DABS could function in the existing heavy ATCRBS interference environment. This was accomplished by a number of techniques which are documented in the DABS Quarterly Technical Summaries and a series of FAA RD reports on the DABS design*.

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*See Bibliography.

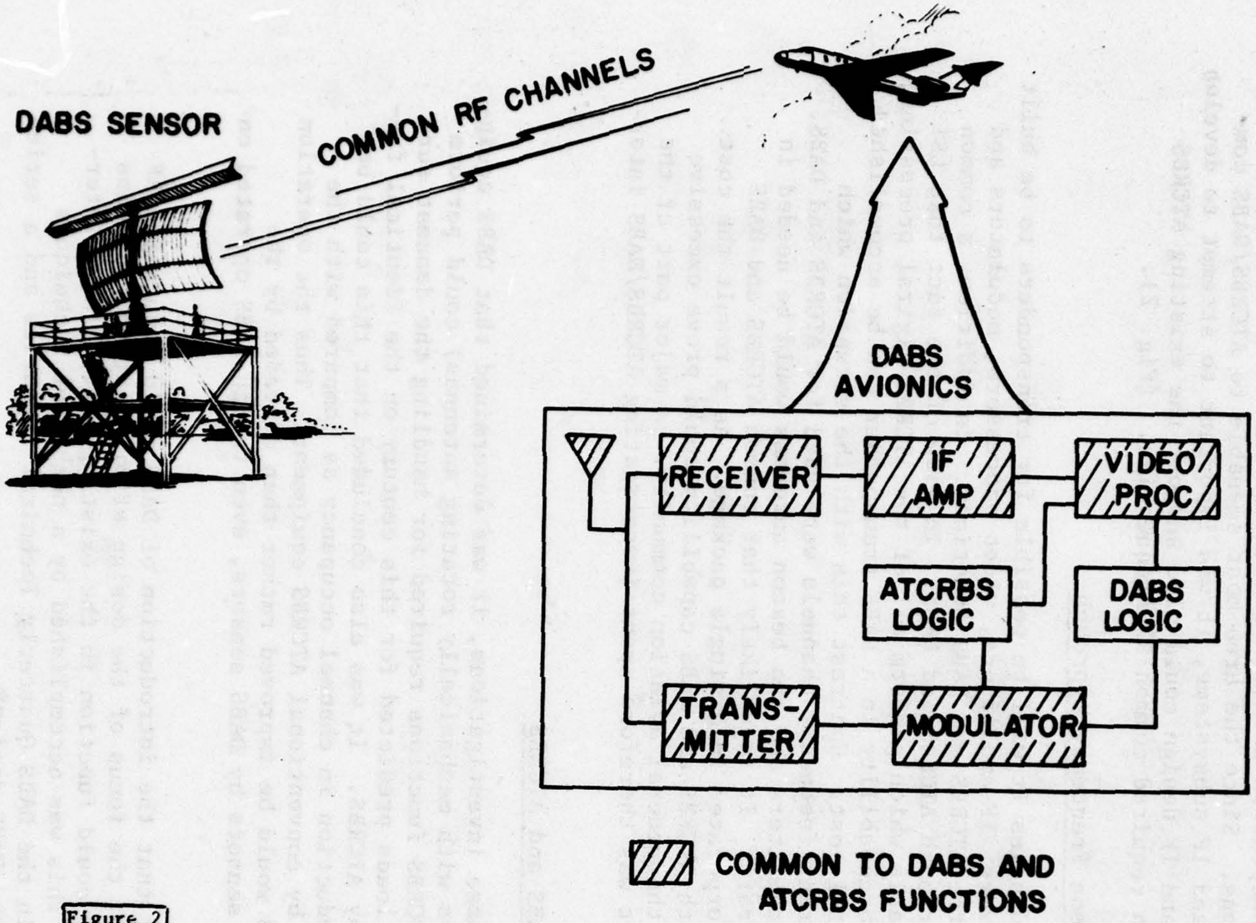

Figure 2

ATCRBS/DABS Commonality. The use of common frequencies leads to lower transponders and sensor cost as well as more efficient use of the frequency spectrum.

ATCRBS/DABS Cross-Compatibility

The result of these investigations of possible mutual interference effects is reflected in the DABS National Standard which defines the DABS signals in space and specifies that DABS waveforms operate on the same frequency channels as used by ATCRBS and that DABS transponders perform all of the functions of the existing ATCRBS transponders. Cross-compatibility is ensured by including the ATCRBS functions in the DABS transponder so that it looks like an ATCRBS transponder to ATCRBS ground stations, yet provides the additional DABS functions when interrogated by a DABS ground station. Similarly, the DABS ground station provides surveillance of ATCRBS-equipped aircraft, as well as DABS-equipped aircraft. (Fig. 3).

ATCRBS Improvement Resulting from DABS Implementation

The DABS signals and system operating protocols have been designed to permit simultaneous noninterfering operation during an extended transition period so that DABS can be implemented gradually, both on the ground and in the air, without interfering with or degrading unmodified ongoing ATCRBS installations.

In order to understand how this is achieved, we will first look at the way in which ATCRBS and DABS operate, and then examine the mutual interference issues to provide a quantitative summary of the possible effects of introducing DABS sensors and transponders into the ATCRBS environment. It will be shown that the ATCRBS uplink and ATCRBS downlink performance are both improved by the replacement of ATCRBS with DABS equipment, and that, because of its efficient design, DABS will not only provide enhanced surveillance for those ATC system users who employ DABS surveillance data, but also for those who continue to rely on existing ATCRBS equipment.

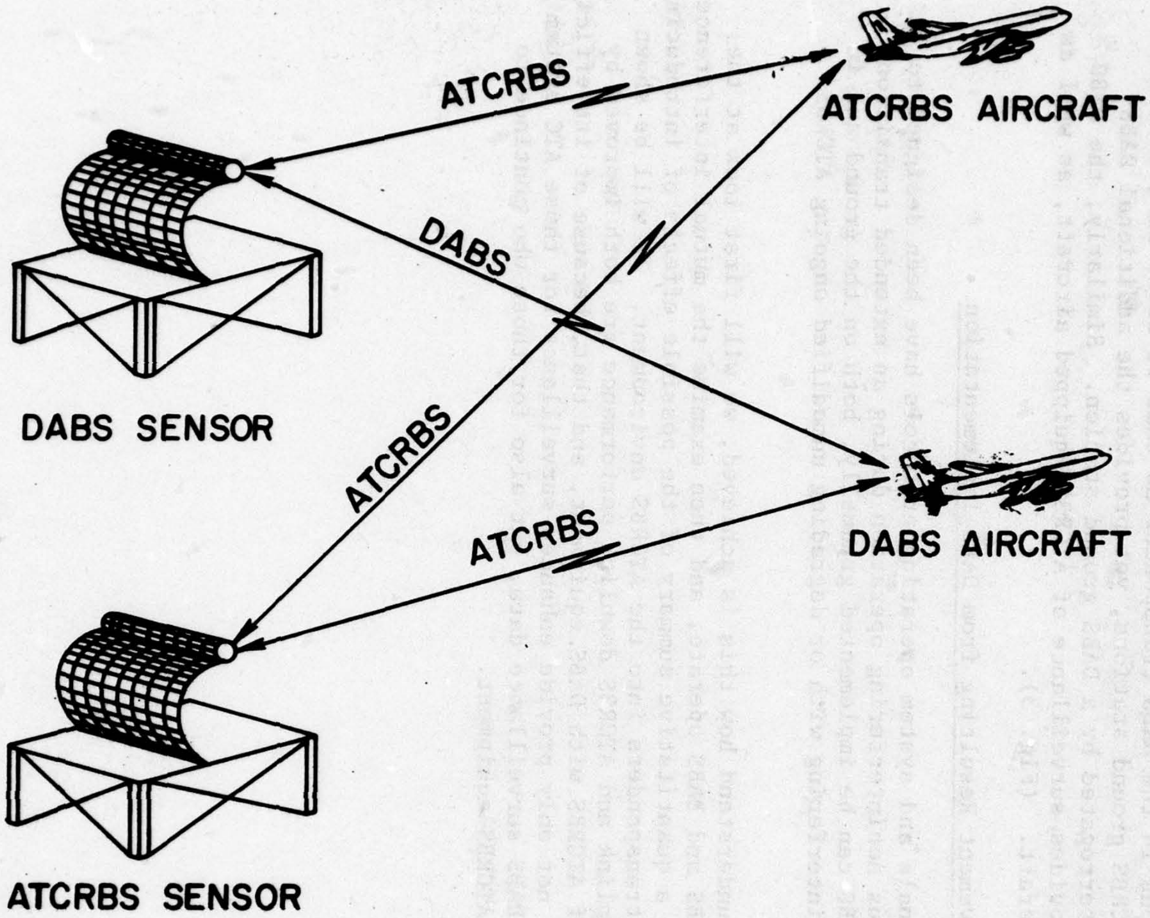

Figure 3

ATCRBS/DABS Cross-compatibility makes evolutionary implementation possible. The DABS sensor is designed to interrogate both ATCRBS and DABS transponders. The DABS transponder will respond to both ATCRBS and DABS sensors.

OPERATION OF THE CURRENT ATCRBS SURVEILLANCE SYSTEM

The Air Traffic Control Radar Beacon System (ATCRBS) now in operation is a cooperative surveillance system which transmits simple two-pulse interrogations at a fixed rate via a rotating directional antenna. Each aircraft transponder typically receives from 10 to 40 interrogations as the antenna beam sweeps past it. After a fixed delay it generates a coded reply in response to each interrogation. The azimuth of the target within the beam is determined by essentially locating the center of the reply run as the beam sweeps past. (Fig. 4) The range of the transponder is determined by measuring the elapsed time between the transmiasion of an interrogation and the receipt of the reply. The reply consists of a string of pulses lasting about 21 μsec.

ATCRBS Synchronous Garble

Since all ATCRBS transponders respond to any ATCRBS interrogation received, it is common for replies from different aircraft to overlap each other at the interrogator receiver. This overlapping or garbling (termed synchronous garble) represents one of the principal limitations of the ATCRBS system. (Fig. 5)

ATCRBS Overinterrogations

An ATCRBS transponder may be queried by any interrogator within range and its replies can be received by all interrogators within range. If there are enough interrogators and beacons operating within a given region, the interference can be dense enough to severely limit the operation of the system. A large potential contribution to the interference problem results from the interrogator antenna sidelobes. At short ranges the signal strength may be sufficient so that transponders are interrogated via leakage through the antenna sidelobes and replies from these unwanted interrogations reach the ground receiver through the same sidelobes.

ATCRBS Sidelobe Suppression

One of the means for controlling this problem is a technique known as interrogation sidelobe suppression (commonly referred to as SLS) in which a separate pulse is transmitted from an omnidirectional antenna each time an interrogation is transmitted. The transponder compares the amplitude of this pulse with the amplitude of the first (P1) interrogation pulse. If the amplitude of the SLS pulse (P2) is greater than the amplitude of the P1 pulse, the transponder does not reply, i.e., suppresses its normal reply.

A modified type of sidelobe suppression is employed at those interrogator sites which are located near buildings or terrain features which could result in reflections of the mainbeam transmission. Like sidelobe leakage, such reflections can also result in unwanted interrogations of transponders outside of the mainbeam, resulting in the appearance of false targets on the controller's display.

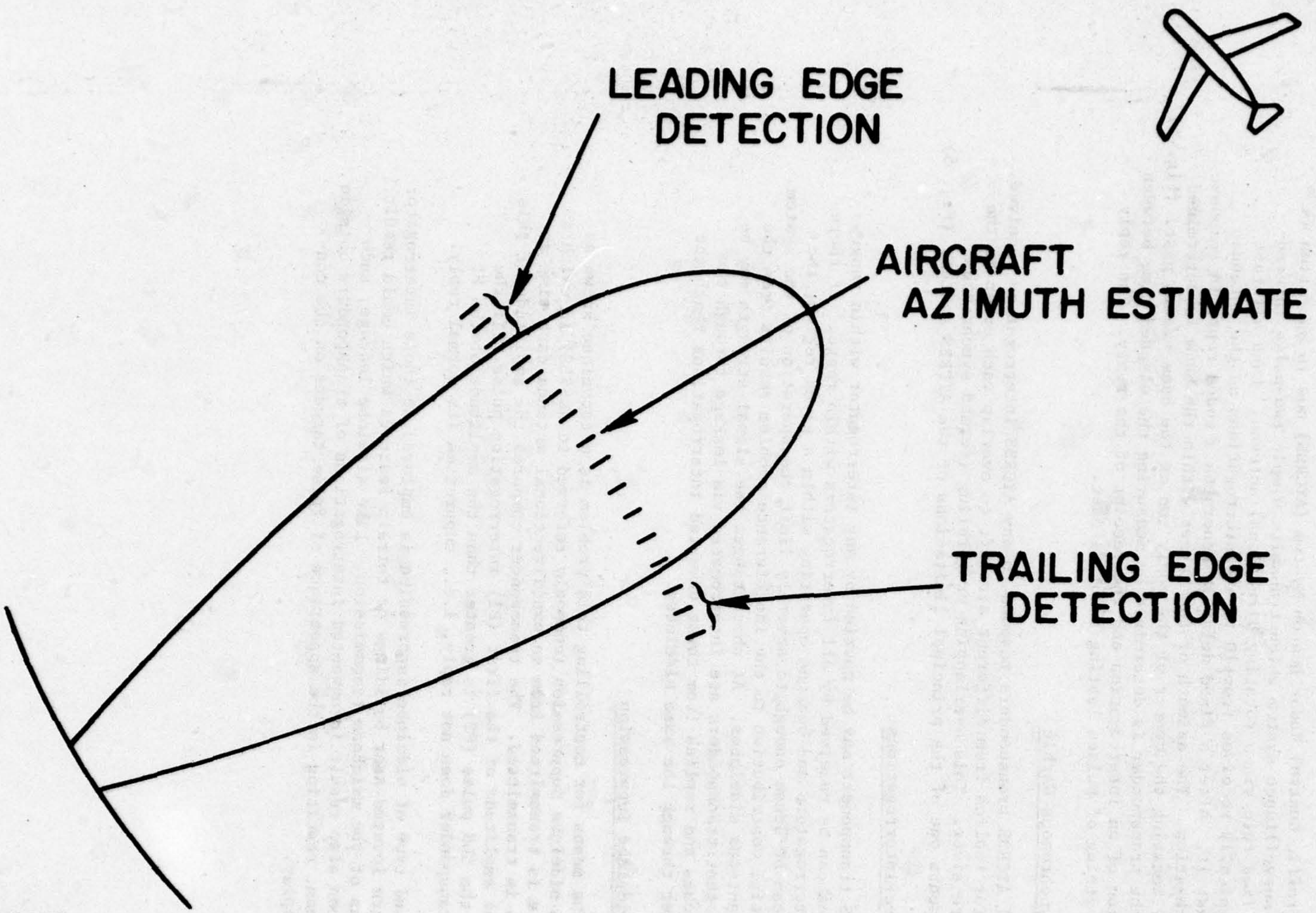

Figure 4

Azimuth Estimation in the current ATC System is based upon a "sliding window detector" that locates the center of the reply run length. This requires a high pulse repetition frequency to achieve the required number of replies in the beam dwell.

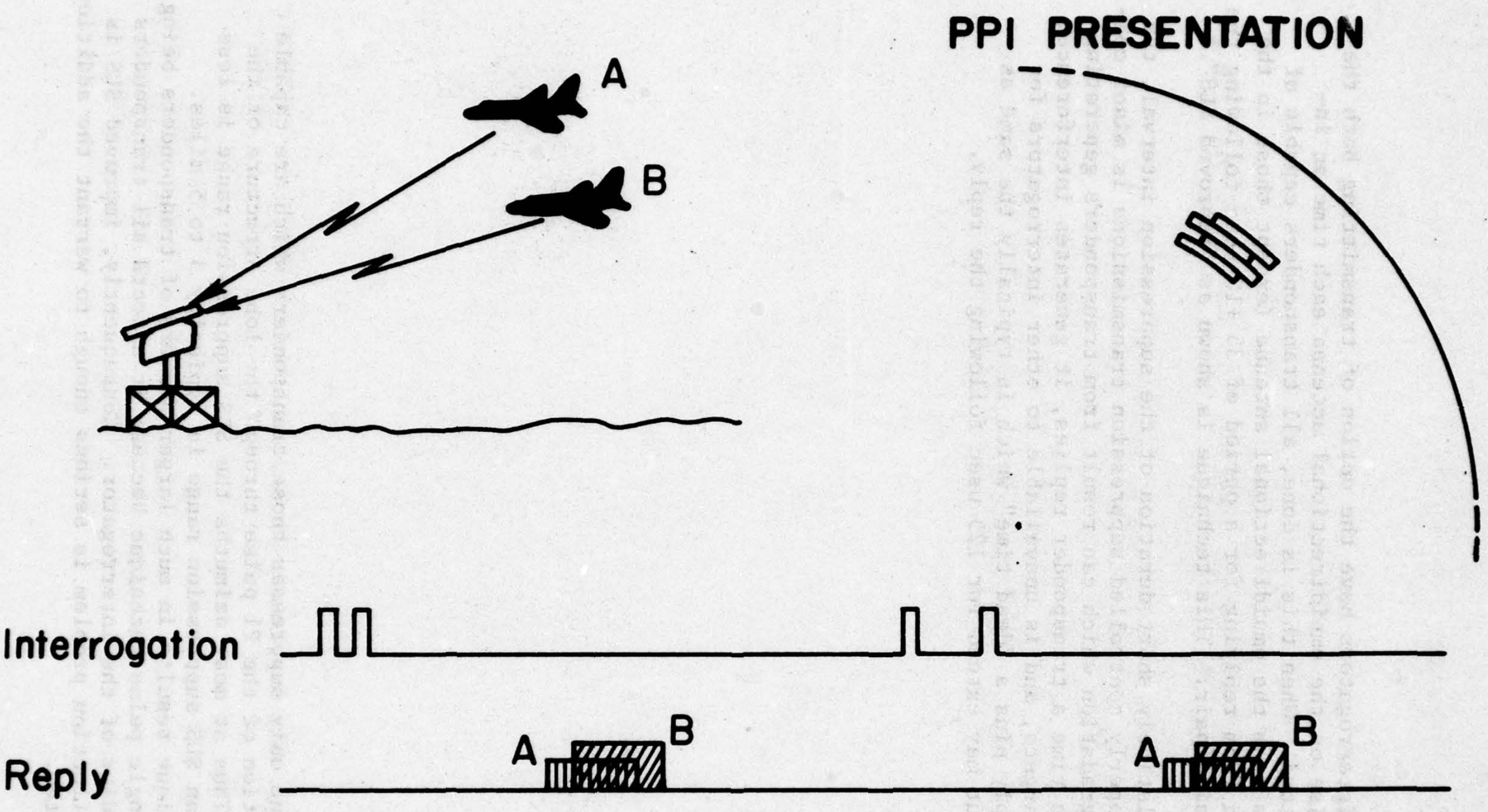

Figure 5

ATCRBS Synchronous Garble. Replies from closely spaced aircraft will overlap at the ATCRBS receiver. This condition will occur when the slant range difference is less than 1.7 nmi.

To prevent this, interrogators have the option of transmitting both the P1 pulse and the P2 pulse on the omnidirectional antenna each time an interrogation is transmitted. When this is done, all transponders capable of detecting the radiation from the omnidirectional antenna (except those in the mainbeam) are prevented from replying for a period of 35 ±10 μsec following the receipt of the suppression pair. This technique is shown as "improved SLS".*

Because of the relatively short duration of the suppression interval, the system penalty from properly controlled suppression transmissions is minor compared to the system degradation which can result from transponders generating unwanted replies. Each time a transponder replies, it generates interference, contributes to false targets, and is unavailable to other interrogators for the duration of the reply plus a "dead time" which is typically the same as the suppression time but may extend for 125 μsec following the reply.

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*The basic SLS technique only suppresses those transponders which are capable of detecting the radiation of the P1 pulse through the lobe structure of the directional antenna. Thus at most azimuths the SLS suppression range is less than a mile and the mean SLS suppression range is typically 3 to 5 miles. The improved SLS technique results in much larger numbers of transponders being suppressed than the single pulse technique because it affects all transponders within a 20-50 mile radius of the interrogator. Consequently, improved SLS is used only where the reflection problem is serious enough to warrant the additional suppressions it generates.

OPERATION OF THE DABS SURVEILLANCE AND COMMUNICATION SYSTEM

The Discrete Address Beacon System (DABS) is a cooperative surveillance and communication system for air traffic control. DABS is under development as an evolutionary replacement for the existing Air Traffic Control Radar Beacon System to enhance the surveillance and to provide a digital data communication capability. Each aircraft is assigned a unique code which permits data link messages to or from a particular aircraft to be accommodated integrally with surveillance interrogations and replies.

As DABS is initially implemented, it will operate in an ATC system based on ATCRBS. Therefore, the DABS sensors have been designed to provide improved surveillance for both ATCRBS and DABS-equipped aircraft.

ATCRBS Mode of DABS

Although the ATCRBS waveforms transmitted by DABS equipment are identical to those transmitted by ATCRBS, DABS has been designed to surpass current performance levels while reducing the interrogation rate. The employment of a monopulse antenna and receiver provides azimuth data for each pulse in the reply and therefore permits more accurate azimuth estimation with fewer interrogations and allows decoding in the presence of up to ~4 overlaps when interference is present. (Fig. 6)

As noted above, a current problem in ATCRBS is the appearance of false targets due to reflections. The DABS sensor can identify and flag many of these false targets by examining the target reply parameters and making use of stored geometric characteristics of the principal reflecting surfaces. It is thus likely that relatively few DABS sensors will require improved SLS.

DABS Surveillance

The use of monopulse direction finding on the reply permits the sensor to provide surveillance of DABS-equipped aircraft using a single interrogation per rotation of the interrogator antenna. If a reply to the interrogation is not received, or is received but cannot be successfully decoded, the interrogator has the capability of reinterrogating the aircraft several times while it is in the antenna beam. The DABS sensor schedules its transmissions so that responses to its discrete interrogations are never received simultaneously, i.e., they do not "synchronously garble" each other. (Fig. 7)

To protect against high interrogation rates in fade situations, there are built-in limits to the number of times that a DABS sensor can reinterrogate a target which is no longer detectable; and there are limits on the number of interrogations which can be transmitted in a beam dwell. In addition, in order to keep interference at a minimum level, DABS has been designed to achieve a round reliability well above 90% for all targets with adequate fade margin even in the highest predicted aircraft traffic densities. As a result, the average reinterrogation rate will remain less than 0.1 at all times. Thus, the reinterrogation capability of the DABS sensor can never result in uncontrolled increases in the DABS interrogation rate.

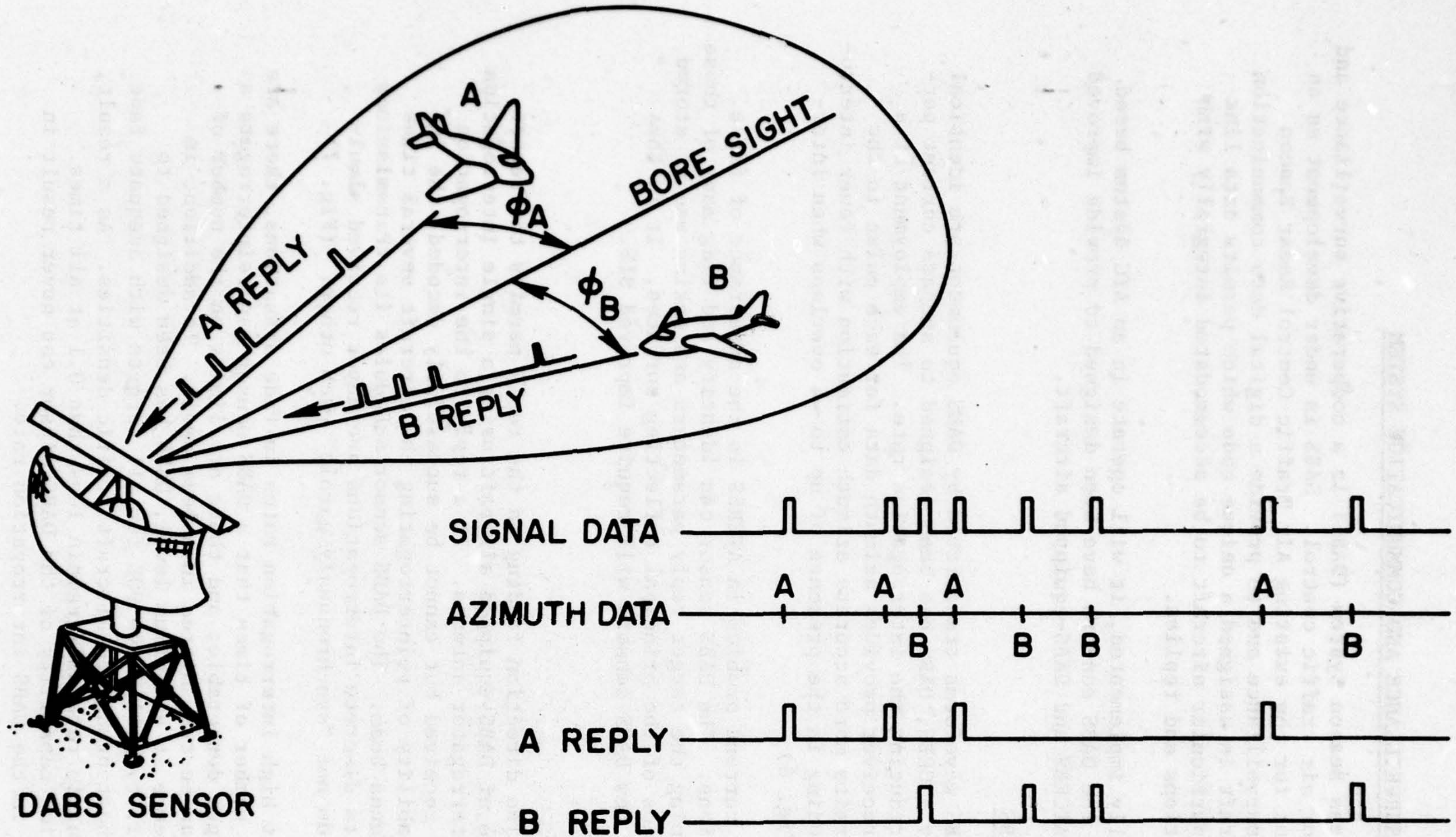

Figure 6

The ATCRBS Mode of DABS. Pulse-by-pulse monopulse azimuth estimation provides reduced interrogation rate, improved azimuth accuracy and reply degarbling based upon azimuth data.

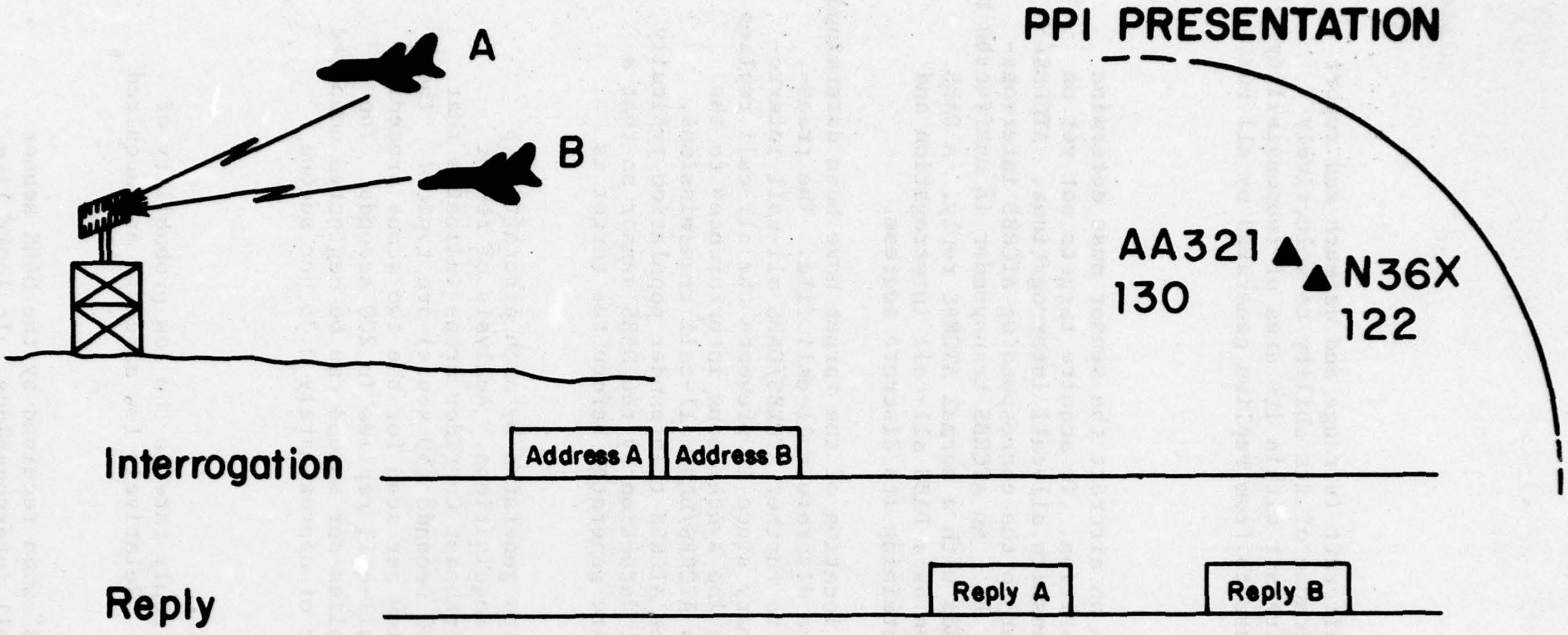

Figure 7

DABS Surveillance. Through the use of unique address and scheduled interrogations DABS can reliably resolve closely spaced aircraft. Monopulse direction finding provides improved azimuth accuracy. Normally, only a single reply per scan is needed for surveillance. Aircraft can be adaptively reinterrogated to achieve a high link reliability in interference.

DABS Coverage Management

Like ATCRBS, DABS will locate an aircraft in range and azimuth and report its altitude and identity. However, because of its ability to selectively interrogate only those DABS-equipped aircraft within its area of responsibility, DABS can avoid the interference that results from replies generated by all the transponders within the ATCRBS beam.

DABS Acquisition

In order to discretely interrogate an aircraft the sensor must determine the target's address and approximate position. To acquire targets not yet on any sensor's roll-call, each sensor transmits all-call interrogations. ATCRBS/DABS all-call interrogations are similar to the corresponding ATCRBS interrogations with an additional pulse P4 (Fig. 8). An ATCRBS transponder is unaffected by the presence of the P4 pulse and responds with a normal ATCRBS reply. A DABS transponder recognizes the interrogation as a DABS all-call interrogation and responds with a DABS all-call reply containing its discrete address.

When the discrete address and the location of the target have been determined, the DABS sensor adds the aircraft to the discrete roll-call file. The transponder is then prevented from replying to further ATCRBS/DABS all-call interrogations. This "DABS lockout" is necessary since it prevents the all-call replies generated by DABS transponders from causing synchronous interference* to the ATCRBS transponders which also reply to ATCRBS/DABS all-call transmissions. The DABS transponder is removed from the ATCRBS transponder population typically within 4 to 8 seconds after its initial detection by the DABS sensor so that a negligible number of all-call replies are generated before the target is acquired.

The total number of all-call replies generated by each aircraft is a function of the length of time between acquisitions. Analysis of recent ATCRBS data from the Los Angeles and Northeast Corridor areas indicates that average track durations in excess of 200 seconds (50 scans) are typical. The aircraft responds with 4 all-call replies per scan for the two scans preceding acquisition, yielding an average of 8 all-call replies in 200 seconds. The resulting reply rate of 8/200 = .04 replies per second can be neglected compared to the average DABS discrete reply rate of approximately 0.25 per second required for surveillance.

Synchronous Garble on Acquisition

A consequence of the low all-call reply rate is the low probability of synchronous garble of all-call replies. Relatively few aircraft are acquired

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*This interference is only "synchronous" when received by the DABS sensor which originally transmitted the all-call interrogations. It looks like asynchronous interference to all other sensors in the area.

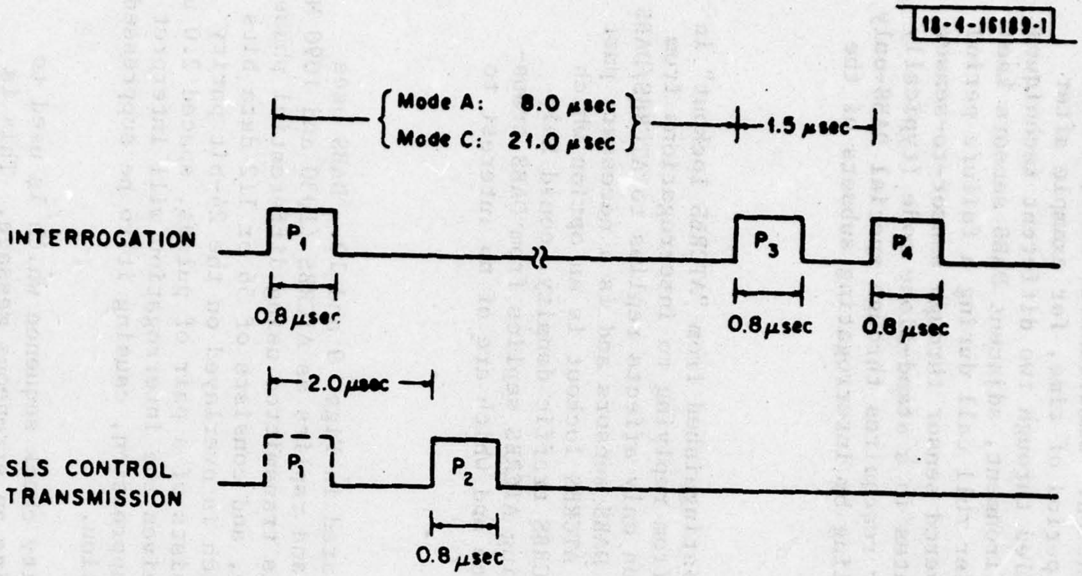

Figure 8

ATCRBS/DABS All-Call Interrogation Format. DABS transponders detect the P4 pulse and respond with an all-call reply, if not already being discretely addressed. ATCRBS transponders are not affected by the P4 pulse and respond normally.

on any particular scan during normal operation. Simultaneous reacquisition of a large number of aircraft in a short period of time, for example after recovering from a sensor failure, is handled through two different techniques in the DABS design. In a multisensor environment, adjacent DABS sensors keep all aircraft in mutual coverage areas under roll call during a failure period and initialize the data base of the recovered sensor through sensor-to-sensor communication links. When a sensor operates in a stand-alone mode (typically in lower density environments) the sensor reacquires through special DABS-only all-call interrogations which avoid garbling by interrogating subsets of the transponder population.

ATCRBS Lockout

The DABS lockout function must be distinguished from "ATCRBS lockout" in which the DABS transponder is prevented from replying to interrogations from ATCRBS sensors. The DABS lockout function only affects replies to ATCRBS/DABS all-call interrogations transmitted from DABS sensors and is a necessary part of the DABS target acquisition process. ATCRBS lockout is an option which if employed in areas of high residual ATCRBS traffic density, could help alleviate ATCRBS interference by preventing ATCRBS replies from DABS transponders which are located in DABS airspace and which are of no interest to other ATCRBS sensors.

Characteristics of the DABS Link

The DABS signal formats are illustrated in Figs. 9 and 10. DABS uses the same frequencies for interrogations and replies as ATCRBS (1030 and 1090 MHz, respectively). The DABS interrogation is transmitted using differential phase shift keying (DPSK) at a 4 Mbit/sec rate, and consists of 56 or 112 data bits including a 24-bit discrete address, which is overlayed on the 24-bit parity field for efficiency. The preamble consists of a pair of pulses, spaced 2.0 μs apart. An ATCRBS transponder which receives the interrogation will interpret this pulse pair as an ATCRBS sidelobe suppression, causing it to be suppressed for the remainder of the DABS interrogation.

The uplink waveform includes a parity check sequence which is used to assure a very low probability of accepting an erroneous message. This is important due to the critical nature of many of the ATC clearance and conflict avoidance messages contemplated for the DABS link. Nevertheless, the throughput of the interrogation link is maintained at a very high level by virtue of the substantial interference rejection properties of the DPSK modulation format. DPSK is totally unaffected by the simultaneous receipt of interference pulses more than 5 or 6 dB below the level of the DABS interrogation.

The reply also comprises 56 or 112 bits including address, and is transmitted at 1 Mbit/sec using binary pulse-position modulation (PPM). The four-pulse preamble is designed to be easily distinguished from ATCRBS replies. It

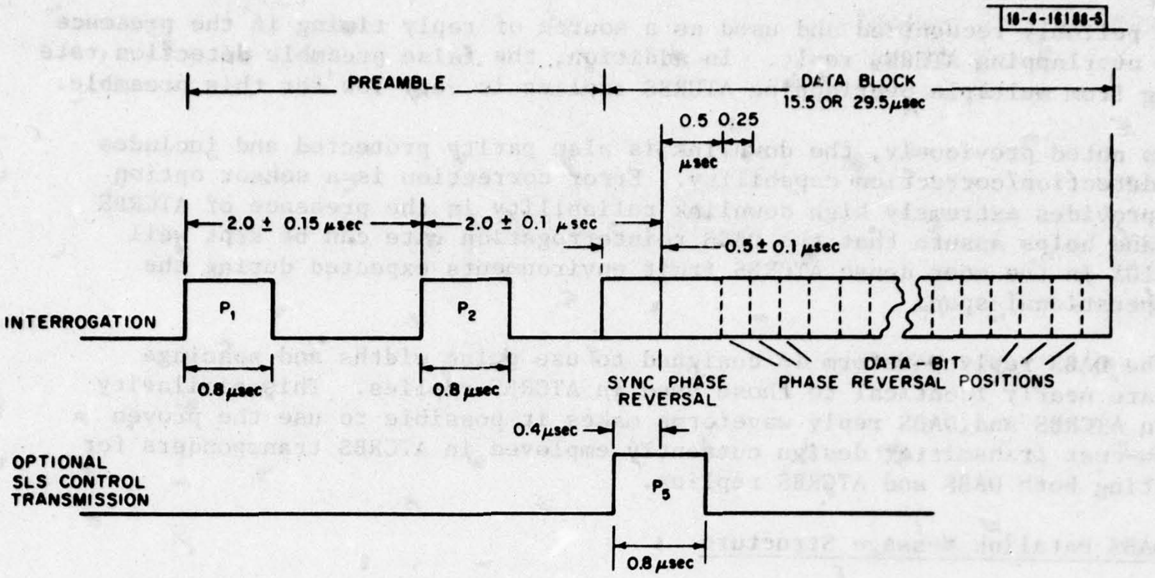

Figure 9

DABS Interrogation Format. Differential Phase Shift Keying (DPSK) enhances decoding reliability in the presence of interference.

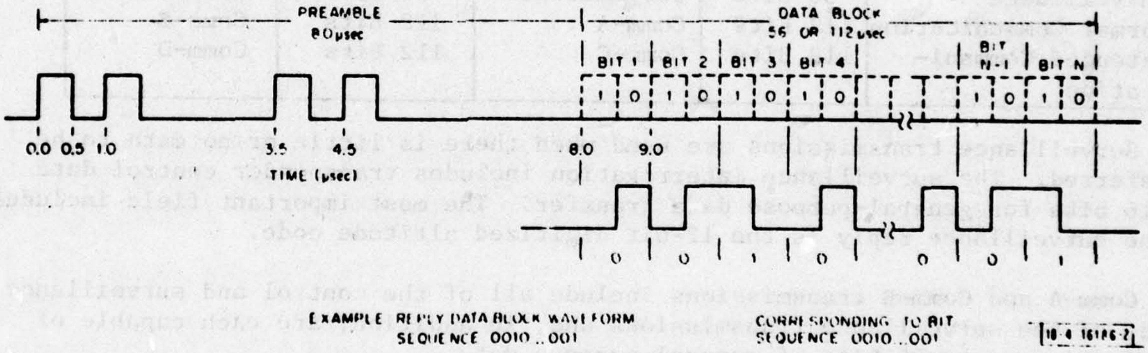

Figure 10

DABS Reply Format. Pulse position modulation enhances downlink decoding while allowing a common transmitter to be used in the transponder for DABS and ATCRBS replies.

can be reliably recognized and used as a source of reply timing in the presence of one overlapping ATCRBS reply. In addition, the false preamble detection rate arising from multiple overlapping ATCRBS replies is very low for this preamble.

As noted previously, the downlink is also parity protected and includes error detection/correction capability. Error correction is a sensor option which provides extremely high downlink reliability in the presence of ATCRBS fruit and helps assure that the DABS reinterrogation rate can be kept well below 10% in the most dense ATCRBS fruit environments expected during the DABS operational span.

The DABS reply waveform is designed to use pulse widths and spacings which are nearly identical to those used in ATCRBS replies. This similarity between ATCRBS and DABS reply waveforms makes it possible to use the proven and low-cost transmitter design currently employed in ATCRBS transponders for generating both DABS and ATCRBS replies.

DABS Datalink Message Structure

The three basic DABS transmission types are identified in the following table:

DABS TRANSMISSION TYPES

Type	Interrogation		Reply	
	Length	Name	Length	Name
Surveillance	56 Bits	Surveillance	56 Bits	Surveillance
Normal Communication	112 Bits	Comm-A	112 Bits	Comm-B
Extended Communication	112 Bits	Comm-C	112 Bits	Comm-D

Surveillance transmissions are used when there is little or no data to be transferred. The surveillance interrogation includes transponder control data and 16 bits for general-purpose data transfer. The most important field included in the surveillance reply is the 12-bit digitized altitude code.

Comm-A and Comm-B transmissions include all of the control and surveillance fields of the surveillance transmissions and, in addition, are each capable of transferring up to 56 bits of general-purpose data.

Extended length messages consist of strings of Comm-C's or Comm-D's transmitted in close succession without need for intervening replies or interrogations. All surveillance data is omitted from these formats, thereby providing a total of 80 general-purpose data bits. Extended length messages provide an efficient means for transferring larger quantities of data. The improved efficiency results both from the greater number of data bits and from the ability to transmit in one direction without need for corresponding transmissions in the opposite direction.

Formats for the DABS datalink message types are shown in Fig. 11. Surveillance transmissions employ the normal format without the 56-bit standard message field.

An uplink ELM is transmitted as a sequence of up to sixteen Comm-C interrogations spaced at minimum intervals of 50 μsec. This minimum spacing was chosen to allow for the reliable resuppression of ATCRBS transponders at the beginning of each Comm-C transmission. A single reply carrying the technical acknowledgment is elicited in response to the sequence of uplink segments.

The downlink ELM operates in a similar fashion. A single Comm-C uplink interrogation elicits a string of up to sixteen Comm-D replies spaced at 136 μsec intervals.

DABS Link Reliability

DABS link reliability is maintained at a high level by means of a number of techniques some of which have been previously described. As stated earlier, it is extremely important for the DABS link to operate reliably so that the DABS surveillance and data delivery functions may be accomplished using a minimum number of transmissions, thereby generating minimum interference to nearby ATCRBS equipment.

Uplink reliability in the presence of interference is enhanced by the use of differential phase shift keyed (DPSK) modulation. In addition, the DABS transponder is designed to continue to decode DABS discrete interrogations following the receipt of an ATCRBS suppression transmission. Consequently, the DABS decoding function is unaffected by ATCRBS SLS pulse pairs. This eliminaties one of the factors contributing to the reduction of ATCRBS transponder reply probability. An additional factor which enhances the DABS transponder reply probability is the fact that a DABS transponder does not reply to discrete interrogations which contain other than its own address. The DABS interrogation is received within a relatively short interval (18.5 or 32.5 μsec., depending on the type of interrogation) so that the transponder may quickly determine whether its own address is included and if not, may immediately prepare to decode the next received interrogation.

The downlink is enhanced by the use of pulse position modulation and by the use of monopulse data to help in degarbling DABS reply waveforms from overlapping ATCRBS reply pulses. These, plus the use of error correction on the downlink, allow the transponder data to be recovered with very high probability even when the DABS reply is completely overlapped by an interfering ATCRBS reply.

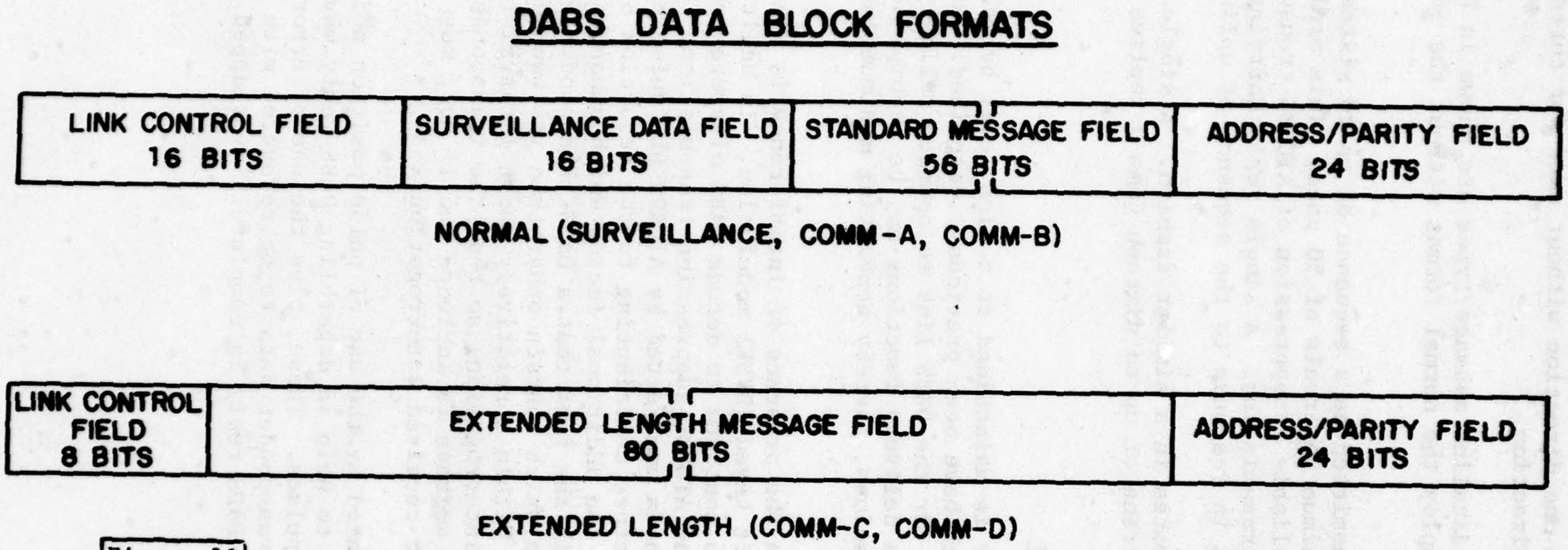

Figure 11

DABS Data Block Formats. The normal DABS link can support surveillance with a 56 bit format or Comm-A (uplink) or Comm-B (downlink) through the addition of a standard 56 bit message field. The extended length format is always 112 bits long and includes an 80 bit message field. ELM uplink or ELM downlink messages can be composed of strings of up to 16 Comm-C or COMM-D formats respectively.

DABS Datalink Loading

A recently completed study of DABS datalink loading* has analyzed the maximum delivery rates required by an exhausive list of potential ATC services, including various levels of Cockpit Display of Traffic Information (CDTI). These services are summarized as follows:

LISTING OF SERVICES CONSIDERED FOR DABS DATALINK

Service	To Whom	Max. Message Rate per Aircraft per Scan
Surveillance	All aircraft	---
ATC (Tactical)	IFR + Cont. VFR	0.03 Comm-A
ATARS + CDTI		
High Option	Well-equipped IFR	12 Comm-C + 2 Comm-D
Mid Option	Well-equipped VFR	3 Comm-A
Low Option	Minimum-equipped VFR	0.03 Comm-A
Weather Messages	IFR + Cont. VFR	0.03 Comm-A
ATIS, etc.	IFR	0.10 Comm-A
	Air carrier aircraft	0.42 Comm-A
Navigation Data	All aircraft	0.5 Comm-A
Aircraft Data	All aircraft	0.5 Comm-B

For the purposes of calculating average interrogation and reply rates, the DABS transaction requirements derived from this study can be divided into two basic categories: extended datalink service and standard datalink service, where standard service includes both mid- and low-option CDTI and requires no extended length messages. The maximum transaction rates for these two services are obtained from the above and are summarized in the following table:

MAXIMUM TRANSACTION RATES FOR DABS DATALINK SERVICE

Transaction Type	Transactions per aircraft per 4-sec Scan	
	Standard	Extended
Datalink Interrogation (Comm-A and Comm-C)	2.66	13.08
Datalink Replies (Comm-B and Comm-D)	0.5	2.5

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* A. Mundra, "DABS Datalink Capacity and Demand", MTR-7943, MITRE Corp., METREK Div., to be published.

The transaction rates for standard service are obtained by assuming equal numbers of aircraft equipped for mid- and low-option CDTI service. These rates represent upper bounds on the datalink demand on the DABS system for both extended and standard services since they are based on the assumption that all datalink equipped aircraft in the environment will be augmented with the I/O devices required to make use of all of the services offered. This assumption is likely to be satisfied only for the 4% or so of the fleet which is made up of air carrier aircraft. However, in the following analyses it will be assumed that all air carrier and high performance general aviation aircraft employ extended services. These high option groups make up approximately 11% of the aircraft in the Standard 1982 L.A. Basin model* and 22% of the aircraft in the standard 1995 L.A. Basin model.**

The maximum high-option CDTI data demand (12 Comm-C and 2 Comm-D transmissions) is based on a study performed by Boeing*** and assumes the ability to display up to 19 targets in the cockpit. It also provides more than adequate range and resolution capability for supporting current concepts of distributed ATC. The coding of the high-option CDTI messages is summarized in the following table:

HIGH OPTION CDTI BIT REQUIREMENTS

Parameter	Bits	Unit	Range
x-position (relative to own)	10	0.05 nmi	-25.6 to 25.6 nmi
y-position (relative to own)	10	0.05 nmi	-25.6 to 25.6 nmi
z-position (relative to own)	7	100 ft.	-6,400 to 6,400 ft.
ground speed	6	10 kt.	0 to 560 kt.
track ID	5	---	1 to 32
vertical maneuver status	2	---	---

Since a total of 40 bits are required per target, two targets can be handled per 80-bit Comm-C transmission. The DABS extended length message

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[*] Cohen, S. and Macinnis, F., "Statistical Summary for Los Angeles Basin Standard Traffic Model", FAA-RD-73-87, April 1973.

[**] S.R. Jones, et al "Study of Alternative Beacon-based Surveillance and Data Link Systems", FAA-EM-74-7, II (MTR-6517), April 1974, p 2-2. (includes air carrier and all general aviation aircraft above 10,000 ft.).

[***] "Cockpit Displayed Traffic Information Study", FAA-EM-77-18, September 1977, p. 38; this report postulates a range of displayed targets for a busy terminal area from a "nominal" of 6 to a peak of 20.

protocol requires 1 Comm-C and 2 Comm-D transmissions to handle initialization and finalization of the data transfer. One Comm-C is used to send own position data. Additional CDTI overhead requires 0.5 Comm-C per scan. Thus 12 Comm-C's allow a total of 19 targets to be displayed per scan. The number of Comm-C interrogations decreases if fewer targets are displayed.

The standard option data demand is obtained by averaging the mid- and low-option CDTI demands. The lowest option is equivalent to the PWI service used in early IPC (now ATARS) flight tests in which 1 Comm-A per scan suffices to provide bearing updates on up to 5 intruding targets. The other (mid-option) scheme employs a maximum of 3 Comm-A's per scan to transfer target data on 6 intruders with lower resolution than in the high option. This is likely to be the most commonly used CDTI option. Its bit requirements are summarized in the following table:

MID OPTION CDTI BIT REQUIREMENTS

Parameter	Bits	Unit	Range
Relative Range	7	0.1 nmi	0 to 12.8 nmi
Bearing from North	8	2 degrees	0 to 360 degrees
Altitude of Threat	7	100 ft.	±6400 ft.
Flash Bit	1	-	-
IFR/VFR Status	1	-	-
TOTAL	24	-	-

A transponder requiring no datalink service receives a single surveillance interrogation each scan from each sensor providing surveillance coverage in its airspace. Dual sensor coverage will eventually be available in most high-density airspace so that a transponder will normally handle two surveillance transactions (interrogation/reply pairs) per scan. However, datalink service to a given target will generally be provided by a single sensor, the so-called "primary" sensor for that target. Since DABS surveillance is accomplished as part of each Comm-A interrogation and Comm-B reply, there is no requirement for separate surveillance interrogations from the sensor providing datalink service.

Datalink Capacity

The specified peak capacity of a single DABS sensor is:

- A peak of 50 aircraft uniformly distributed in one sector (1/32 of a scan or 11.25°) for up to 8 consecutive sectors with each aircraft interrogated up to three times for surveillance or Comm-A or Comm-B delivery. In addition, three aircraft in each sector must be able to send, and three receive, ELM messages of up to 16 segments.

- A short term peak of 12 aircraft per degree for up to 4 degrees with each aircraft interrogated up to two times for surveillance and communications.

In addition, a growth capability is specified in order to handle a peak of 90 aircraft per sector for 8 sectors with the three surveillance and Comm-A or -B interrogations as above but with ELM capacity expanded to the equivalent of five complete uplink and downlink ELMs per sector. The short term peak remains the same as above.

The 80 message segments contained in 5 complete ELM messages may be distributed among a larger number of ELM's with fewer segments since the additional Comm-C and Comm-D messages required for the ELM protocol can be interspersed with standard surveillance and communication transactions. Since the high-option CDTI service defined above requires a maximum of 12 uplink Comm-C transmissions per target, the DABS sensor design can support a total of 6 full extended CDTI transactions in one 11.25 degree sector. The sensor has a resulting overall capability of 192 full extended CDTI transactions per scan. However, the average high-option CDTI transaction would include fewer than 12 Comm-C transmissions so that even more than 192 aircraft could be serviced with extended CDTI if required.

The inherent capacity of the DABS link is approximately 30% greater than the specified capacity presented herein. Higher data link delivery requirements in a given geographic area will generally be handled by the deployment of additional DABS sensors.

SUPPRESSION OF ATCRBS TRANSPONDERS BY DABS INTERROGATIONS

Rationale for the Intentional Suppression of ATCRBS Transponders

In the design of a new beacon system operating on the same frequencies as the ATCRBS, the goals are to permit both systems to operate with a minimum of interaction. In particular, although the waveforms must be compatible in the sense that they can be transmitted and received with common hardware, they should also be incompatible in the sense that they can not be erroneously interpreted as signals associated with the other system. In selecting an interrogation waveform for the DABS system, it was found* from tests with a large cross section of ATCRBS transponders that any form of data modulation on the 1030 MHz uplink frequency, if sustained long enough, will trigger unwanted replies from a significant number of ATCRBS transponders.

The triggering of unwanted ATCRBS replies by DABS interrogations must be avoided since these replies would add to the existing ATCRBS fruit environment. In addition, each time an ATCRBS transponder transmits a reply, the transponder is unavailable to respond to other ATCRBS interrogations. ATCRBS replies triggered by DABS interrogations can also synchronously garble the desired DABS reply.

To avoid triggering of unwanted ATCRBS replies, the DABS uplink waveform was designed to intentionally suppress all ATCRBS transponders in the beam for the nominal 35 μsec ATCRBS suppression interval. The net result is superior to generating an ATCRBS reply, for such a reply may lead to a longer period of transponder unavailability (reply plus dead time) in addition to generating downlink interference. In spite of these intentional suppressions, it will be shown below that a DABS sensor can replace an existing ATCRBS sensor and provide both improved ATCRBS surveillance as well as extremely reliable DABS surveillance and datalink service for hundreds of DABS-equipped aircraft while actually suppressing ATCRBS transponders less than the original ATCRBS interrogator.

Suppression Rates From ATCRBS Interrogators

An ATCRBS interrogator equipped with sidelobe suppression capability generates an omnidirectional suppression transmission with each interrogation. These SLS transmissions are transmitted at relatively high power levels and, when improved SLS is used, are effective in suppressing all ATCRBS transponders within a 20 to 50 nmi radius of the ATCRBS interrogator. They are transmitted at rates ranging from about 300 to 450 per second. (Fig. 12) Thus a victim ATCRBS transponder within suppression range of such an ATCRBS sensor will be regularly suppressed by these transmissions except during the mainbeam passage,

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*J.R. Samson, et al, "Final Report DABS/ATCRBS Transponder Bench Testing Program", FAA-RD-73-160 (ATC-25), 28 November 1973.

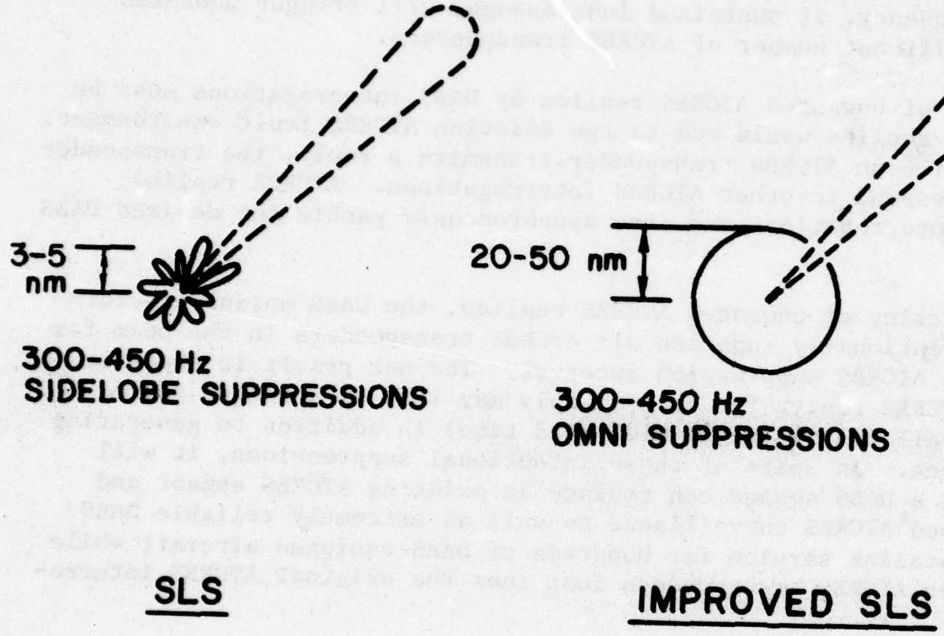

Figure 12

ATCRBS P1-P2 SUPPRESSIONS. SLS consists of P1 sidelobe leakage and P2 omni transmissions. Improved SLS consists of P1 and P2 omni directional transmissions.

when it will reply to each interrogation. If the victim transponder's suppression time is 45 μsec (the maximum value allowed by the ATCRBS National Standard), and if the interrogation rate is 400/sec, the percentage of time that it will be unable to respond to interrogations from other ATCRBS sensors is approximately 400/sec × 45 μsec = 1.8%.

Factors Affecting DABS Suppression Rates

A DABS interrogator transmits preamble suppression pairs in the mainbeam each time it transmits a discrete DABS interrogation. In addition, if it uses improved sidelobe suppression, it transmits an intentional suppression omnidirectionally each time it transmits an ATCRBS/DABS all-call interrogation from the mainbeam. We now examine the factors which influence the mainbeam suppression rates.

Since a DABS interrogator suppresses ATCRBS transponders each time it transmits a DABS interrogation, the suppression rate is proportional to the interrogation rate and varies with the number of transponders requiring surveillance and datalink service from the interrogator. In addition, the suppression rate depends on the average reinterrogation rate required to complete all transactions each scan. Since DABS discrete interrogations can be detected only in the mainbeam and sidelobes of the DABS directional antenna, antenna considerations are also important in determining rates of received suppressions. Because the interrogation load in a region of airspace can be distributed among multiple sensors, the deployment and netting of nearby DABS sensors also has a strong bearing on the suppression rates received at a particular location in space. The following sections treat each of these effects in more detail.

Target Density and Sensor Deployment

The DABS interrogation rate from a DABS sensor depends on the number of DABS equipped aircraft receiving surveillance and datalink service from that interrogator. Deployment of DABS sensors will be matched to the traffic environment so that individual sensors will not normally handle more than about 400 aircraft simultaneously.* DABS sensors will generally be located at existing FAA ATCRBS sites, so that multiple surveillance coverage will continue to be provided in most high density airspace. This is desirable since it allows sensors to assume responsibility for adjacent sensor traffic in the case of sensor outages. Thus each DABS sensor will be required to handle peak target loads of up to about 700 aircraft. When a sensor assumes responsibility for another sensors' targets, it can usually continue to provide full datalink service for the complete transponder population except in regions of extreme bunching where it may be necessary to omit some of the lower priority datalink services.

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*Current ATCRBS sensors typically handle fewer than 200 aircraft.

Reinterrogation Rates

A DABS sensor is capable of performing DABS surveillance with as few as one DABS interrogation per scan. If no reply is received to the first interrogation, additional interrogations can be scheduled during the beam dwell until the target reply is successfully received. Field tests have been performed with the DABS Transportable Measurement Facility to determine the average reinterrogation rate required for DABS surveillance. It has been found that the DABS probability of success per reply is typically greater than 90%. Thus the average reinterrogation rate per DABS target is less than 10% for all interrogation types.

Effective Sidelobe Range for Detection of Mainbeam Transmissions

Since DABS discrete interrogations are transmitted on the mainbeam, the only suppressions resulting from these interrogations which have effect outside of the mainbeam are those detected by aircraft in the sidelobes of the directional antenna. The effects of these sidelobe interrogations must be distinguished from the effects of intentional ATCRBS suppression transmissions radiated on a separate omnidirectional antenna. The effective sidelobe level of an interrogator antenna is the gain of a hypothetical omnidirectional antenna which would result in the same average number of aircraft being suppressed (i.e., aircraft with received suppression power above some stated threshold). This effective sidelobe level has been determined to be -12.5 dBI* for a typical beacon interrogator antenna, assuming a uniform-in-area distribution of aircraft (see Appendix A). If the mainbeam transmits sufficient power to interrogate aircraft at a range of 50 nmi with a fade margin of 10 dB, and if the gain of the mainbeam is 21 dB, with an effective sidelobe level of -12.5 dBI, the effective range for detection of mainbeam transmissions in the sidelobes (with 0 dB fade margin) is approximately 3.2 nmi. If the mainbeam range is increased to 100 nmi, the effective sidelobe range is about 4.5 nmi. In either case, only 0.05% of the sensor coverage volume falls within the effective sidelobe range, so that outside of the mainbeam very few ATCRBS transponders will detect the DABS suppression preamble.

The Effect of Multiple Sensors on Suppression Rates

Since the suppression of ATCRBS transponders by discrete DABS interrogations occurs only in the mainbeam and in the airspace in very close proximity to the interrogator site, it is possible to effect a reduction of the suppression rates in particular regions of airspace by judiciously siting and sharing the interrogation load among multiple sensors. If the cooperating sensors are separated by sufficient distances such that their sidelobes do not illuminate common volumes of space, the DABS discrete suppression rate can be lower everywhere than if a single sensor handles the same interrogation load.

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*dB relative to isotropic ... this may be compared to the +6 dBI gain of the omnidirectional antennas used for intentional ATCRBS suppressions.

The use of redundant sensors is also helpful in situations in which dense target bunching is experienced. By dividing the interrogation load in such a region, the interrogations are spread out in time, thereby reducing the peak mainbeam suppression rates in the bunching region.

Suppression Rates Due to ATCRBS/DABS All-Call Interrogations

A DABS Interrogator interrogates ATCRBS transponders with the ATCRBS/DABS all-call. The use of monopulse angle estimation allows reliable surveillance of ATCRBS targets with as few as three or four of these interrogations per beam dwell. To assure 4 replies per dwell, the ATCRBS interrogation rate for a terminal DABS sensor with a 2.4° antenna beamwidth must be 600 per 4-second scan or 150 per second. For a DABS enroute sensor at a joint FAA-USAF site, scanning with a 12-second period, the interrogation rate will be typically 900 per scan or 75 per second.

If the DABS interrogator is equipped with improved SLS, each all-call interrogation will be accompanied by the transmission of an SLS suppression pair on an omnidirectional antenna. The effective radiated power from the omni is typically set about 20 dB below the effective radiated power of the mainbeam, resulting in approximately a 10 to 1 ratio of mainbeam to omnidirectional ranges. (Fig. 13)

If the DABS interrogator transmits standard sidelobe suppressions, the suppressions will only suppress those transponders which are sufficiently close to the sensor site to detect P1 transmissions radiated through the sidelobes of the directional antenna. Thus, although the radiated P2 pulses may be detected at relatively long ranges, the actual range for suppression due to standard SLS transmissions is identical to the range at which DABS discrete interrogations are detected in the sidelobes. This is the effective sidelobe range, which was previously shown to be about 1/50 the nominal mainbeam range.

Suppression Rates Due to Discrete DABS Interrogations

Within the effective sidelobe range of a DABS interrogator, a transponder will detect every discrete interrogation transmitted by the sensor. For a terminal sensor, the suppression rate in this sidelobe region is given by the following expression:

$$N_{ss} = \frac{N_t}{T} (1 + R) (1 + D),$$

where N_t is the number of DABS transponders served by the sensor

R is the average reinterrogation rate in the environment

T is the sensor scan period

and D is the average number of datalink interrogations required per target.

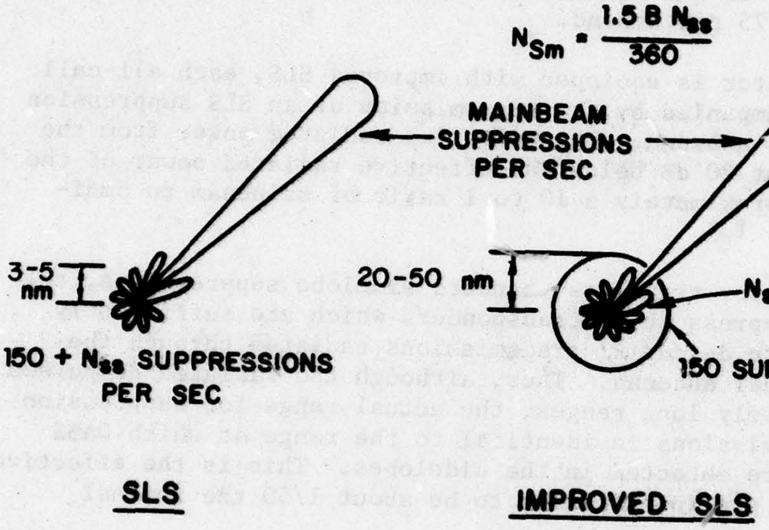

Figure 13

DABS P1-P2 SUPPRESSIONS. With SLS, P1 sidelobe leakage from all-calls combines with the omnidirectional P2 to suppress nearby aircraft at 150 + N_{SS} suppressions per second. N_{SS} is the sidelobe suppression rate due to discrete DABS interrogations.

With improved SLS the dominant suppressions are due to P1-P2 omnidirectional suppresions accompanying all-call interrogations. In both cases, mainbeam suppressions occur at a rate N_{sm}. See text for further details.

For a target ouside of the effective sidelobe range, discrete interrogations are detected only as the mainbeam sweeps by. This occurs roughly over a fraction of each scan given by 1.5B/360, where B is the antenna beamwidth in degrees. Thus the discrete suppression rate outside the sidelobes is given by:

$$N_{sm} = \frac{1.5B}{360} N_{ss}$$

These expressions will be used in the next section to show the change in suppression rates which occurs when ATCRBS interrogators are replaced by DABS interrogators in a region of multiple sensor coverage.

A COMPARISON OF ATCRBS AND DABS SUPPRESSION RATES IN A MULTIPLE INTERROGATOR ENVIRONMENT

Figure 14 is a plot of the suppression rates experienced by an ATCRBS transponder in the sidelobes of three terminal interrogators*. It illustrates the effect of replacing ATCRBS interrogators with DABS interrogators as the DABS transponder population grows. It is assumed that the initial deployment includes three ATCRBS interrogators with a mutual coverage overlap region. In this region a "victim" ATCRBS transponder experiences improved SLS suppressions from all three interrogators.

Initially, the suppression rate remains constant as the transponder population increases, since the ATCRBS interrogation rate is fixed. If no DABS sensors were deployed, the suppression rate would remain constant at 1200 per second for all time. When an ATCRBS sensor is replaced by a DABS sensor, the suppression rate decreases because the ATCRBS interrogation rate from that site drops from 400/sec to 150/sec. The suppression rate then gradually builds up due to growth in DABS transponder and datalink usage.

The fraction of the DABS transponders equipped for datalink service is assumed to remain constant at 50% throughout the period represented by this figure. The fraction of the total DABS population equipped for extended service is 11%, consistent with the 1982 L.A. Basin model aircraft distribution of air carrier and twin-engine general aviation aircraft. The remaining 39% of the DABS aircraft which are datalink equipped receive the standard option service. Since the datalink service provided by the DABS sensors is distributed over the total DABS population, the extended service is assumed to consist of 10 Comm-C's on the average, rather than an absolute peak of 13 Comm-C's per scan. This includes 9 Comm-C's for CDTI and is sufficient to display an average of 12 targets in the cockpit of each aircraft equipped for high-option CDTI service. This is twice the nominal target load identified in the Boeing CDTI study. For the purposes of this illustration, the standard datalink service is rounded to 2.5 interrogations per scan, rather than 2.66 as indicated in the section on DABS datalink loading.

The transponder population is assumed to begin growing when the first DABS sensor is installed in the region. Subsequent DABS sensors are installed each time the suppression rate in the vicinity of one of the DABS sensors climbs back to the original ATCRBS rate of 1200/sec. It is assumed that the transponders in the area are serviced only by the DABS sensors identified in this figure (i.e., there are no interrogations from other DABS sensors included in the suppression counts). In practice, if the transponder population continued to grow as shown here, additional DABS interrogators would be deployed outside of this mutual suppression area to help service the expanding load.

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*See Appendix B for the detailed assumptions used in plotting Figure 14.

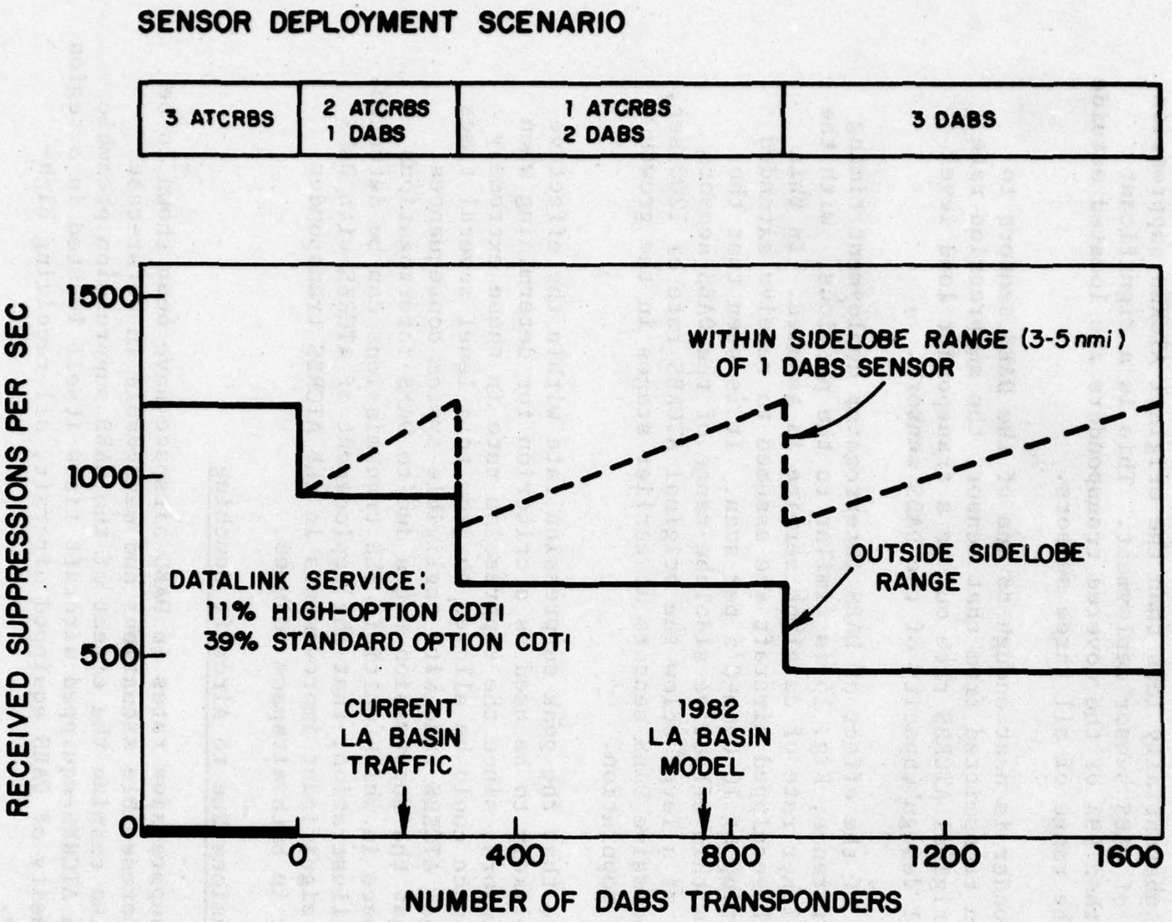

Figure 14

Comparison of Suppression Rates for ATCRBS and DABS Sensors. The suppression rate drops each time an ATCRBS sensor is replaced. By timing the replacement of ATCRBS sensors, the peak DABS suppression rate can be maintained below the original ATCRBS rate through all stages of DABS deployment. Furthermore less than 1% of the airspace served by these sensors experiences this peak suppression rate.

It is seen from the solid curve, which represents suppressions detected outside of the sidelobes of the interrogators, that the DABS suppression rate in this region will be substantially less than the original ATCRBS suppression rate through all stages of DABS sensor deployment. This is a significant conclusion, since more than 99% of the covered transponders are located outside of the effective sidelobe range of all three sensors.

Even when a transponder is near enough to one of the DABS sensors to detect every suppression transmitted from that sensor, the suppression rate can be kept below the original ATCRBS rate out to a transponder load level which exceeds the normal design capacity of the DABS sensors.

As an illustration of the effect of DABS interrogator deployment timing on the control of interference, Fig. 15 is similar to the previous, with the exception that a much higher rate of datalink service is assumed. In this scenario, 50% of the DABS-equipped aircraft are assumed to receive extended datalink service consisting of 10 Comm-C's per scan. It is seen that the peak suppression rates within effective sidelobe range of the DABS sensors can still be maintained at a level below the original ATCRBS rate of 1200/sec, merely by deploying successive DABS sensors at earlier stages in the growth of the DABS transponder population.

It should be noted, that the peak suppression rate within the effective sidelobe region is not likely to be used as a criterion for determining when to deploy additional sensors, since the suppression rate in these extremely limited volumes of airspace could be allowed to grow to a level several times greater than the original ATCRBS rate with negligible system consequences. It is more important that the suppression rates due to DABS interrogations remain low in the airspace in which multiple SLS transmissions can be detected. It is clear from this illustration, that the replacement of ATCRBS with DABS sensors will result in significant improvements in the ATCRBS transponder suppression environment in both airspace volumes.

Peaking of Suppressions due to Aircraft Bunching

Although average suppression rates in DABS airspace have been shown to be of no concern in most foreseeable situations and manageable in worst-case situations, one must also examine the effect of the DABS suppression preamble in the case in which an ATCRBS-equipped aircraft finds itself located in a region with a locally high density of DABS equipped aircraft, all receiving high-option datalink service.

The most meaningful way to estimate the effect of aircraft bunching is to determine the peak short term interrogation rate specified for a DABS sensor and determine the effect of the resulting suppressions on an ATCRBS transponder. This will lead to an upper bound on interference due to aircraft bunching.

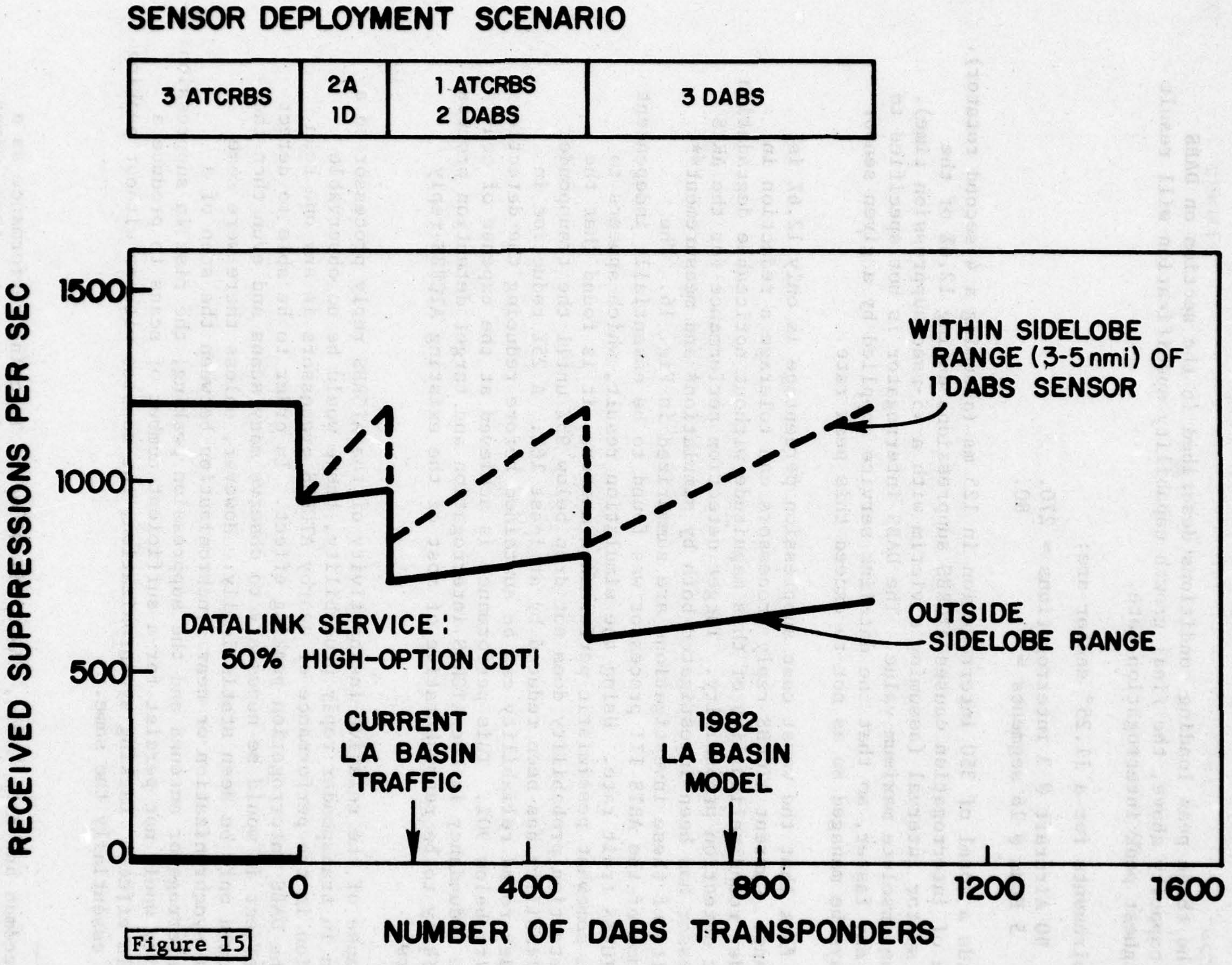

Figure 15

Comparison of Suppression Rates for ATCRBS and DABS Sensors. In this figure a significantly greater data link demand is assumed. The DABS suppression rate is kept below 1200/sec by earlier deployment of DABS sensors.

Of the three peak loading conditions described in the section on DABS datalink capacity above, the final growth capability specification will result in the highest peak interrogation rate.

Requirements for a 11.25° sector are:

90 Aircraft @ 3 interrogations = 270.
5 ELMs @ 16 segments = 80.

This yields a total of 350 interrogation in 125 ms (assuming a 4 second rotator). This rate of interrogation causes ATCRBS suppressions during 12.6% of the 125-msec sector interval (assuming a victim with a 45-μsec suppression time). This is an absolute maximum value. The DABS interrogator is not specified to transmit any faster, so that the datalink service supplied by a given sensor will always be managed so as not to exceed this peak rate.

The fact that the worst case suppression percentage is only 12.6% is significant. Current ATCRBS reply processors can tolerage a reduction in transponder round reliability of this magnitude without noticeable degradation in target detection probability. Target detection performance for the ARTS III processor has been investigated both by simulation* and measurement**. The results of these investigations are summarized in Fig. 16. The performance of the ARTS III processor was found to be essentially independent of the ATCRBS fruit rate. Using the simulation result, which appears to provide a somewhat pessimistic performance measure, it is found that the Mode-C detection probability does not drop below 95% until the transponder round reliability has been reduced by at least 16%. A 25% reduction in transponder round reliability can be sustained before reducing the detection probability below 90%. This performance is achieved at the expense of considerable redundancy in the ATCRBS interrogation and target detection process, and is likely to be representative of most of the existing ATCRBS reply processors.

Because of the relative insensitivity of the ATCRBS reply processor to a reduction in transponder reply probability, there would be no observable degradation in the performance of nearby ATCRBS processors in any one scan due to the DABS interrogation peaking effect. In order to be able to detect such an effect it would be necessary to observe many scans and even then the effect could only be seen statistically. However, unless there were some degree of synchronization or near synchronization between the scan of a victim interrogator antenna and the suppression peaking, the rise in suppression probability would not persist for a sufficient number of scans to produce a measurable effect. Lacking synchronization, the results with or without peaking would be essentially the same.

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*J.E. Freedman and K.M. Levin, "ARTS III Detector Tracking Performance as a Function of Degraded Beacon Environments", MTR-6245, 5 September 1972, MITRE Corp., Washington. (p. 3-23)

**M. Holtz, "Test and Evaluation of the Level 1 Beacon Automated Radar Terminal System (ARTS III)", FAA-RD-73-182, January 1974. (p. 30)

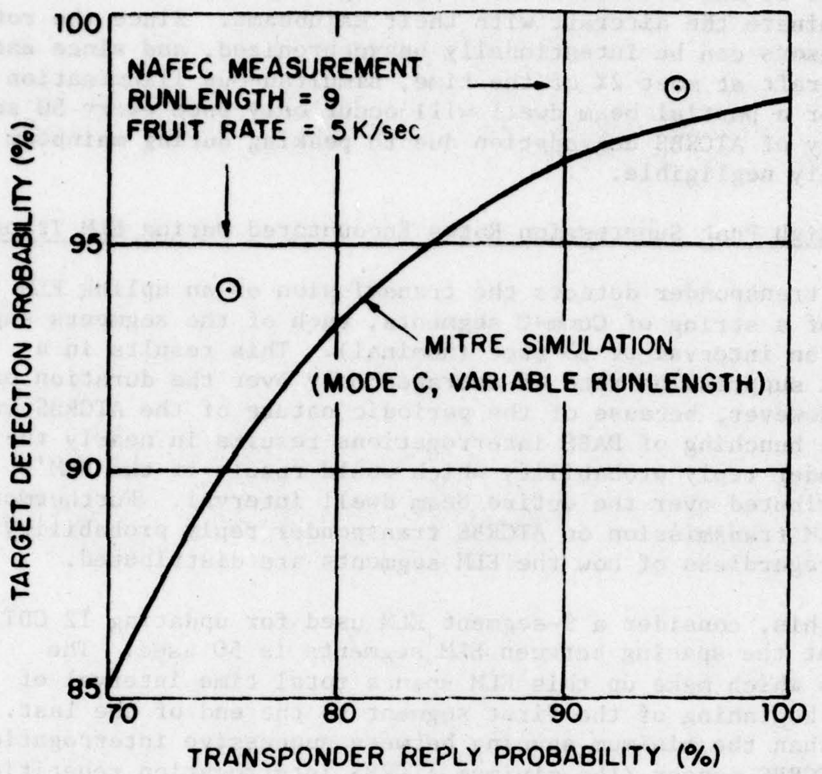

Figure 16

Target Detection Probability of ARTS III The MITRE simulation and the NAFEC measurements are based on optimum parameter settings. The results are essentially independent of ATCRBS fruit rate. From the simulation curve it is seen that a 16% reduction in transponder reply probability can be sustained without reducing the detection probability below 95%.

The degree of synchronization between the scan of the victim interrogator and the interference peaking depends on aircraft location. If the aircraft is more than a few miles from the DABS sensor so that it only detects DABS interrogations when the DABS sensor's main beam sweeps past, then the victim interrogator will be subject to the effects of this peaking only when both sensors simultaneously illuminate the aircraft with their mainbeams. Since the rotation rates of the two sensors can be intentionally unsynchronized, and since each sensor sees the aircraft at most 2% of the time, simultaneous illumination of the aircraft even for a partial beam dwell will occur only once every 50 scans. Thus, the probability of ATCRBS degradation due to peaking during mainbeam overlaps is completely negligible.

Effect of the High Peak Suppression Rates Encountered During ELM Transmissions

When an ATCRBS transponder detects the transmission of an uplink ELM message consisting of a string of Comm-C segments, each of the segments suppresses the transponder for an interval of 35 μsec (nominal). This results in a relatively high peak suppression rate if averaged only over the duration of the ELM transmission. However, because of the periodic nature of the ATCRBS interrogation process, this bunching of DABS interrogations results in nearly the same ATCRBS transponder reply probability which would result if the ELM's were uniformly distributed over the entire beam dwell interval. Furthermore, the effect of the ELM transmission on ATCRBS transponder reply probability is extremely small regardless of how the ELM segments are distributed.

To illustrate this, consider a 9-segment ELM used for updating 12 CDTI targets. Assume that the spacing between ELM segments is 50 μsec. The nine Comm-C segments which make up this ELM span a total time interval of 482.5 μsec from the beginning of the first segment to the end of the last. Since this is less than the minimum spacing between successive interrogations transmitted by an ATCRBS sensor (the minimum ATCRBS interrogation repetition interval is approximately 2200 μsec), this transmission cannot interfere with more than a single interrogation from an ATCRBS sensor in a scan. If each of the Comm-C segments in the ELM causes a victim ATCRBS transponder to suppress for 35 μsec, the total suppression time due to the ELM is 315 μsec. The probability that this extended length transmission will cause the loss of an ATCRBS reply is the product of the probability P_o that both sensor beams simultaneously illuminate the victim and the conditional probability P_i that, during the beam overlap interval, one of the ATCRBS interrogations received by the victim transponder overlaps a suppression interval induced by one of the Comm-C preambles.

Let us assume, in the calculation of P_o, that the target is not in the sidelobes of the DABS interrogator. Both the DABS interrogator and the ATCRBS interrogator illuminate the victim transponder once per scan. If the DABS interrogator is capable of suppressing ATCRBS transponders within an angular wedge 1.5 times greater than the 3-dB beamwidth B, the probability of simultaneous illumination is $P_o = 1.5B/360°$. If the beamwidth is 2.4°, $P_o = 0.01$.

Given a convergence of mainbeams, the probability that an ATCRBS interrogation is received during a suppression interval is:

$$P_i = \frac{N}{T} (t_s + t_a),$$

Where N is the number of Comm-C segments (=9)

T is the ATCRBS interrogation repetition interval (=2500 μsec, nominal)

t_s is the ATCRBS suppression interval (=35 μsec, nominal)

t_a is the average ATCRBS interrogation duration ($= \frac{8+21}{2}$, or 14.5 μsec, assuming an AC mode interlace)

The unconditional probability of ATCRBS reply failure due to the 9-segment ELM transmission is $P_f = P_o \cdot P_i = 1.782 \times 10^{-3}$. The probability of two or more ATCRBS interrogation failures during a beam dwell is identically zero as stated above. The relative durations and spacings of the DABS ELM and the overlapping ATCRBS interrogations are illustrated in part (a) of Fig. 17.

Now let us examine the probability of ATCRBS interrogation failure which would result if the 9 Comm-C segments were not closely spaced, but rather were distributed randomly over the entire 25-μsec beam dwell interval. The relative timing and spacing would be as illustrated in part (b) of Fig. 17. Since there are approximately 16 ATCRBS target hits per beam dwell, the nine DABS interrogations would likely be spaced such that no more than one Comm-C occurs within each ATCRBS interrogation repetition interval. In this case, the probability that exactly one ATCRBS transaction will fail due to an overlap with the DABS-induced suppression interval is obtained by considering each possible overlap event as an independent Bernoulli trial with probability $p = (t_s + t_a)/T$. Application of the binomial probability formula then gives the probabilities as summarized in the second column of the following table:

PROBABILITY OF ATCRBS REPLY LOSS DUE TO 9-SEGMENT ELM

EVENT	PROBABILITIES	
	ELM Bunched Within One ATCRBS Interrogation Interval	ELM Distributed Over Entire Beam Dwell
1 ATCRBS reply lost	0.1782%	0.1519%
>1 ATCRBS reply lost	0.0000%	0.0129%

It is seen that increasing the spacing between the Comm-C interrogations reduces by about 15% the probability of one ATCRBS interrogation failure during a beam dwell. However, the probability of multiple interrogation failures,

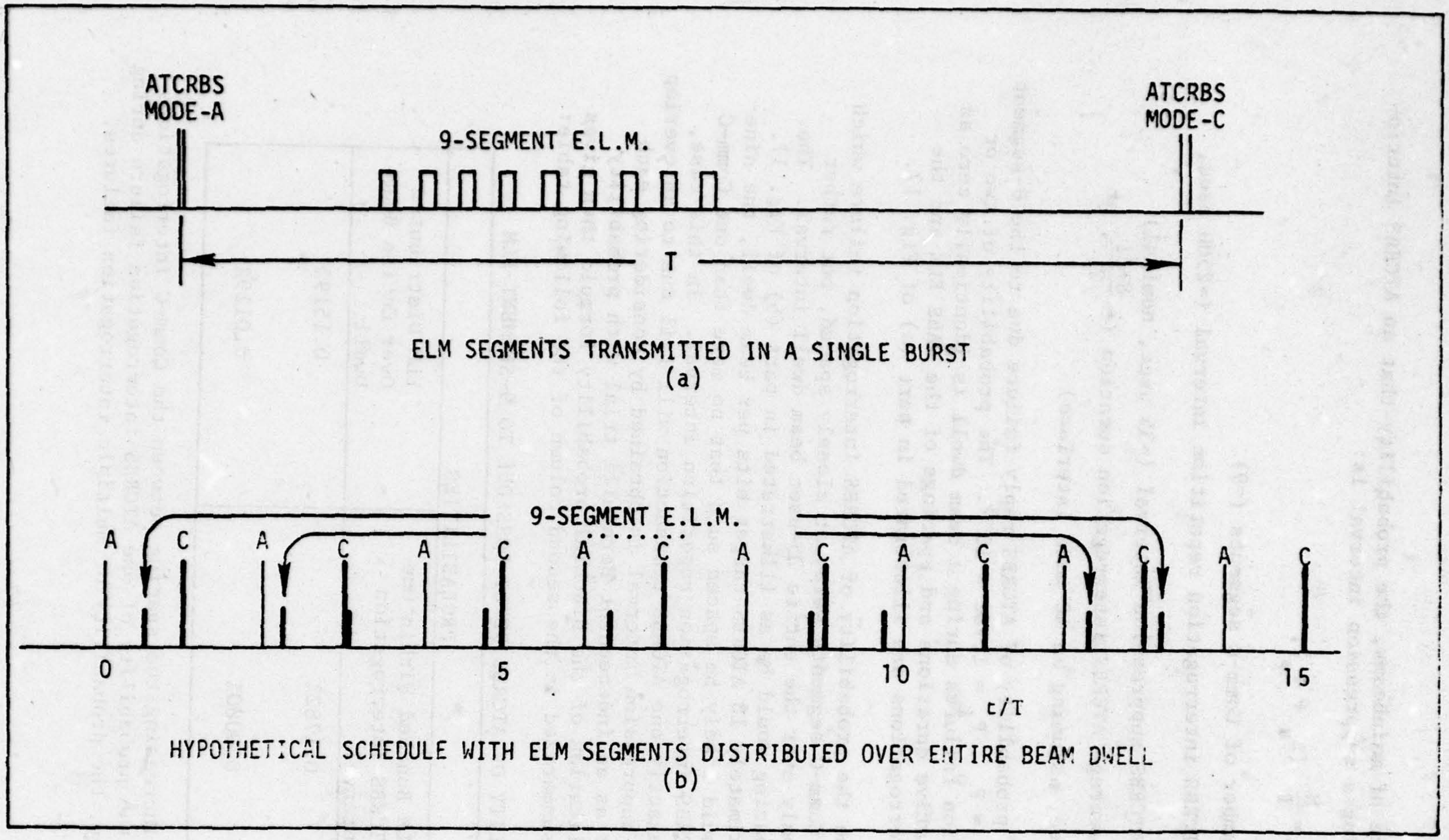

Figure 17

The Effect of DABS Interrogation Bunching on Uplink Interference Calculations. The probability of one segment of a 9-segment extended length message (ELM) overlapping one ATCRBS interrogation in a scan differs by only 15% between cases (a) and (b).

although extremely small, is no longer zero. Since the quantitative effect of multiple missed replies during a scan is greater than the effect of a single missed reply, it can be argued that in the worst case spreading out the data transmissions will have more effect on the performance of the ATCRBS system.

Similar arguments apply when one considers the interference generated by DABS fruit replies received at an ATCRBS ground station. Since ATCRBS replies occur in fixed intervals, the probability that a single ATCRBS reply will be lost on a given scan is essentially the same whether one accounts for the bunching of DABS replies in detail or calculates the channel occupancy of the DABS fruit on a Poisson arrival basis or merely assumes a uniform DABS arrival rate. Consequently, the results presented elsewhere in this paper are valid to first order regardless of how the DABS transmissions are distributed in time, and the calculations are based on assumed uniform arrival rates.

SUPPRESSION OF MILITARY TRANSPONDERS BY DABS INTERROGATIONS

The considerations regarding compatibility of DABS transmissions with military AIMS* equipment are essentially identical to the compatibility of DABS and ATCRBS. Possible interference effects occur on both the interrogation and reply links. Since AIMS transponders include the standard ATCRBS Mode A (known as Mode 3/A) and Mode C capabilities, all of the above considerations regarding potential DABS interference to ATCRBS transponders apply: i.e., the effects of DABS transmissions on the ATCRBS performance of military IFF transponders are negligible.

In addition to the civilian Modes A and C, military transponders also respond to three other interrogation modes: Modes 1, 2, and 4. Modes 1 and 2 transmissions are identical in format to civilian mode A interrogations, except that the P1-P3 spacings are 3 and 5 μsec, respectively. The Mode 4 interrogation is a distinct format used for secure IFF. All considerations of DABS-ATCRBS compatibility apply to the military Modes 1 and 2 unchanged. In particular, these selective identification (SIF) modes all use the same sidelobe suppression technique. When a military transponder detects a P1-P2 suppression pair, decoding for modes 1, 2, 3/A, and C is suppressed for 35 ±10 μsec. However, Mode 4 uses entirely different formats including a distinct sidelobe suppression format. Mode 4 decoding is not suppressed by the receipt of a P1-P2 pair.

The mode 4 interrogation is illustrated in Fig. 18. The DABS interrogation waveform is included for comparison. Like the DABS interrogation, the Mode 4 interrogation includes a P1-P2 pulse pair which is used to suppress ATCRBS transponders which receive the interrogation, thereby preventing them from generating unwanted replies upon detecting the remainder of the interrogation signal. The Mode 4 interrogation includes an additional pair of pulses which, together with P1 and P2, make up the Mode 4 sync sequence or preamble. If a Mode 4 transponder detects this preamble, but does not detect a Mode 4 SLS pulse following P1 by 8 μsec, it transfers the remaining pulses of the interrogation to an external device which examines the pulse sequence for the proper IFF code. When a Mode 4 sync sequence is declared, the transponder also suppresses all further decoding for an additional 75 to 125 μsec interval. This Mode 4 suppression is the principal effect to be avoided in interrogating Mode 4 transponders with non-standard waveforms. Because of the cryptographic encoding of the interrogation, the probability of the transponder generating a Mode 4 reply to an non-Mode 4 interrogation is very small.

The DABS interrogation waveform is designed to prevent Mode 4 triggers. The DABS format employs binary phase reversals spaced at 1/4-μsec intervals, whereas the Mode 4 transponder looks for 1/2-μsec pulses. The Mode 4 transponder should also reject the DABS interrogation because of continuous

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*AIMS = Air Traffic Control Radar Beacon System, Identification Friend or Foe, Mark XII, System.

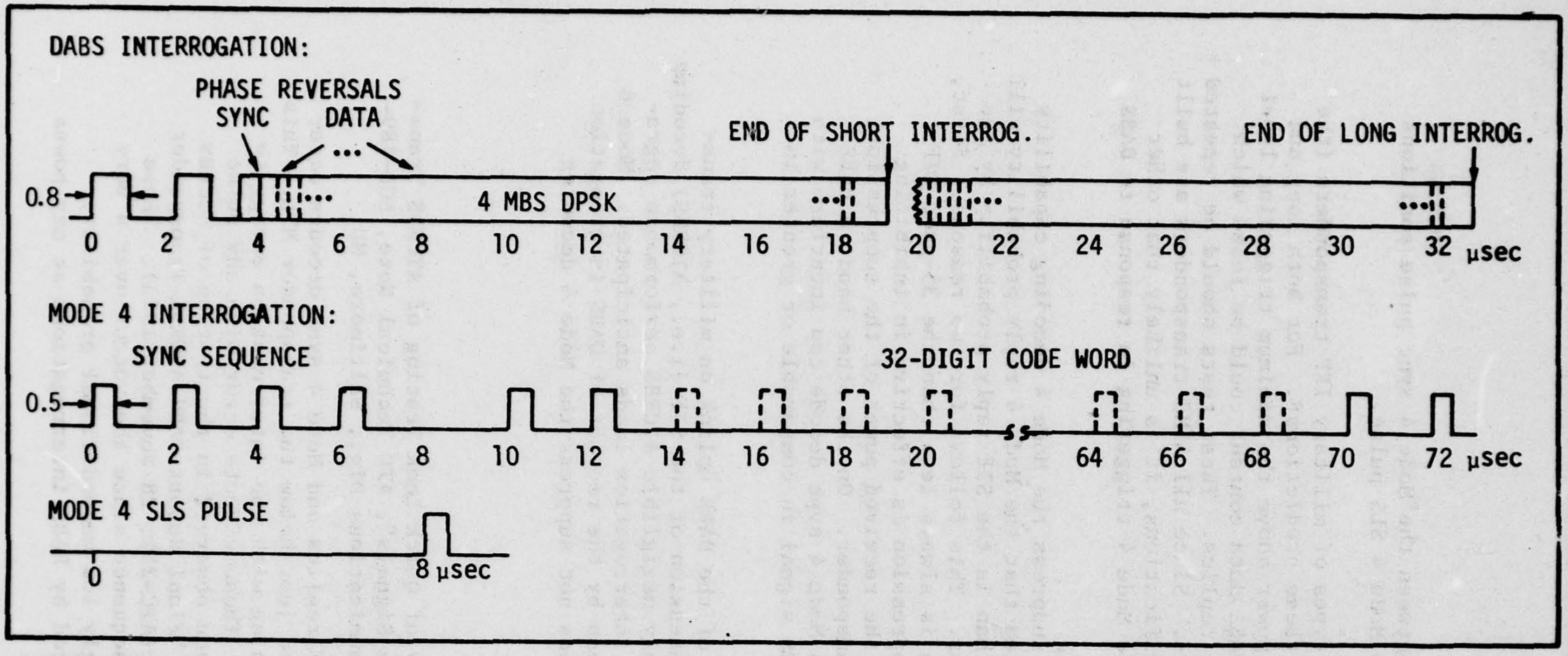

Figure 18

Comparison of Mode 4 and DABS Interrogations. Both DABS and Mode 4 interrogations intentionally suppress SIF decodes for 35 μsec. The DABS interrogation format is designed to avoid false Mode 4 sync decodes since each sync decode initiates a 100-μsec suppression gate. To generate a false Mode 4 sync, the AIMS transponder would have to: a) fail to distinguish DABS phase reversals from pulses, and b) fail to detect DABS energy in the Mode 4 SLS position, and c) fail to detect the continuous carrier energy between the Mode 4 sync pulse positions.

If an AIMS transponder were to generate a false Mode 4 sync decode from a DABS interrogation, it would be virtually impossible to decode a valid Mode 4 code word in the crypto computer since the DABS interrogation is too short and is neither properly modulated nor properly encoded.

Because Mode 4 decoding is not suppressed by DABS it is less affected by DABS interrogations than are the SIF modes.

carrier energy present in the spaces between the Mode 4 sync pulse positions and in the position designated for the Mode 4 SLS pulse.

Preliminary bench tests with two types of military IFF transponders (the APX-72 and the APX-100) have verified these predictions*. For both long and short DABS interrogations with signal power above the minimum triggering level (MTL) of these AIMS transponders, no DABS data content could be found which would trigger Mode 4 sync decodes** or replies. These tests should be repeated with other types of Mode 4 transponders. Since all AIMS transponders are built to essentially identical decoding specifications, it is unlikely that other transponder types will experience false Mode 4 triggering in response to DABS interrogations.

Since DABS interrogations do not suppress the Mode 4 decoding capability of the AIMS transponder, it is predicted that the Mode 4 reply probability will be reduced by an even smaller factor than is the SIF reply probability by the receipt of DABS interrogation waveforms. This follows for two reasons. First, the duration of the DABS interrogation is always less than the 35-μsec SIF suppression interval. Secondly, a suppression is effective in inhibiting transponder performance regardless of the received power of the suppression, provided it exceeds the MTL of the transponder. On the other hand, a DABS interrogation which does not trigger a Mode 4 sync decode can interfere with a Mode 4 interrogation only if the DABS signal is comparable or greater in power than the Mode 4 signal.

In summary, the principal effect of the DABS uplink on military transponders should be the intentional suppression of the SIF (i.e., ATCRBS) decoding capability, which is known to cause only negiglible ATCRBS performance degradation under even the worst DABS peak interrogation loads anticipated. Mode 4 performance should be affected even less by the receipt of DABS interrogation waveforms because the DABS preamble does not suppress the Mode 4 decoding capability of the AIMS transponder.

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*G.L. Vogt and L.W. Beachler, "Summary of Quick Look Testing of ATCRBS Transponder Responses to DABS Interrogation Signals", ATC Technical Note, BCD-489-TNATC-01, 1 December 1978, Bendix Communications Div., Baltimore, MD.

**Occasional random triggerings of SIF replies and Mode 4 sync decodes occur when DABS interrogations are introduced just below the transponder MTL. This effect is due to receiver noise combining with the interrogation energy to produce spurious threshold crossings. These effects occur with any pulse amplitude detection system and have been observed in the testing of ATCRBS transponders (see J.R. Samson, et al, "Final Report DABS/ATCRBS Transponder Bench Testing Program", FAA-RD-73-160 (ATC-25), 28 November 1973). These random triggers are of negligible consequence since they occur over a very small dynamic range and with exceedingly low unconditional probability. Mode 4 replies have never been triggered by DABS interrogations at any power level.

FRUIT RATE COMPARISON FOR DABS AND ATCRBS INTERROGATORS

Asynchronous interference in the 1090 MHz band, or fruit, will be reduced significantly when DABS is introduced. Table 3 compares the probabilities of reply loss due to fruit generated by an ATCRBS interrogator and a DABS interrogator. For purposes of comparison the DABS interrogator is assumed to provide surveillance and datalink service to as many aircraft as the ATCRBS interrogator. Although the DABS interrogator provides surveillance service for a total of 400 aircraft and datalink service for the half of those which are DABS equipped, the lower fruit rate generated by the DABS system is evident. Even though each DABS reply is longer than an ATCRBS reply, the DABS replies result in a 6% lower probability of reply loss for the victim ATCRBS sensor.

In computing the reply rates it is assumed that all of the DABS transponders are datalink equipped and that 22% of them receive high option datalink service. It is seen that the use of the extended length message capability for this service results in a relatively low reply rate from the 44 transponders receiving this service. The reply rate is essentially independent of the type of data link service provided to the aircraft.

In calculating the fruit rates received at the victim sensor, it is assumed that the victim is effectively colocated with the DABS interrogator. Thus the victim sensor sweeps out the same volume of airspace as the interrogator which elicits the fruit replies. It is shown in Appendix C that the rate of receipt of fruit above the fixed receiver threshold of a beacon interrogator is approximately 1/10 the total reply rate of all the transponders within range of the interrogator mainbeam. (If the receiver employs sensitivity time control, this fruit reduction factor may become considerably larger than 10 to 1). The fruit calculations summarized here assume a 10 to 1 factor.

The probability of overlap calculations show that, despite the greater duration of the DABS reply, the total channel occupancy of replies to interrogations from the DABS sensor is less than the channel occupancy of replies to the ATCRBS sensor.

Channel occupancy is not the whole story, however. If an ATCRBS reply is overlapped by a DABS reply, it is almost certain that an ATCRBS ground sensor will be unable to properly decode the ATCRBS reply. Thus, as a worst case estimate, one may assume that the conditional probability of incorrectly decoding a desired ATCRBS reply is 1.0, given that it is overlapped by a DABS reply. In comparison the probability is approximately 0.32 that a desired ATCRBS reply overlapped by a single ATCRBS fruit reply cannot be correctly decoded by the ARTS-III reply processor*. Taking these numbers into account,

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*FAA-ED-74-7, II (MTR-6517) S.R. Jones, et al, "Study of Alternative Beacon-Based Surveillance and Datalink Systems", April 1974, Appendix F.

TABLE 3

TRANSPONDER POPULATION	ATCRBS CASE		DABS CASE
ATCRBS Transponders	400		200
DABS Transponders	-		200
% Standard Datalink	-		78%
% High Option Datalink	-		22%
FRUIT GENERATED BY ATCRBS REPLIES	**ATCRBS CASE**		**DABS CASE**
Run Length	16		6
Replies/Scan	6400		1200
Replies/Sec	1600		300
Fruit/Sec (Received by Victim)	160		30
Probability of Overlap (42 μsec Window)	0.672%		0.126%
Probability of Reply Loss (0.32/ Overlap)	0.215%		0.040%
FRUIT GENERATED BY DABS REPLIES	**SURVEILLANCE**	**COMM-B**	**COMM-D**
Transponders	200	200	44
Replies/Transponder/Scan	2	0.5	2
Replies/Scan	400	100	88
Replies/Sec	100	25	22
Fruit/Sec (Received by Victim)	10	2.5	2.2
ATCRBS Overlap Window (μsec)	64+21=85	120+21=141	120+21=141
Prob Reply Loss (=Prob Overlap)	0.084%	0.035%	0.032%
OVERALL PROBABILITY OF REPLY LOSS	**ATCRBS CASE**		**DABS CASE**
	0.22%		0.19%

<u>Fruit Rate Comparisons For Individual ATCRBS and DABS Interrogators.</u> It is seen that the probability that a desired ATCRBS reply is lost due to fruit generated by an ATCRBS sensor is approximately 6% greater than the corresponding probability of loss due to fruit from a DABS sensor. The DABS sensor handles the same number of targets and provides datalink service.

for the assumed environment, the probability of lost reply is only 0.19% for the DABS sensor and 0.22% for the ATCRBS sensor. In both cases, the probabilities of lost reply due to fruit are negligible compared to other ATCRBS reply loss mechanisms.

As the number of interrogators is increased in an area, the ATCRBS and DABS fruit rates are both increased. However, the ATCRBS fruit rate is proportional to the number of ATCRBS interrogators, whereas DABS fruit is relatively more independent of the number of DABS interrogators since only one DABS sensor provides datalink service to each DABS transponder and generally no more than 2 or 3 DABS sensors provide surveillance coverage in a given airspace. Thus, if 10 ATCRBS sensors have overlapping coverage in airspace containing 400 ATCRBS transponders, the fruit rate detected by a sensor in that area will be 1600 per second and the resulting probability of reply loss will be 2.15%. In comparison, the DABS fruit rate for the same set of targets within range of 10 DABS sensors would not increase beyond about 3 times the rate resulting from a single DABS sensor.

In summary, ATCRBS reply loss due to overlapping DABS fruit will remain negligible as DABS usage grows. In fact there will be a reduction in interference conditions in the reply frequency band, with the result that as DABS is deployed, the ATCRBS sensors remaining in use will benefit from the DABS deployment. The two mechanisms which are the basis of this improvement are: (1) whereas an ATCRBS sensor now elicits 15 to 45 ATCRBS replies in order to produce one surveillance report, a DABS sensor elicits only one DABS reply for this purpose, and (2) whereas an ATCRBS transponder now replies to 20 to 40 different ATCRBS sensors at one time, a DABS transponder replies to only 1 to 3 DABS sensors at one time.

False Bracket Detections Due to DABS Fruit

Although loss of ATCRBS replies due to overlapping DABS fruit has been shown to be negligible, a DABS reply arriving in the clear at an ATCRBS sensor (operating without a defruiter) can be falsely decoded as a string of overlapping ATCRBS reply brackets. Strings of up to 50 such brackets could be decoded on receipt of a long DABS reply if the bracket detector were sufficiently tolerant of out-of-specification bracket spacings.

The effect of these false brackets on the ATCRBS processor clearly depends on the details of the processor design. There are currently many types of ATCRBS processors in use. Most of them fall into three broad categories: 1) receivers which perform a minimum of processing other than simple bracket detection and generation of target pulses for video display, b) receivers which employ real-time hardware processing and phantom elimination circuitry, and c) receivers which employ software (or firmware) processing and phantom elimination schemes. Any of these receiver types may also be preceded by defruiting devices which are usually realized in hardware. The third type of ATCRBS receiver, when operating without a defruiter, is most susceptable to degradation due to bursts of false bracket decodes. A long string of closely spaced brackets could conceivably cause bracket detection buffers or phantom elimination buffers to overflow in such a software-based processor.

The ATCRBS reply processor intended for use in the ARTS-IIIA system (known as the SRAP-I processor) is an example of a processor using firmware degarbling and phantom elimination subsystems. Preliminary tests with this processor at the FAA NAFEC have indicated that it is capable of handling DABS fruit at rates of up to 250 fruit per second without significant reply processor degradation. This DABS fruit level is several times larger than would be ever experienced in an operational environment. Analysis of the existing ARTS processor and the Common Digitizer processor indicate that these processors, which both employ hardware-based bracket rejection schemes, would be less susceptible to DABS fruit than the SRAP-1. Most of the other processors in use are of the first type which employ minimum processing and thus would likely be able to tolerate even higher levels of DABS fruit without performance degradation.

Due to the exceedingly low predicted rate of receipt of DABS fruit, it is not expected that tests of operational ATCRBS processors will uncover performance degradation due to the detection of false brackets. However, in the unlikely event that a particular processor were to experience measurable target loss due to DABS fruit, several known techniques could be applied: (a) conventional defruiting, (b) receive sidelobe suppression, wherein pulses received from antenna sidelobes are rejected, thus eliminating most of the DABS fruit pulses (this technique is used successfully for rejecting ATCRBS fruit now in the DABS sensor), and (c) receiver blanking, initiated by a DABS preamble detector (a technique also used in DABS sensors). The blanker results in a probability of reply loss which is essentially the same as that which occurs naturally due to overlapping DABS fruit replies and prevents any possible degradation of ATCRBS processing due to false bracket decodes.

EFFECTS OF DABS FRUIT ON MODE 4 SENSORS

Since the DABS fruit rate is extremely low, the overlapping of DABS and Mode 4 replies will be rare. The question remains as to the effect on a Mode 4 sensor when a DABS fruit reply is received in the clear. The effects of DABS fruit replies on military Mode 4 sensors are considered in Fig 19. It is seen that the Mode 4 reply consists of a simple 3-pulse group with variable reply delay coding. It is possible for a DABS reply to contain 4-pulse groups (the inner 4 pulses of the code sequence 111100), three of whose pulses would be accepted by a Mode 4 sensor as a valid Mode 4 reply pulse group*. However, the extra pulse within this sequence should cause the group to be rejected. If a Mode 4 sensor were to fail to reject this sequence in a DABS reply and therefore declare a false Mode 4 reply, it is unlikely that a false target would be reported because of the defruiting capability inherent in the Mode 4 reply delay encoding process. The very low DABS fruit rates anticipated and the low probability of encountering the required data code sequence in the DABS reply should combine to make the occasional decoding of a false reply an event of negligible consequence.

If a particular Mode 4 sensor were found to experience measurable performance degradation due to DABS fruit, the same techniques suggested above for an ATCRBS sensor could be applied. Of these, the installation of a simple DABS preamble detection circuit in the reply decoder to reject all DABS replies is most attractive. Because of the very low DABS fruit rates, this approach would be certain to have negligible impact on the performance of a Mode 4 sensor in even the densest DABS fruit environments.

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*Note that code pulses included in two ATCRBS replies could also combine to form a good approximation to the Mode 4 reply group, as shown in Fig. 19.

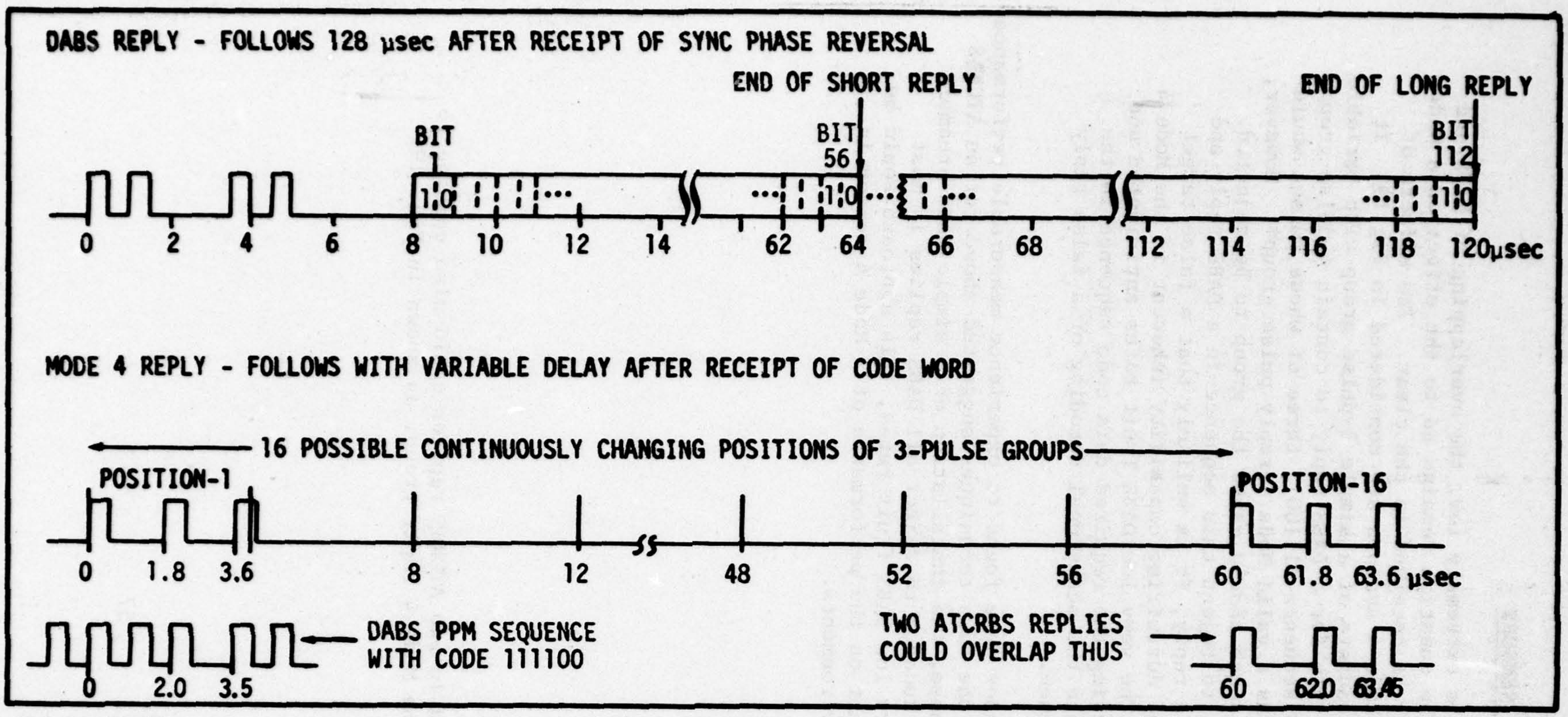

Figure 19

Comparison of Mode 4 and DABS Replies. The DABS fruit rate is very low (~70/sec in the worst case). Interference with Mode 4 replies will be negligible. However, DABS replies containing PPM sequences as shown will approximate Mode 4 three-pulse groups. (Note also that two ATCRBS replies can align to form a good approximation to the Mode 4 group - with no intervening pulses)

To accept the DABS sequence as a Mode 4 reply, an AIMS sensor would have to fail to detect the extra pulse. The AIMS sensor still should not declare false targets because asynchronous replies are rejected by the variable delay encoding process. Therefore DABS replies are very unlikely to cause Mode 4 performance degradation. If a particular AIMS sensor is affected by DABS fruit, a DABS preamble detector circuit can be used to reject all DABS replies.

A COMPARISON OF INTERFERENCE RESULTING FROM THREE HIGH-DENSITY SCENARIOS

Many assumptions presented in this discussion of the effects of DABS interference on the ATCRBS system have been based on the capacity limits built into the DABS equipment which is currently being tested by the FAA. These design limits were in turn based on traffic and datalink demand models and interference analyses generated during the DABS system design and engineering model specification process. Not all of the documentation of these considerations is widely available. It is therefore possible for one to postulate unusual rates of datalink service which would saturate the DABS link and would generate uncomfortable levels of interference to residual ATCRBS sensors.

Table 4 compares the worst case scenarios which have guided the DABS system design with a set of assumptions suggested by one of the respondents to the publication of the Proposed DABS National Standard in the Federal Register.

The respondent's model assumes an aircraft loading of 2000 aircraft within range of the DABS sensor. This assumption is within the theoretical surveillance capability of a DABS sensor provided the targets are relatively uniformly distributed in space around the sensor. It is then assumed that 1000 of these transponders require a very high rate of datalink service to support a CDTI system with the ability to display up to 30 intruder tracks in the cockpit of each aircraft. Each track update is assumed to include X, Y, Z, ID, and velocity vector codes (no resolution indicated), resulting in a requirement for one Comm-C per scan per target displayed. The resulting interrogation rate is nearly 9000 per second resulting in an ATCRBS transponder suppression time percentage of 40.9%.

The actual upper limits on the ability of the DABS link are represented in the column based on the 1995 L.A. Basin traffic model. In this model there are a total of 1700 aircraft in the basin. Of these, 700 are within detection range of one of the sensor sites located in the highest density part of the area. Normally, a DABS sensor is required to provide surveillance coverage for up to 400 aircraft. In order to accommodate adjacent sensor failure, sensors can be expanded to handle a peak of up to 700 targets. The datalink service for this situation consists of high-option CDTI service for 22% of the targets, mid-option CDTI (6 targets displayed) for 40% and normal low-option service for the rest. In the design model, the high-option CDTI service is handled by an average of 9 Comm-C transmissions per scan as opposed to approximately 30 Comm-C's per scan in the respondent's model.

The resulting suppression time percentage for a victim transponder outside of the interrogator sidelobes is 0.75% for the design model. If the victim flies

TABLE 4

DABS INTERFERENCE TO ATCRBS - COMPARISON OF THREE SCENARIOS

Model	DABS Design Models 1982	DABS Design Models 1995	Respondent's Model
Total A/C in Model	735	1700	2000
% DABS Equipped	100%	100%	100%
A/C in Mainbeam Range of Victim ATCRBS Sensor	535	700	2000
A/C Interrogated by Busiest DABS Sensor (1)	400	700	2000
Fraction of A/C with High-Option CDTI & Datalink (2)	0.11	0.22	0.5
High Option CDTI Transmissions Per Scan	10	10	30
DABS Interrogation Rate (3)	365/sec	799/sec	8938/sec
% Suppressed Time for Victim with Range <1 NMI (4)	2.33%	4.27%	40.89%
% Suppressed Time for Victim with Range >5 NMI (5)	0.71%	0.75%	1.48%
Reply Rate of All Targets in Range of Mainbeam (6)	499/sec	663/sec	2494/sec
DABS Fruit Rate Above MTL of ATCRBS Sensor (7)	50/sec	66/sec	249/sec
Probability of ATCRBS Reply Loss Due to DABS Replies (8)	0.60%	0.80%	2.99%

NOTES:

1. Assumes Adjacent Sensor Failure
2. Remainder Have Mid- and Low-Option Service
3. Reinterrogation Rate is 10%
4. SLS is Used; All Transmissions are detected by ATCRBS Transponder; ATCRBS Interrog. Rate = 150/sec; Xponder Supp. Time = 45 μsec
5. Only Mainbeam DABS Interrogations are Detected; All SLS Pulses are Detected within Improved SLS Range (20 to 50 nmi)
6. Each Target Gets Dual Surveillance and Single Data Coverage; Link Failures Divide Equally Between Up & Downlink
7. Fixed Threshold at -79 dBm (S.T.C. would further reduce the Fruit Rate); BCAS Squitters Locked Out
8. ATCRBS Receiver Blanked for 120 μsec on Receipt of DABS Preambles; No ATCRBS or All-Call Fruit Included

within the effective sidelobe range of the sensor, it experiences a suppression rate of 949 suppressions per second. This suppression rate is less than the suppression rate experienced by ATCRBS transponders in large areas of the Northeastern U.S. today*.

According to the design model, the fruit rate resulting from the replies of all of the DABS targets within DABS interrogator range is 66/sec detected above a fixed threshold of -79 dBm, assuming a standard ATCRBS interrogator antenna. As predicted above, the probability of reply loss due to fruit is completely negligible.

The first column in this table represents what might be considered a more reasonable early deployment design based on model 1982 L.A. Basin predictions (as generated in 1974). Again, the resulting suppression and fruit rates would cause negligible degradation of conventional ATCRBS performance in common airspace.

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[*] F. Nagy, Jr. "Uplink ATCRBS Environment Measurements Along the Boston-Washington Corridor, Volume 1: The RF Environment", FAA-RD-78-33 (Lincoln Laboratory ATC-83), 27 June 1978.

SUMMARY

This paper has examined the potential interference effects of DABS transmissions on the existing ATCRBS system. It is concluded that the effects of DABS interrogations and replies on ATCRBS interrogators and transponders are predictable and that DABS suppression of ATCRBS transponders and the fruit resulting from interrogations by DABS sensors will not degrade the surveillance ability of existing ATCRBS sensors. Rather, the modification of an ATCRBS ground station to include DABS capability will provide better quality surveillance data to the users of that ground station while at the same time enhancing the performance of other ATCRBS ground stations.

Similar conclusions hold regarding the potential interference effects of DABS transmissions on military IFF equipment. The DABS interrogation format is expressly designed to avoid false Mode 4 sync decodes. The generation of false Mode 4 code word decodes in the IFF crypto computer is virtually impossible since the DABS interrogation is not properly modulated or encoded. In addition, since Mode 4 decoding is not suppressed by the DABS preamble, it should be less affected by DABS interrogations than are the ATCRBS modes. Since the DABS fruit rate is extremely low, overlapping of Mode 4 replies will be rare. The probability of accepting DABS reply pulse sequences as false Mode 4 replies should be low and the probability of declaring such false replies as targets should be negligible because of the Mode 4 reply evaluation algorithms. Thus, the replacement of ATCRBS equipment with DABS equipment, with its lower interrogation and reply rates, should result in a net improvement to the ability of the military AIMS equipment to perform its crucial surveillance and identification functions.

The principal technical assumptions and design considerations which influenced the development of the DABS concept have also been reviewed along with operational constraints, economic considerations and demand predictions which determined the parameters of the system. It has been shown that the DABS design reflects many factors including: technical findings concerning link reliability and monopulse performance; predictions of future surveillance and datalink demands on the system; constraints on replacement of sensors at existing sites; hardware capability, evolutionary upgrading, long-term deployment and phase-in plans; economic factors influencing the need for commonality in sensor hardware, avionics, and antennas; as well as the issue of mutual interference between DABS and existing systems.

An attempt has also been made to clarify a number of common misconceptions concerning technical characteristics of the DABS and ATCRBS systems such as distinctions between omnidirectional and sidelobe range, ATCRBS and DABS lockout, suppression time and dead time following a reply, and transponder reply rates and detected fruit levels.

Extensive tests are now beginning with a set of engineering model DABS sensors and transponders at the FAA's National Aviation Facilities Experimental Center. Potential interference mechanisms will be examined during the course of those tests with particular emphasis on validating the predictions presented herein regarding the effects of DABS transmissions on ATCRBS processor types other than the widely-used ARTS processors.

Important interference questions have been raised in response to the publication of the Proposed DABS National Standard. The intention of the DABS design is to improve the overall beacon surveillance environment and to provide a basis for supporting future advances in air traffic control. At the same time the DABS system must be compatible with the existing beacon system. Analysis shows that a controlled and rational deployment and implementation of the DABS design can achieve these goals while simultaneously enhancing the performance of residual ATCRBS beacon equipment.

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APPENDIX A

EFFECTIVE SIDELOBE GAIN

Definition

We define the "effective sidelobe level," G_{eff}, of an interrogator antenna as the gain of an omni antenna (omni in azimuth) having the same average number of fruit-producing aircraft (that is, aircraft with received power above some stated threshold). The mainbeam angular wedge θ_M is excluded from the count for both antennas. All aircraft are assumed to have the same effective radiated power, ERP.

Case 1. Aircraft Uniform in Range

For a small azimuth wedge $\Delta\theta$, in radians, the average number of aircraft counted ΔN is

$$\Delta N = \frac{\Delta\theta}{2\pi} \rho_R \sqrt{\frac{ERP\,\lambda^2}{16\pi^2 T}} \sqrt{G(\theta)}$$

where ρ_R = range density of aircraft
λ = wavelength
T = threshold, expressed at antenna terminals
$G(\theta)$ = the average interrogator antenna gain in the azimuth wedge $\Delta\theta$

Therefore the total number N is

$$N = \frac{\rho_R}{2\pi} \sqrt{\frac{ERP\ \lambda^2}{16\pi^2\ T}} \int_{2\pi-\theta_M} \sqrt{G(\theta)}\ d\theta$$

For the reference omni antenna, the result is

$$N = \frac{\rho_R}{2\pi} \sqrt{\frac{ERP\, \lambda^2}{16\, \pi^2 T}} \quad (2\pi - \theta_M) \sqrt{G_{eff}}$$

The desired result follows:

$$G_{eff} = \left[\frac{1}{2\pi - \theta_M} \int_{2\pi-\theta_M} \sqrt{G(\theta)} \; d\theta \right]^2 = \text{the "square-mean-root" gain.}$$

The result is independent of range density of aircraft, ERP of the aircraft, and the stated power threshold.

Case 2. Aircraft Uniform in Area

In this case, a similar argument leads to

$$G_{eff} = \frac{1}{2\pi - \theta_M} \int_{2\pi-\theta_M} G(\theta)\, d\theta \quad = \text{the average gain.}$$

Again the result is independent of absolute aircraft density, ERP, and threshold T.

Observations

1. It follows from Schwarz's inequality that, for any antenna,

$$G_{eff} \text{ [concentrated traffic] } \leq G_{eff} \text{ [uniform traffic]}$$

2. In either case, G_{eff} depends on the distribution of G values and on no other property of the G (θ) function.

3. Of the two cases, case 1 (concentrated traffic) appears to be the more useful characterization of a DABS-ATCRBS antenna. This is because the situations in which fruit problems are most serious tend to be situations in which traffic is concentrated around the interrogator location.

Examples

Figure A-1 shows gain distributions for several antennas. The information for the ATCRBS hogtrough antennas (Las Vegas, Miramar, and Ontario) was extracted from antenna-pattern field measurements provided (unofficially) by L. Kleiman. The DABSEF data was extracted from 360° pattern measurements made by Hazeltine on an antenna range.

By numerical integration we obtain G_{eff} values from the Miramar and Ontario antennas. Although the DABSEF data is not complete, from similarities among the plotted curves we can estimate the G_{eff} values. Results are as follows:

Distribution of Fruit Aircraft	Effective Sidelobe Gain, G_{eff} (dB)		
	Computed		Estimated
	Miramar (field meas.)	Ontario (field meas.)	DABSEF (ant. range meas.)
Uniform in range	-13.5	-14.8	-20
Uniform in area	-12.5	-12.5	-18

<u>Note</u>. Ordinate $= \frac{1}{2\pi - \theta_m} \int_{\theta^*} d\theta$

where θ^* = set of angles satisfying $G(\theta) <$ abscissa.

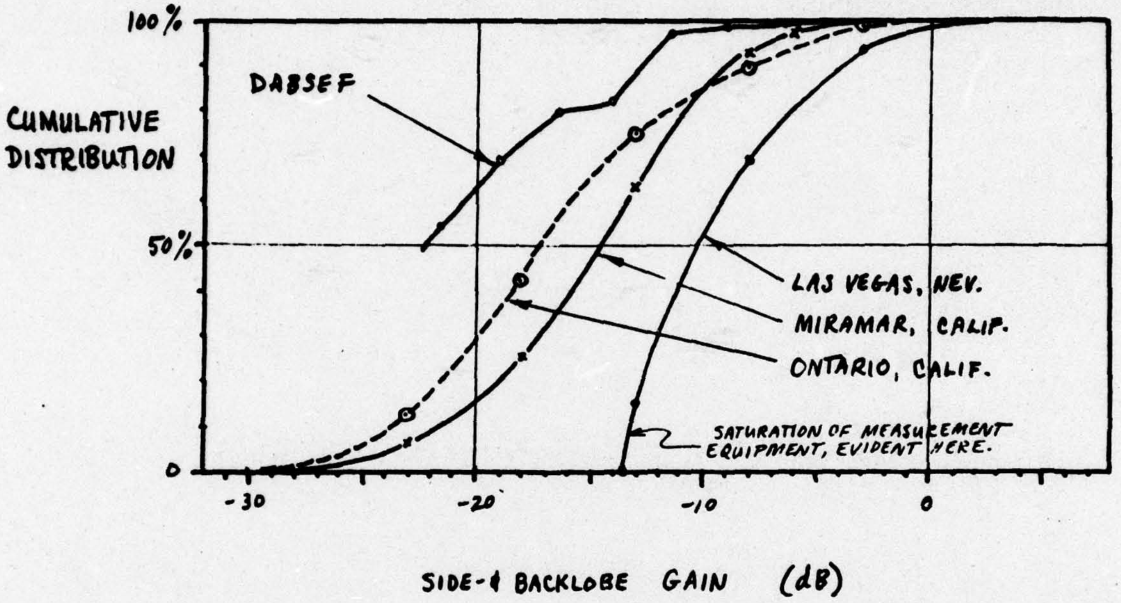


Figure A-1. Antenna Gain Distributions.

APPENDIX B

CALCULATION OF SUPPRESSION RATES IN MULTI-SENSOR SCENARIO

This appendix presents a derivation of the formulas which are used to calculate the suppression rates in a scenario containing a mix of ATCRBS and DABS sensors. In this calculation it is assumed that each DABS sensor provides surveillance to all DABS targets, but that the datalink load is divided so that each DABS sensor handles an equal share of the targets.

Two cases are considered:

a) the suppressed transponder (the "victim") is not near enough to any of the interrogators to allow it to detect discrete DABS interrogations leaking through the antenna sidelobe structure. DABS interrogations are detected only during mainbeam passage.

b) The victim is close enough to one of the sensors to detect all of sensor's discrete DABS interrogations from the antenna sidelobe structure (i.e., the victim is within the "effective sidelobe range" of the DABS sensor).

Definition of Terms

N_A = Number of ATCRBS sensors in the scenario

N_D = Number of DABS sensors in the scenario

N_T = Number of DABS transponders in the scenario

F_H = Fraction of N_T which receive high-option datalink service

F_L = Fraction of N_T which receive low-option datalink service

R = Average DABS reinterrogation rate

B = Antenna Beamwidth

T = Antenna Scan Rate

SLS Assumptions - It is assumed that all sensors are terminal sensors rotating with a common scan rate (T = 4 sec) and employing common antenna beamwidths (B = 2.4°). The ATCRBS sensors are assumed to transmit with a PRF of 400/sec. The DABS sensors are assumed to transmit ATCRBS/DABS all-call interrogations with a PRF of 150/sec. Both sensors transmit improved SLS and the victim is assumed to be within SLS range of all sensors.

Datalink Loading Assumptions - The fraction of DABS transponder population receiving only surveillance service is assumed to be 50%. 11% of the DABS transponders receive extended datalink service and 39% receive standard service. Thus $F_H = 0.11$ and $F_L = 0.39$.

Extended service is assumed to require 10 interrogations per target per scan on the average and low-option service requires 2.5 interrogations per target per scan. The average number of datalink transactions per DABS transponder is thus:

$$10\,F_H + 2.5\,F_L = 2.075$$

Mainbeam Illumination Assumption - It is assumed that a victim detects mainbeam interrogations within an azimuth wedge which is 1.5 times greater than the nominal interrogator beamwidth.

CASE a. (Victim well outside of effective sidelobe range of all sensors, but within SLS range of all sensors).

ATCRBS SLS rate = $400\,N_A$

DABS SLS rate = $150\,N_D$

DABS Surveillance Interrogation rate = $\frac{N_T}{T}(1+R)\cdot\frac{1.5B}{360}\cdot N_D$

DABS Datalink Interrogation rate = $\frac{N_T}{T}(1+R)\cdot\frac{1.5B}{360}\cdot(10\,F_H + 2.5\,F_L)$

Total Suppression rate = $400\,N_A + 150\,N_D + \frac{N_T}{T}(1+R)\cdot\frac{1.5B}{360}\cdot(N_D + 10\,F_H + 2.5\,F_L)$

CASE b. (Victim within effective sidelobe range of one DABS sensor, and within SLS range of all sensors).

ATCRBS SLS rate = $400\,N_A$

DABS SLS rate = $150\,N_D$

DABS Surveillance Interrogation rates

from nearest sensor = $\frac{N_T}{T}(1+R)$

from other sensors = $\frac{N_T}{T}(1+R)\cdot\frac{1.5B}{360}(N_D - 1)$

DABS Datalink Interrogation rates

from nearest sensor = $\frac{N_T}{T}(1+R)\frac{1}{N_D}(10\,F_H + 2.5\,F_L)$

from other sensors = $\frac{N_T}{T}(1+R)\cdot\frac{N_D-1}{N_D}\cdot\frac{1.5B}{360}(10\,F_H + 2.5\,F_L)$

Total Suppression rate = $400\,N_A + 150\,N_D +$

$$\frac{N_T}{T}(1+R)\quad\left[1+\frac{1.5B}{360}(N_D-1)+\frac{D}{N_D}+\frac{1.5B}{360}\,D\,\frac{N_D-1}{N_D}\right]$$

where $D = 10\,F_H + 2.5\,F_L$

APPENDIX C

FRUIT RATE RECEIVED WITH A DIRECTIONAL ANTENNA

For a ground based ATCRBS or DABS sensor using a directional antenna, let:

F_t = total fruit (ATCRBS or DABS) transmission rate including all aircraft within line-of-sight.

F_r = received fruit rate, via the directional antenna, including only those replies over receiver threshold.

The purpose of this appendix is to evaluate the ratio F_r/F_t, which is the factor by which fruit rate is reduced as a result of the directional antenna.

FORMULATION

The following defines a simple model for calculating received fruit rate, including the effects of the directional antenna, receiver threshold, and the traffic distribution about the location of the sensor.

Each aircraft is modeled as having a fruit transmission rate of f, a constant, and an ERP (effective radiated power) of 250 watts (which is the nominal value for both DABS and ATCRBS transponders). It follows that:

$$F_t = f \times N$$

where N is the total number of transponder equipped aircraft within line-of-sight. Directional antenna fruit reception F_r is given as the sum of mainbeam fruit F_m and sidelobe fruit F_s,

$$F_r = F_m + F_s$$

where

$$F_m = \eta_m \times f \times N$$

$$F_s = (1-\eta_m) \times f \times N(R_s)$$

$$\eta_m = \frac{2 \times B}{360°} = \text{mainbeam fraction}$$

B = 3 -dB beamwidth

N(R) = number of transponder equipped aircraft within range R of the sensor.

R_s = effective range for sidelobe reception.

POWER BUDGET

		UPLINK	DOWNLINK
TRANSMITTER POWER REFERRED TO ANTENNA	dBm	57 (500 w)	54 (250 w, nom.)
TRANSMITTER ANTENNA GAIN	dB	G_s	G_a
PATH LOSS	dB	L	L
RECEIVING ANTENNA GAIN	dB	G_a	G_s
RECEIVED POWER REFERRED TO ANTENNA	dBm	$57+G_s-L+G_a$	$54+G_s-L+G_a$
RECEIVER THRESHOLD REFERRED TO ANTENNA	dBm	-71 (nom.)	-74
MARGIN	dB	$128+G_s-L+G_a$	$128+G_s-L+G_a$

CONCLUSION

TO BALANCE AN INTERROGATOR TRANSMITTER OF 500 WATTS REFERRED TO THE ANTENNA, THE RECEIVER THRESHOLD SETTING IS -74 dBm (AT ANTENNA). OTHER SETTINGS WHICH BALANCE ARE:

INTERROGATOR POWER (AT ANT.)	RECEIVER THRESHOLD (AT ANT.)
100 WATTS	-67 dBm
200 WATTS	-70 dBm
1000 WATTS	-77 dBm

Fig. C-1. ATCRBS Interrogator and Receiver Settings.

Sidelobe range R_s depends on the receiver threshold as well as the sidelobe levels of the receiving antenna. For purposes of fruit rate calculation, antenna sidelobes may be characterized by an effective gain level, G_e, as defined in Appendix A. In particular, for the widely used FA7202 hogtrough antenna, $G_e = -12.5$ dB (approximately). Using this value of antenna gain, and a receiver threshold of $T = -74$ dBm referred to the antenna (the value which balances uplink and downlink for a 500 Watt ATCRBS interrogator - see Fig. C-1) results in a sidelobe range as follows.

transponder power (at antenna)	54 dBm
G_e	-12.5 dBi
receiver theshold (at antenna)	-74 dBm
path loss, 20 log $4\pi R_s/\lambda$	115.5 dB

Under these conditions, the solution for R_s is 7.1 nmi. More generally, R_s is given by:

$$R_s = 7.1 \text{ nmi} \times 10^{\left(\frac{\Delta G - \Delta T}{20}\right)}$$

$$\Delta G = G_e + 12.5 \text{ dBi}$$

$$\Delta T = T + 74 \text{ dBm}$$

These formats for calculating fruit rates and the antenna reduction factor are summarized in Fig. C-2.

NUMERICAL RESULTS

The antenna reduction factor F_r/F_t depends on beamwidth B, relative range distribution $N(R_s)/N$, effective sidelobe gain G_e, and receiver threshold T. The traffic distribution data (ref. 1) plotted in Fig. C-3 relates to $N(R_s)/N$. In terms of this data, results are calculated for the following cases.

$N(R_s)/N$ = N.Y. and Phila. data, curves 2 and 3, Fig. C-2.

$$\left.\begin{array}{l} B = 2.35° \\ G_e = -12.5 \text{ dBi} \end{array}\right\} \text{FA7202 hogtrough antenna}$$

$T = -74$ dBm at antenna

It follows that

$N_m = 0.013$

$R_s = 7.1$ nmi

$N = 1200$

$$N(R_s) = \begin{cases} 24 \text{ at N.Y.} \\ 10 \text{ at Phila.} \end{cases}$$

TOTAL FRUIT RATE, $F_t = f \times N$

RECEIVED FRUIT RATE, $F_r = F_m + F_s$

ANTENNA REDUCTION FACTOR, $F_r/F_t = \eta_m + (1 - \eta_m) \times \dfrac{N(R_s)}{N}$

f = FRUIT TRANSMISSION RATE PER AIRCRAFT

N = TOTAL NUMBER OF AIRCRAFT WITHIN LINE-OF-SIGHT

$F_m = \eta_m \times f \times N$ = MAINBEAM FRUIT RATE

$F_s = (1 - \eta_m) \times f \times N(R_s)$ = SIDELOBE FRUIT RATE

$\eta_m = \dfrac{2 \times B}{360^o}$

B = 3-dB BEAMWIDTH

$N(R)$ = NUMBER OF TRANSPONDER EQUIPPED AIRCRAFT WITHIN RANGE R OF THE SENSOR

$R_s = 7.1 \text{ nmi} \times 10^{[(\Delta G - \Delta T)/20]}$ = SIDELOBE RANGE

$\Delta G = G_e + 12.5$ dBi

$\Delta T = T + 74$ dBm

G_e = EFFECTIVE SIDELOBE GAIN

T = RECEIVER THRESHOLD REFERRED TO THE ANTENNA

Fig. C-2. Summary of Fruit Rate Formulas.

and the antenna reduction factor is

$$\frac{F_r}{F_t} = \begin{cases} 0.033 \text{ at N.Y.} \\ 0.021 \text{ at Phila.} \end{cases}$$

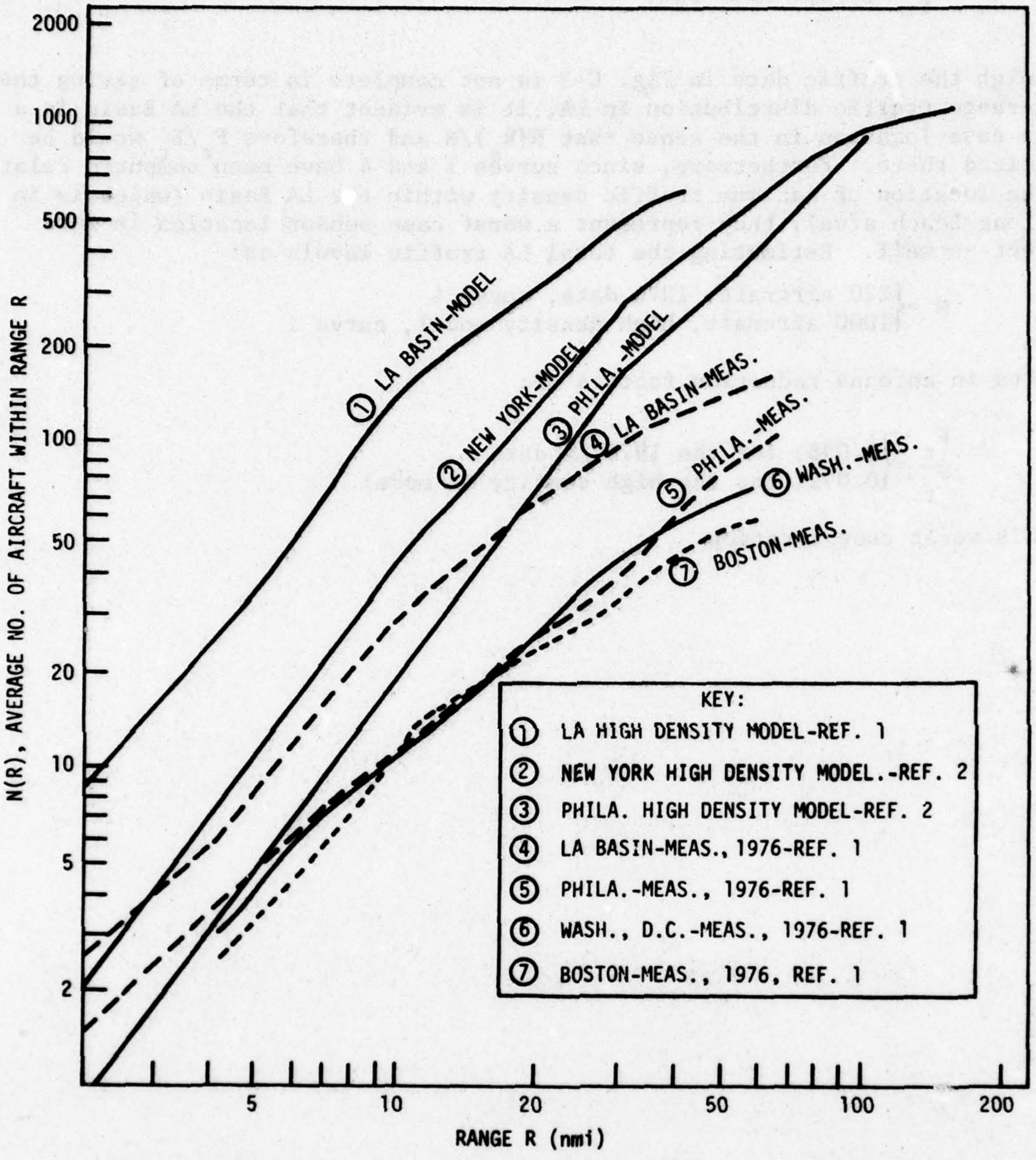
Although the traffic data in Fig. C-3 is not complete in terms of giving the long-range traffic distribution in LA, it is evident that the LA Basin is a worst case location in the sense that $N(R_s)/N$ and therefore F_r/F_t would be maximized there. Furthermore, since curves 1 and 4 have been computed relative to the location of maximum traffic density within the LA Basin (which is in the Long Beach area), they represent a worst case sensor location in this respect as well. Estimating the total LA traffic levels as:

$$N = \begin{cases} 220 \text{ aircraft, 1976 data, curve 4} \\ 1000 \text{ aircraft, high density model, curve 1} \end{cases}$$

results in antenna reduction factors of:

$$\frac{F_r}{F_t} = \begin{cases} 0.098\text{, for the 1976 LA data} \\ 0.092\text{, for the high density LA model} \end{cases}$$

in this worst case location.



NOTE: FOR CURVES 1, 4, 5, 6, AND 7, N(R) WAS COMPUTED ABOUT THE LOCATION OF MAXIMUM TRAFFIC DENSITY. CURVES 2 AND 3 ARE RELATIVE TO THE JFK AND PHILA. AIRPORTS RESPECTIVELY.

Fig. C-3. ATCRBS Traffic Distributions in Range.

APPENDIX D

PRELIMINARY EXPERIMENTAL INVESTIGATION OF THE EFFECT OF DABS SUPPRESSION ON A NEARBY ATCRBS SENSOR

On 27 July 1978 a test was run using a DABS sensor at the Texas Instruments plant at Plano, Texas to determine the effect of DABS suppressions on the operation of a nearby (about 6 1/2 miles) ATCRBS sensor located at Addison, Texas. This ATCRBS sensor is one of the two serving the Dallas/Ft. Worth ARTS facility.

The test procedure covered the operation of the DABS sensor in three configurations.

- <u>Not transmitting</u> - to measure the baseline performance without a new sensor.
- <u>Transmitting as a standard ATCRBS sensor</u> - to establish the performance of the environment including the Plano sensor.
- <u>Interrogating a traffic load of the live ATCRBS aircraft plus an additional traffic load building to 350 DABS aircraft, uniformly distributed in azimuth</u> - to measure the effect on the ARTS of converting the Plano sensor from an ATCRBS to a DABS sensor.

Data collection for this experiment was performed via the ARTS extractor tapes with parameters set to record data only from the Addison sensor.

The resulting blip/scan ratios obtained for the various data runs were as follows.

Case	Data Run Blip/Scan Ratio	Avg. Blip/Scan Ratio
Existing Environment (DABS sensor not transmitting)	.969 .957	.963
DABS operation as standard beacon interrogator at 360 PRF	.956	.956
DABS sensor interrogating existing ATCRBS plus up to 350 DABS aircraft	.969 .961 .960 .953 .952	.959

These results of this test indicate that the blip/scan ratio of the Addison sensor is generally unaffected by the presence of the DABS sensor. The observed differences are too small to be statistically significant.