AD-A046 758 IIT RESEARCH INST ANNAPOLIS MD F/G 17/7

COMPUTER SIMULATIONS OF ATCRBS PROCESSING EQUIPMENT FOR USE WIT--ETC(U)

JAN 76 C R CRAWFORD F19628-76-C-0017

UNCLASSIFIED FAA/RD-76/102 NL

| OF |

AD A046758

END

DATE FILMED

12-77

DDC

FAA-RD-76-102

9

COMPUTER SIMULATIONS OF ATCRBS PROCESSING EQUIPMENT FOR USE WITH THE AIMS AND TRANSIENT EFFECTS PERFORMANCE PREDICTION MODELS

C. Randall Crawford
of
IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

January 1976

FINAL REPORT

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, DC 20591

FAA-RD-76-102

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

(19)

1. Report No. (18) FAA-RD-76-102, ECAC, PR-75-062	2. Government Accession No.	3. Recipient's Catalog No. (12) 47p.
4. Title and Subtitle (6) COMPUTER SIMULATIONS OF ATCRBS PROCESSING EQUIPMENT FOR USE WITH THE AIMS AND TRANSIENT EFFECTS PERFORMANCE PREDICTION MODELS.		5. Report Date (11) Jan[redacted]76
		6. Performing Organization Code
7. Author(s) (10) C. Randall Crawford of IIT Research Institute		8. Performing Organization Report No. ECAC-PR-75-062
9. Performing Organization Name and Address: DoD Electromagnetic Compatibility Analysis Center, North Severn, Annapolis, MD 21402		10. Work Unit No. Project 213-061-10 (15) F19628-76-C-0017 DOT-FA70WAI-175, Task-20-a.2
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Systems Research & Development Service, Washington, DC 20591		13. Type of Report and Period Covered (9) FINAL REP[redacted]T,
		14. Sponsoring Agency Code FAA/ARD-60

15. Supplementary Notes

Performed for the Spectrum Management Staff, Systems Research and Development Service, FAA.

16. Abstract

Computer models of Air Traffic Control Radar Beacon System (ATCRBS) processing equipment have been developed for use with the Transient Effects and ATCRBS IFF MARK XII System (AIMS) Performance Prediction Models. The computer programs include simulations of FAA defruiters, the analog decoder, and automated processing equipment such as the AN/FYQ-47 Common Digitizer, the Automated Radar Terminal System (ARTS) III, and the AN/TPX-42 processor set.

The Transient Effects PPM is a pulse-by-pulse simulation of ATCRBS operation, which was developed to assist in the investigation of the short-term, or transient phenomena of ATCRBS performance. The pulse-by-pulse correlation technique of the defruiter, the functions of the analog decoder, and the target-detection and code-validation functions of the digital processor have been incorporated into these models. The models which were developed for the AIMS PPM provide predictions of equipment performance in terms of probabilities of target detection and code validation.

The results of this study have been and will be useful to the FA[illegible] for the purpose of analyzing the impact of new systems, such as the Automa[illegible]minal System (ATS), and the U.S. Army Very Lightweight Air Traffic Management [illegible]ipment (VLATME) on ATCRBS processing equipment performance.

17. Key Words		18. Distribution Statement
ATCRBS	COMPUTER MODELING	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161
DECODER	ARTS III	
DEFRUITER	AN/TPX-42	
COMMON DIGITIZER		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	48	

Form DOT F 1700.7 (8-69)

175300 Jmc

PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military department and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Office of the Secretary of Defense, Director of Telecommunications and Command and Control Systems and the Chairman, Joints Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-76-C-0017, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

Reviewed by:

C. Randall Crawford
C. RANDALL CRAWFORD
Project Engineer, IITRI

J. M. DETERDING
Director of Contractor Operations

Approved by:

for R. E. BEERY
Colonel, USAF
Director

M. A. SKEATH
Special Projects
Deputy Director

METRIC CONVERSION FACTORS

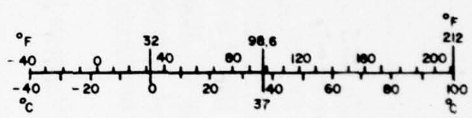
Approximate Conversions to Metric Measures

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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 236, 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



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

TABLE OF CONTENTS

Subsection | Page

SECTION 1

INTRODUCTION

SECTION 2

SYSTEM DESCRIPTION

SECTION 3

MODEL DESCRIPTIONS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

INTRODUCTION

BACKGROUND

The use of the ATCRBS[a] and IFF[b] systems for civilian air traffic control and military functions is constantly expanding. The systems are highly susceptible to self-interference, a contributing factor to which has been the increasing number of secondary surveillance radars (SSR's) in the environment. As the number of these equipments increases, the problem of managing the operation of the ATCRBS so that self-interference does not degrade system operation becomes more complex.

As a result of these concerns, the FAA tasked ECAC to develop a mathematical model which would simulate the short-term or transient phenomena associated with the performance of the ATCRBS. This simulation was intended to complement the capabilities of the AIMS Performance Prediction Model (PPM)[1] by predicting the performance of the ATCRBS on a pulse-by-pulse basis. As a part of these system simulations, ECAC was to develop models of the processing equipment used by the FAA with ATCRBS. These equipments include defruiters, decoders, and statistical target-detection equipment.

There was a need to model the following equipment for use with both the time-step and probabilistic simulations of the ATCRBS: the storage tube defruiter, the MX-8757 digital defruiter, the FAA analog decoder, the AN/FYQ-47 Common Digitizer, the ARTS III processor, and the AN/TPX-42 processor set. Modeling of the ARTS II processor was not within the scope of this project.

OBJECTIVE

The objective of this effort was to develop mathematical models of FAA defruiters, decoders, and statistical-detection equipment for use with the Transient Effects and AIMS Performance Prediction Models, to predict the performance of these equipments.

---

[a]ATCRBS - Air Traffic Control Radar Beacon System.

[b]IFF - Identification, Friend or Foe.

[1]Sutton, S. and Ehler, W., "Application of Markov Chain Theory of the Modeling of IFF/SSR Systems," *AGARD Conference Proceedings, No. 159*, NATO, November 1975.

APPROACH

Since a pulse-by-pulse simulation of the ATCRBS had already been devised by the FAA Transportation Systems Center (TSC), it was decided to adapt that model to the UNIVAC 1110 computer system. ECAC would then modify it as necessary to simulate the aspects of the ATCRBS that were not programmed into the original model.

One concern of the FAA is to be able to predict, for a given environment, the interference that will result from improperly assigned pulse repetition rates.

The first step in developing the equipment models was to determine if enough information was available about the performance of these processors, particularly the defruiters, in the presence of both near-synchronous and non-synchronous fruit. Since the information on near-synchronous fruit was not generally available, a test plan was devised to determine the reaction of the equipments to a controlled environment of near-synchronous interference and varying levels of non-synchronous background fruit. The test program was undertaken at NAFEC[a], the FAA experimental center in New Jersey. The results of the tests were used, in conjunction with available manuals and equipment descriptions, to develop the simulations.

The equipment models developed for use with the Transient Effects simulation were designed to process incoming replies, both valid and invalid, on a pulse-by-pulse basis. The basic structure of these models was derived from the original coding used in the TSC simulation. Modifications were made to include certain aspects of equipment and system operation which were left out of the original model. In addition, changes were necessary in the program coding in order to make it compatible with ECAC's computer facilities.

A major modification to the existing TSC simulation was the inclusion of transponder reply codes. The original simulation considered only the framing pulses of the ATCRBS reply. This alteration led to changes in the defruiter routines, which operate on a pulse-by-pulse basis rather than a reply-by-reply basis, and to the inclusion of code-data sampling functions for the other processors. In addition, the code-validation functions of each of the statistical detectors were modeled to complete the processor simulations.

The methods used by TSC for simulating the sliding-window detectors of the Common Digitizer and AN/TPX-42 processors were incompatible with the ECAC computer and were reprogrammed.

---

[a]NAFEC - National Aviation Facilities Experimental Center.

Models of the Common Digitizer, the ARTS III, the AN/TPX-42 processor, the analog decoder and the defruiters were also developed for use with the AIMS PPM. The methods used to develop target-detection and code-validation probabilities for the digital system, as well as the simulation of the analog equipments, involved the collection of statistics based on Monte Carlo techniques. For each processor, a new subroutine was appended to the AIMS PPM. Inputs to the subroutines are the transponder reply probabilities and fruit rates calculated by the AIMS PPM, and the parameters associated with each processor.

SECTION 2

SYSTEM DESCRIPTION

GENERAL DISCUSSION

The FAA surveillance system (ATCRBS) and the military identification system (AIMS) operate on 1030 and 1090 MHz as illustrated in Figure 1. The AIMS and the ATCRBS usually operate in conjunction with the primary surveillance radar, and the interrogator transmits coded interrogations on 1030 MHz. The transponder, mounted in an aircraft, receives the interrogations, decodes them, deactivates its receiver after each decode, transmits a reply on 1090 MHz, and reactivates its receiver in preparation for another interrogation. The interrogator's receiver system receives replies, processes them, and displays the targets on a radar plan position indicator (PPI).

Four interrogation modes (1, 2, 3/A, C) are used by both ATCRBS and AIMS to obtain position and identity information from properly equipped military and civilian aircraft. The ATCRBS equipment PRF is a submultiple of the radar PRF. When ATCRBS equipments are not used with a primary radar, an internal trigger establishes the PRF. The modes are transmitted automatically in a repetitive sequence (mode interlace) at the given PRF. Modes 1, 2, 3/A are normally used by the military for identification and air traffic control. The ATCRBS uses mode 3/A for identification and surveillance. Both military and civilian systems use mode C for altitude determination.

A more detailed description of the ATCRBS may be found in Reference 1, page 1.

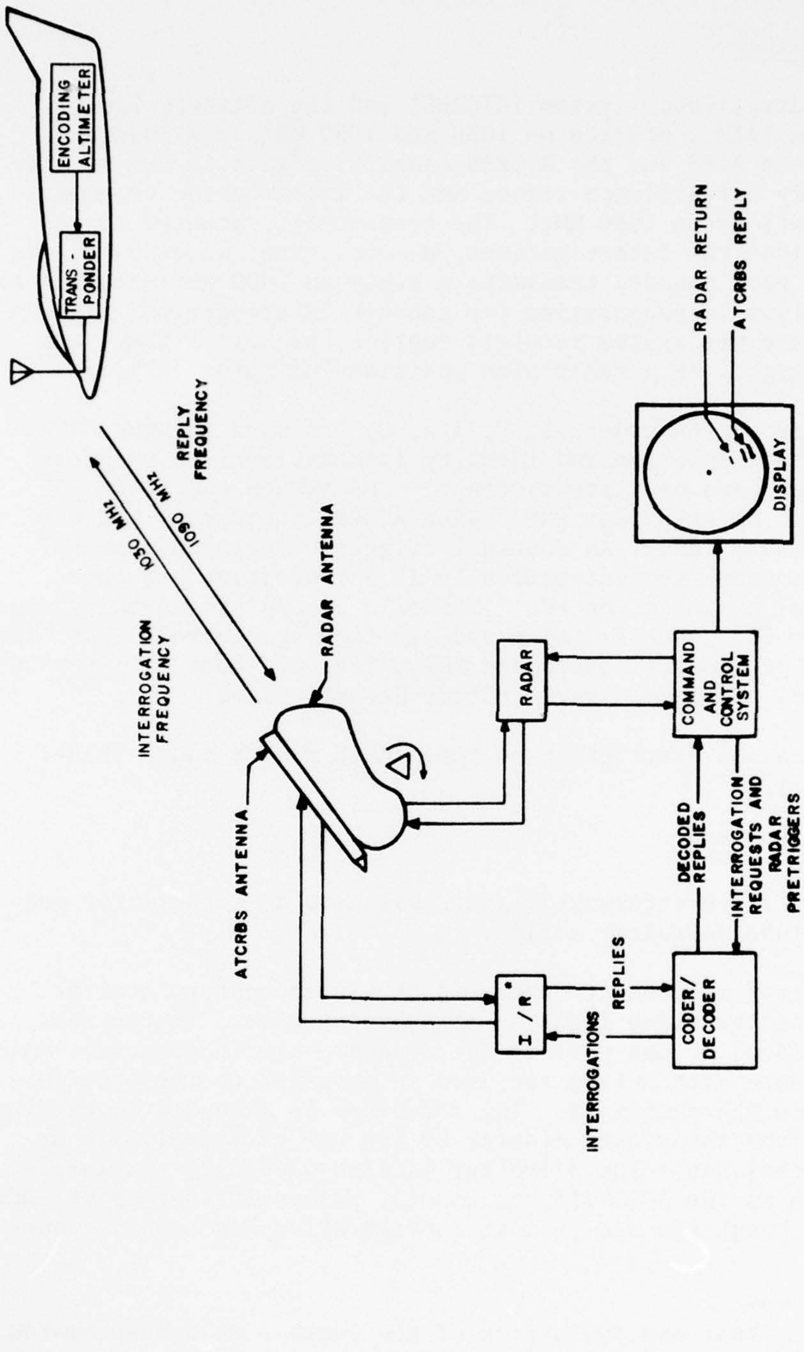
STORAGE TUBE DEFRUITER

The AN/GPX-27 interference blanker was used as a basis for modeling storage-tube defruiter action.

The defruiter is connected between the Interrogator-Receiver video output and the video input to the Decoder unit. It can pass all incoming video, or can pass to the decoder only those pulses which are in coincidence with pulses received in response to the previous interrogation on the same mode. The defruiter is intended to eliminate random pulses from the ground display by the use of correlation or coincidence techniques. The defruiter is also used with statistical processors such as the ARTS III processors, primarily to improve code validation, although its use in that configuration has been discouraged.[2]

---

[2]Holtz, Martin, *Test and Evaluation of the Level 1 Beacon Automated Radar Terminal System*, NAFEC, FAA-RD-73-182, January 1974.



*INTERROGATOR/RECEIVER

Figure 1. General configuration of ATCRBS equipments.

Each interrogator in the ATCRBS receives many asynchronous reply pulses (fruit) in addition to the synchronous replies to its own interrogation. These interference pulses affect normal ground decoding and cause code garbling, false code readouts, and clutter on the displays, making it difficult to track true target returns.

Figure 2 is a simplified system block diagram of the AN/GPX-27 storage-tube defruiter. When the unit is in standby, the video input is fed directly through a 0.6-μs delay line to output. This delay is equivalent to the insertion delay of the operating equipment and prevents any range shift in the beacon display. In the defruit condition, the video is sent to the coincidence detector unit and to a storage tube, where the signals are stored for one pulse repetition period. The coincidence stage gates the undelayed video with the video output from the storage tube on a pulse-to-pulse basis. That is, coincidence must exist between each pulse in the pulse train and the corresponding pulse in the stored video used to set up the coincidence gate (also called the acceptance gate). The output of the coincidence stage is fed to the output of the defruiter.

Interlace mode selection is initiated in the interrogator, and the interrogator mode triggers provide the defruiter with the correct sequence of operation.[3]

DIGITAL DEFRUITER

The MX-8757 digital defruiter has essentially the same function as the storage tube defruiter, but utilizes digital storage and logic circuitry for memory instead of the analog storage provided by storage tubes. Video signals of modes 1, 2, 3/A, and C are stored and compared with signals received on the previous interrogation of the same mode.

The digital defruiter accepts beacon video output from the interrogator receiver, stores it for one PRF period, and compares it with the video in the next interrogation of that interrogation mode. Correlation is accomplished on a pulse-by-pulse basis. Only those pulses received within the acceptance gates set up by the stored video will pass the defruiter.

Again, as with the storage tube defruiter, the interrogator provides the mode triggers which transmit interlace information to the defruiters.

[3]Tech Manual, *Interference Blanker Group AN/GPX-27*, AIL, T.O. 31P4-2GPX27-2, December 1968.

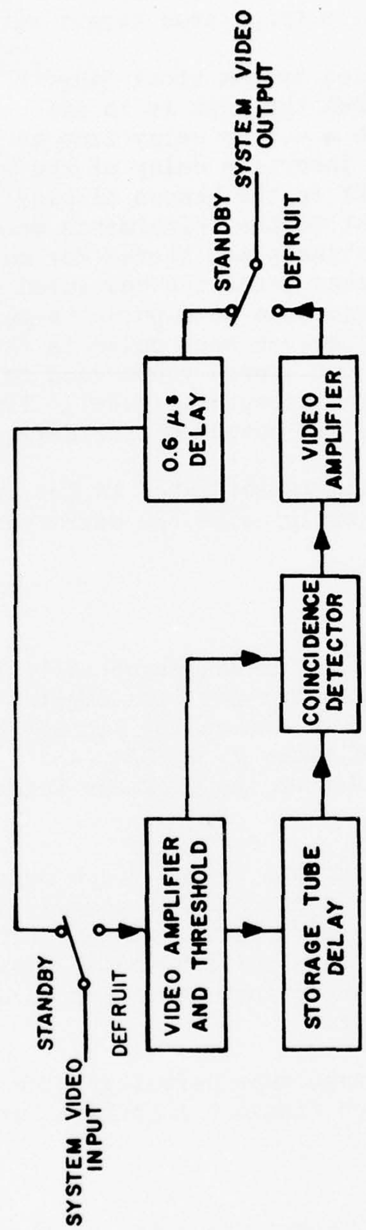


Figure 2. AN/GPX-27 interference blanker unit, simplified block diagram.

FAA ANALOG DECODER

The FAA analog decoder (or ten-channel decoder) receives beacon video from the interrogator receiver, decodes it, and transmits the information to a PPI for display. In most installations, the incoming replies are first passed through a defruiter to eliminate non-synchronous returns which the decoder might otherwise send to the display. The decoder is used in the beacon system primarily as a backup for one of the digital processors such as the ARTS III or the AN/FYQ-47 Common Digitizer.

The analog decoder normally operates in one of two modes. In the first mode, a pulse is passed to the display each time a pair of bracket pulses (the transponder reply) is detected. In this case, when a pulse is received, the decoder requires another pulse 20.3 μs later to complete the bracket pair. The tolerance on the leading edge detection of the framing pulses is approximately ±0.6 μs.[4]

The decoder can also be set to detect certain code pulses and display only those aircraft that respond with that particular code. In this case, after a pair of framing pulses have been detected 20.3 μs apart, the pulse positions between the framing pulses are checked for the presence of a code pulse. The decoder looks for only the "A" and "B" pulses of an ATCRBS reply or the equivalent of a two-digit code. The tolerance on code-pulse detection is ±0.1 μs from the leading edge.

The analog decoder has no wide-pulse discrimination; therefore, overlapping pulses will result in decoding an apparent single pulse. The decoder has built-in narrow-pulse discrimination, in that pulses with a width less than 0.35 μs (National Standard) are not detected.

THE ARTS III SYSTEM

The ARTS III[a] system accepts beacon video from the ATCBI-3 or ATCBI-4[b] and converts it into digital target reports. The ARTS III tracking program utilizes the target reports to generate target tracks. For each tracked target, a data block that includes target identity, velocity, altitude (for mode C-equipped aircraft) and an indication of a special identity pulse is displayed adjacent to the physical location of the target track on the ARTS display.

The ARTS III System includes the Beacon Data Acquisition Subsystem (BDAS), the Input/Output Processor (IOP), a digital tape drive, a

[a]Automated Radar Terminal System.

[b]Air Traffic Control Beacon Interrogator.

[4]Discussion with C. A. Gobs, FAA, Leesburg AR May 1975.

teletype, and several displays. Figure 3 shows an ARTS III system at NAFEC.

Beacon Data Acquisition Subsystem (BDAS)

The BDAS is a beacon processor that performs azimuth decoding, mode-trigger recognition, bracket detection, identity, altitude code-pulse recognition, and garble sensing, and transfers the above data in digital form to the Input/Output Processor (IOP) (Reference 2). In addition, the BDAS provides partially decoded beacon video (brackets) to the display subsystem via an analog channel. The BDAS consists of an Azimuth, Range, and Timing Group (ARTG), a Beacon Reply Group (BRG) and an Azimuth Pulse Generator (APG). A block diagram of the BDAS is shown in Figure 4.

Azimuth, Range, and Timing Group (ARTG). The ARTG accepts the beacon pretriggers and the azimuth-change and reference pulses from the Azimuth Pulse Generator (APG) and synchronizes the BDAS to these inputs. In addition, mode triggers are received and examined to determine if mode 3/A or C is being interrogated.

Beacon Reply Group (BRG). The BRG extracts beacon reply information from the incoming beacon video. Pertinent operations performed in the BRG are:[5]

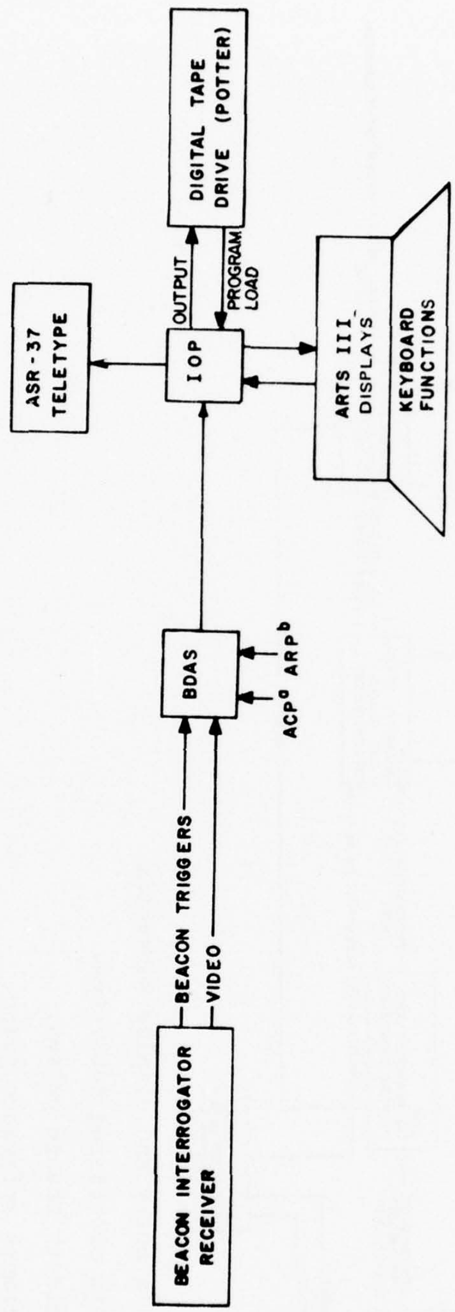
1. Video conditioning and suppression.
2. Bracket detection.
3. Code data sampling.
4. Garble sensing.
5. Quantization for PPI display.

A pulse-width detector is used preparatory to reply decoding to sense the pulse width of the beacon pulse and determine if a maximum pulse width is exceeded. If a wide pulse is detected, overlapping pulses are assumed to be present, and an estimated leading edge is inserted into the shift register at the time the trailing edge would normally be detected.

A shift register delay line is employed to detect the presence of framing pulses and information-code pulses. A detection tolerance of ±0.1 or ±0.2 μs can be selected.

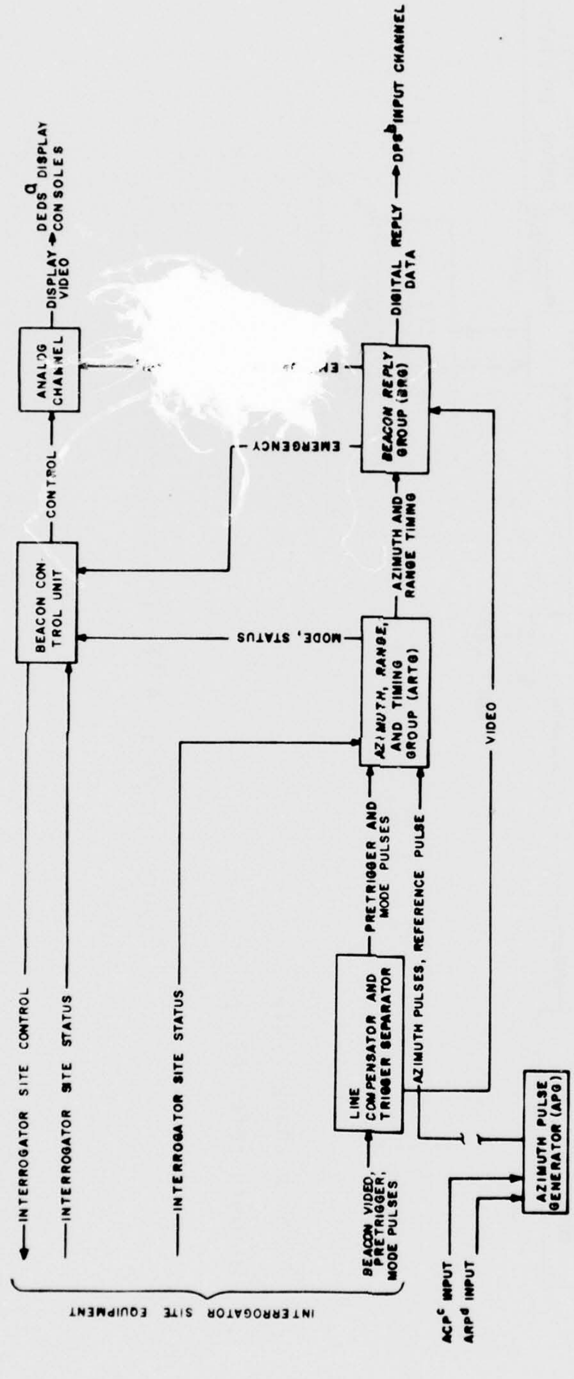
A garble situation is reported when one or more pulses of one reply appear at pulse positions of another reply. Such replies are flagged as garbled and transferred to the IOP for code-validation functions.

[5] *Data Acquisition Subsystems*, Burroughs Corporation, DOT-FA69NA-2071, October 1971.



[a]Azimuth change pulses.
[b]Azimuth reference pulse.

Figure 3. Basic ARTS III configuration.



[a]Data entry and display subsystem.
[b]Data processing subsystem.
[c]Azimuth change pulses.
[d]Azimuth reference pulse.

Figure 4. Functional block diagram of the ARTS III beacon data acquisition subsystem.

Input/Output Processor (IOP)

The IOP accepts azimuth information, coded replies, and status-information words from the BDAS and performs target-detection, target-tracking, and display functions (Reference 2).

Two alternating input buffers are used to process incoming reply data. The replies are merged with existing reply data to form a new target record. This process results in a new record, a hit, or a miss. An incoming hit to an existing target record must have a range within ±1/16 nmi of the record range.

Target Detection Logic. Target detection is performed by an expanding-window technique. Target leading edge (T_L) is declared if N hits are received before M consecutive misses. When a possible T_L has been detected, an expanding window is constructed beginning with the first hit used to declare T_L. The window is actually a combination of hit, miss, and interrogation counts. Target processing continues for a number of interrogations to guard against split targets. A minimum run length must be obtained, and trailing edge (T_T) is declared after a number of consecutive misses are received. If T_T has not occurred after a number of sweeps, the target is declared a ring-around target. Sample target-detection parameters are listed in TABLE 1.

Four counts are maintained during the target-detection process. These are a hit count, miss count, interrogation count and a "Sum-H" count. The miss count is cleared upon the receipt of each hit. "Sum-H" is maintained by incrementing the count by the value of the interrogation count each time a hit is detected. The "Sum-H" count is used in the calculation of target azimuth.

The center azimuth of the target is calculated as follows:

$$\text{AZc} = \text{AZt} - f\ (\text{INTERROGATIONS-SUM-H/HIT})$$

where

AZc = Center azimuth

AZt = Azimuth at trailing edge

f = Center azimuth coefficient in azimuth change pulses (ACP's)

TABLE 1

ARTS III DETECTOR THRESHOLD PARAMETERS

Description	Parameter Values for Mode 3/A-Only Interlace						Parameter Values for Modes 3/A, 3/A, C Interlace					
	Detection Parameter Set No.						Detection Parameter Set No.					
	1	2	3	4	5	6	1	2	3	4	5	6
Number of consecutive misses prior to T_L to discard a record as fruit	3	3	4	4	4	4	2	2	3	3	3	3
Number of hits required to declare T_L	3	2	2	2	2	2	3	2	2	2	2	2
Number of consecutive misses after T_L to declare T_T	5	5	4	4	4	4	4	4	3	3	3	3
Minimum number of hits required to class a record as a valid target	5	5	4	5	3	4	7	7	6	7	4	5
Minimum number of interrogations which must be observed before T_T can be declared	20	20	15	15	15	15	20	20	15	15	15	15
Number of hits to declare a strong target	9	9	8	8	8	8	13	13	9	9	9	9

SUM-H = "SUM-H" Counter

HIT = Hit Counter

Code validation begins as soon as the target leading-edge flag is set. Validation is done on both modes A and C.[6] The four levels of code validation are defined as follows:

1. Mode 3/A identity

   a. All replies garbled
   b. One ungarbled reply
   c. One garbled reply, codes match
   d. Two consecutive ungarbled replies, codes match.

2. Mode C altitude

   a. No mode C replies
   b. All replies garbled
   c. One ungarbled reply
   d. Two consecutive ungarbled C replies.

In addition to simple target detection, the IOP also supplies a strong-target azimuth confidence label for those targets exceeding a specified run length. This label indicates that the target is of sufficient run length to provide an accurate azimuth report.

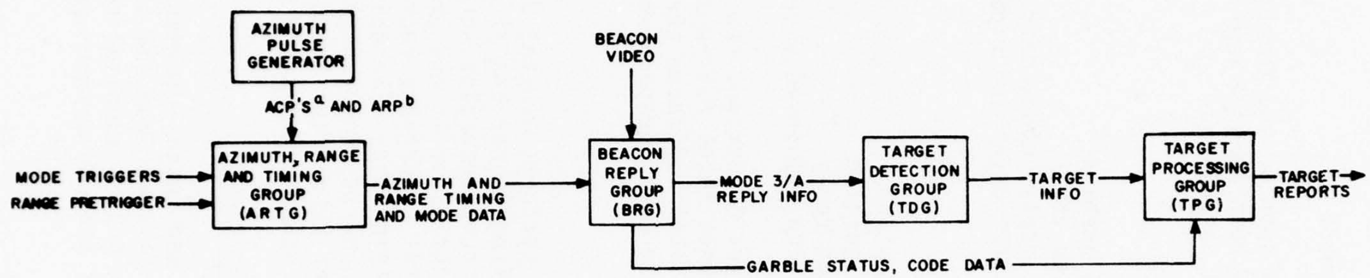
COMMON DIGITIZER AN/FYQ-47

The common digitizer (CD) performs digital data processing on beacon and radar video inputs from either FAA or Air Force equipment. The CD applies a statistical target-detection scheme to these inputs to declare the presence of target aircraft and prepares digital messages for transmission to central processing centers. The units of the CD pertinent to this discussion are: the Azimuth, Range, and Timing Group (ARTG), the Beacon Reply Group (BRG), the Target Detection Group (TDG), and the Target Processing Group (TPG). Figure 5 is a block diagram showing the beacon-processing portion of the CD.

Azimuth, Range, and Timing Group (ARTG)

The ARTG supplies azimuth and range information to the CD. The azimuth information is usually derived from the azimuth-pulse generator on the radar antenna. The pulses supplied to the ARTG include the azimuth-change pulses (ACP) and one azimuth-reference pulse for each rotation of the antenna.

[6] *ARTS III Coding Specifications*, NAFEC, Atlantic City, NJ, August 1972.



[a] Azimuth change pulses.

[b] Azimuth reference pulse.

Figure 5. Block diagram of AN/FYQ-47 common digitizer beacon processing.

The range timing is set by the range pretrigger from the radar. The mode-trigger pulses from the interrogator are also decoded in the ARTG.

Beacon Reply Group (BRG)

The BRG detects and processes beacon video received for modes 2, 3/A, and C. When a reply is received in the response to one of these modes, the incoming pulses are sampled for the 20.3 ± 0.1 or 0.2 μs pulse spacing required for the framing pulses, and a bracket pulse is generated for each pair of framing pulses received. The code-data bits are examined serially at 1.45 μs intervals to determine beacon code. Only mode 3/A replies are passed to the Target Detection Group for statistical processing.

Garble Sensing. After the receipt of two code trains where two sets of framing pulses are received within 40.6 μs, three conditions can result in the BRG:

1. Closely spaced replies are not garbled.
2. Interleaved replies are not garbled.
3. Overlapped interfering replies are garbled and flagged.

The garble flags are used in the code validation process of the Target Processing Group.

Target Detection Group (TDG)

The statistical detector employed by the CD utilizes a sliding-window technique to determine the presence of a target aircraft. When mode 3/A replies are received and detected by the BRG in the same range cell, they are passed to the TDG for inclusion in the sliding window. The window is 11 bits long and is a series of ones and zeros, with the ones representing received replies. Each time a mode 3/A interrogation/reply sequence occurs, either a one or a zero is placed in the first position in the window and the previous 10 bits in the range cell are shifted back in the memory, thus eliminating the eleventh bit. After each shift sequence, the number of hits is totaled and compared against a target leading-edge threshold (T_L). After T_L has been declared, the TDG continues to process incoming replies until the total window count is reduced to the target trailing edge threshold (T_T), and a target is reported. In addition to these two thresholds, a begin-validation threshold (T_V) is set which initiates code validation processes in the Target Processing Group.

The TDG will report only one target per quarter-nautical-mile range cell. The range accuracy is 1/8 nmi, as the target is flagged in either the first or second half of the range cell. The azimuth accuracy of the beacon is ± 3 ACP's. Typical target leading edge and target trailing edge thresholds are T_L = 6 or 7, and T_T = 2, respectively. Trailing edge (T_T) is actually declared at one less than T_T, or a value of 1. T_V is set at 3 or 4.

Azimuth Centermark

The center azimuth is calculated in the following manner. The number of ACP's at trailing edge detection time is added to the number of ACP's at the time of target start and divided by two. The azimuth bias is added (clockwise or counterwise) to account for beacon search antenna offset.

Target Processing Group (TPG)

The TPG, in addition to providing a storage area for data associated with each target detected in the TPG, works with the BRG to perform code-validation functions for the CD. Code validation is performed for modes 2, 3/A, and C. The TPG simply compares sequential replies in the same mode, and if the code data bits match and no garble flags are associated with either return, the code for that mode is validated. This process is continued until the code is validated or the target ends.[7]

THE AN/TPX-42 INTERROGATOR/PROCESSOR SET

The AN/TPX-42 Interrogator/Processor Set generates interrogations and receives and processes replies on modes 1, 2, 3/A, and C. The processor portion of the AN/TPX-42, called the Beacon Reply Processor (BRP), is made up of two units: the Reply Detection Unit (RDU) and the Target Detection Unit (TDU) as seen in Figure 6. The primary function of the BRP is to process the incoming beacon video and produce a single digital target report for each aircraft.

Reply Detection Unit (RDU)

The RDU accepts azimuth change pulses (ACP's) and one azimuth reference pulse per scan, converted to digital azimuth information from the azimuth pulse generator. Mode triggers are also decoded by the RDU and the beacon video is fed directly to the RDU input.

The RDU performs bracket detection on the incoming video with a sensing tolerance of 20.3 ± 0.15 μs. After detection of the framing pulses, the RDU checks the code data positions of the beacon reply in 1.45 μs-increments.

---

[7]Technical Manual, *Transmitting Set, Coordinate Data*, AN/FYQ-47, AN/FYQ-49, February 1972.

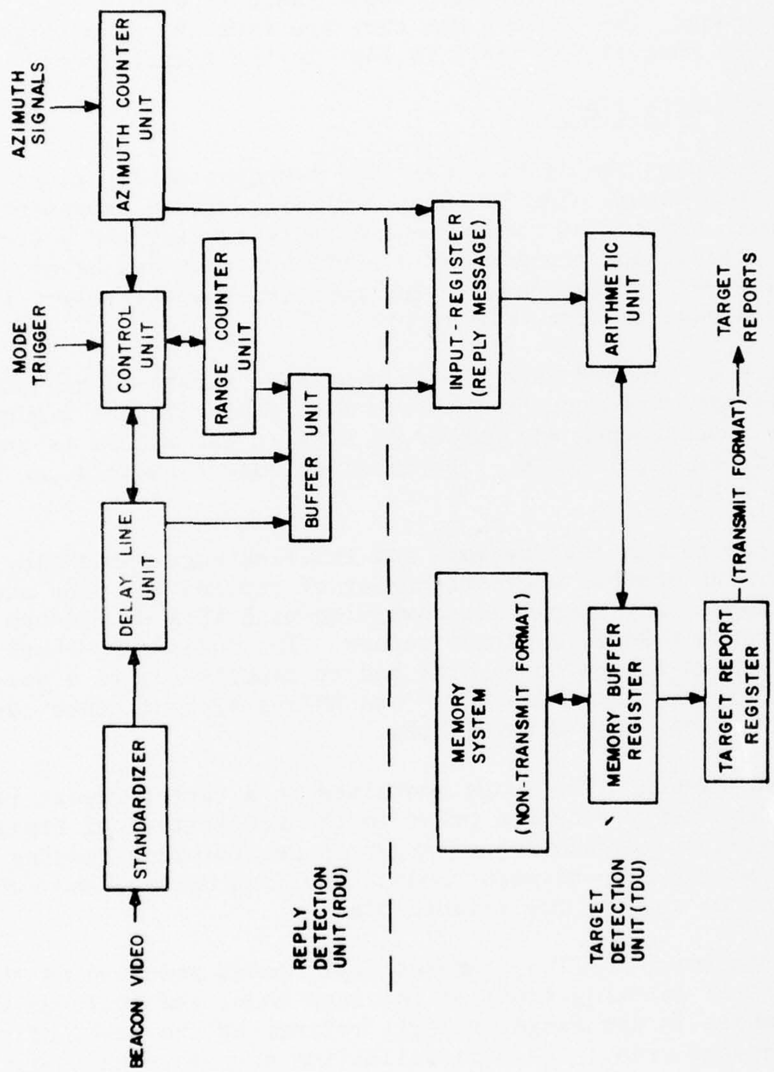


Figure 6. Block diagram of AN/TPX-42 beacon reply processor.

Garble sensing is also accomplished in the RDU. If a garble situation is detected, an indicator is set in the reply message which is sent to the Target Detection Unit. The garble flag is set if, after the RDU detects a reply, another bracket decode is detected which overlaps and falls in a code-data pulse position of the first reply.

The range-correlation technique of the RDU is such that the range of an incoming reply is compared with that of the reply received on the previous sweep. If the incoming reply range is within ± 1/16 nmi of the record range, the RDU assumes they are from the same target. The range of the most recent reply is kept in the target record.

Target Detection Unit (TDU)

The TDU performs the statistical target-detection functions of the AN/TPX-42 processor. The TDU uses a sliding-window representation of the past history of target replies to establish the presence of a target. The window consists of a series of ones and zeros, representing received replies and missing replies, respectively. The length of the window is from 8 to 12 bits.

The target is started when the leading-edge threshold has been reached. This threshold can be set from 1 to 4 hits in the window. Target end is reached when the number of hits in the window is reduced to the trailing-edge threshold. The trailing-edge threshold can be set from 0 to 2 hits.

In addition to the leading-edge and trailing-edge threshold, the TDU will determine whether a preset number of replies has been received in a primary mode. Any target not complying with this confidence check will not be transmitted as a target report. The confidence-check level can be set anywhere from 0 to 31 hits and is usually set to 6 mode-A replies on a 2:1 interlace (AACAAC). The AN/TPX-42 confidence check level can be anywhere from 0 to 31 hits.

Range and Azimuth. The range contained in a target report is the range of the last reply received prior to the declaration of trailing edge. The center of azimuth for a target is determined by adding the leading and trailing-edge azimuth counts, dividing by two, and subtracting a constant to account for azimuth bias.

Code Validation. The TDU compares reply codes received as the result of sequential interrogations of the same mode, and includes code-validation numbers in the target report, reflecting the level of confidence in a reported code. The code-validation numbers, and their meaning,[8] are shown below:

---

[8]CEI Detail Specification, *Interrogator Set AN/TPX-42*, January 1966.

0. No replies received on the indicated interrogation mode.
1. Only garbled reply codes reported.
2. A non-garbled code received, but back-to-back code content does not match.
3. Two back-to-back matching non-garbled reply codes received on the indicated interrogation mode.

SECTION 3

MODEL DESCRIPTIONS

GENERAL DISCUSSION

The description of the equipment models is divided into two subsections. The first subsection deals with the models designed for use with the ATCRBS Transient Effects PPM, which was developed at TSC and adapted to the ECAC UNIVAC 1110 computer. These processor models were designed to simulate the operation of the equipment as each pulse passed through the processing system. The second subsection deals with the processor models developed for use with the AIMS PPM (Reference 1), a time-average model system that generates probabilistic evaluations of equipment performance.

ATCRBS TRANSIENT EFFECTS PPM/EQUIPMENT MODELS

Defruiters

Since the coincidence-detection techniques of the digital and storage-tube defruiters are similar, with the exception of the method of storage, the following discussion of defruiter modeling will apply to both equipments.

Code pulses. The original TSC model provides the defruiter simulation an array of reply pulses consisting of the two framing pulses of the ATCRBS reply. Since the defruiter performs its correlation techniques on a pulse-by-pulse basis, the inclusion of reply-code pulses was essential. At the point in the simulation where the sensitivity of the interrogator receiver is compared with the signal level of the incoming pulses to determine which pulses are received, a check is made to determine which aircraft is responding, and the assigned reply code is examined to calculate the elapsed time of each code pulse as it is entered into the array. The change in receiver sensitivity determined by the Gain-Time Control (GTC) characteristic of the interrogator of interest is considered as each new pulse signal level is compared with the receiver sensitivity. The pulses are then reordered chronologically before they are processed by the defruiter.

Acceptance Gate. Simulating the defruiter operation requires that the size of the acceptance gate reflect the actual width of the gate and the minimum pulse width which can be detected by the processor fed by the defruiter. Figure 7 demonstrates the idea of a minimum usable pulse in calculating the effective acceptance gate of the defruiter, given a particular equipment configuration. In Figure 7, the minimum usable pulse for the ARTS III processor is 0.21 μs, while the "acceptance gate" is shown to be ± 0.79 μs. In other words, an incoming pulse would have to overlap the defruiter acceptance gate by at least 0.21 μs in order to be

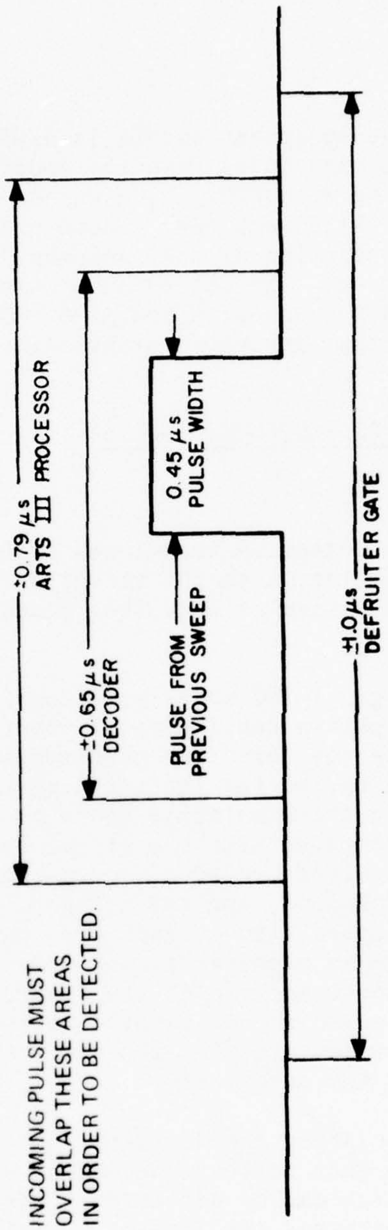


Figure 7. Defruiter acceptance gate.

detected by the ARTS III processor. Since the analog decoder requires a pulse width of 0.35 μs, the effective gate size decreases to ± 0.65 μs. In the simulation, the difference in times of arrival of the leading edges of two pulses is calculated and compared to the effective acceptance gate to determine whether a usable pulse will pass to the output of the defruiter.

Correlation Techniques. This part of the simulation is derived from the TSC model. The defruiter routine is divided into four parts, one for each interrogation mode (1, 2, 3/A, C). Each part is identical to the other parts except for the array in which the pulses from the previous sweep of that mode are stored. The defruiter is simulated as follows:

1. The mode of interrogation is determined.
2. Incoming pulses are stored in an array for comparison on the next interrogation.
3. The differences in elapsed time between incoming pulses and pulses received on the last interrogation of that mode are calculated.
4. This difference is compared against the size of the acceptance gate to determine if the pulse can be passed to the output of the defruiter.
5. The array of pulses is restructured to include only those pulses accepted by the gate.

The size of the acceptance gate of the storage tube and digital defruiters has been determined through testing and is a variable in the simulation.

FAA Analog Decoder Model

The introduction of reply-code pulses into the simulation entailed restructuring of the decoder model supplied with the TSC simulation. The input to the decoder consists of the aforementioned array of reply pulses. The defruiter routine may be switched either on or off before the beacon video simulation is passed through the decoder.

The decoder model steps through the chronologically ordered array or reply pulses, checking for pulse separations of 20.3 μs. The tolerance on the detection of the framing pulses is an input variable. The detected-reply range is loaded into a new array. After a bracket pair is detected, a new subroutine, called DECODE, performs code-pulse detection. In this subroutine, the intervening pulses are checked to determine if they fall in a code-pulse position. The criterion used is a spacing of n(1.45) ± 0.1 μs from the first framing pulse. The letter n refers to the multiple of 1.45 μs for which the "A" and "B" code pulse positions exist.

After the routine has determined which code pulse positions are filled, the code of the reply is loaded into another array and control is returned to the main program. The program can later be switched to display "brackets only" or targets replying with a specified code.

AN/FYQ-47 Common Digitizer Model

The model of the Common Digitizer (CD) used with the Transient Effects PPM has the same structure as the original TSC simulation, with one modification and one additional routine. The modification consists of reprogramming the sliding-window function of the Common Digitizer (CD) for compatibility with the ECAC computer, and limiting the amount of core storage required. The additional routine, necessary to complete the simulation of the beacon processor portion of the CD, is a model of the code-validation functions performed in the Target Processing Group (described in Section 2). Also included is a simulation of the garble conditions required as an input to the code-validation subroutine. The input and output variables are listed in TABLE 2. The CD model operates as follows:

1. Preparatory to entering the statistical detector routine, bracket- and code-pulse detection is accomplished in a manner similar to that discussed above for the decoder model. Detection tolerances are set as per the discussion in Section 2.
2. Garble detection is simulated as follows: if a bracket pair is detected which overlaps and falls in the pulse position of a previously detected bracket pair, both replies are flagged as garbled.
3. Mode 3/A interrogation is checked. If not mode 3/A, control is transferred to the code-validation routine in Step 13. If 3/A, statistical detection is continued.
4. Azimuth degrees are converted to azimuth-change pulses.
5. A check is made for replies at the current azimuth. If there are none, the contents of the sliding window are shifted back in the memory, and a zero is added in the first slot in the window. This is done for all range bins. The window consists of a series of ones and zeros in the 11 right-most bits of a computer word. Updates are made in the right-most bit. This configuration helps conserve available core-storage area.
6. A similar process is followed for a hit, in that a one is entered in the right-most bit, and the contents of the window are shifted left.
7. The window count is compared against target-start and target-stop thresholds.
8. If target start occurs, the leading-edge flag is set and the start azimuth is recorded.

TABLE 2

AN/FYQ-47 COMMON DIGITIZER MODEL/TRANSIENT-EFFECTS PPM INPUT AND OUTPUT VARIABLES

Inputs
Window Length
Target Leading Edge Threshold
Target Trailing Edge Threshold
Reply Ranges
Reply Codes
Garble Status
Outputs
Target Start Azimuth
Target Stop Azimuth
Corrected Center Azimuth
Target Range
Reported Code
Code Validation Status

9. If target end occurs, and the leading-edge flag has been set, target-end azimuth is recorded.

10. After the target ends, the center azimuth is computed as follows:

a. Average the target start and stop azimuths.
b. Subtract a bias:

BIAS = [(ITL-1) + (IWNL + 1-ITL - ITT)/2.]

where

ITL = Target leading-edge threshold

IWNL = Window length

ITT = Target trailing edge threshold.

Bias is converted to ACP's before correcting the azimuth.

11. Range is calculated by finding the correct range bin for the reply, and setting a flag in the half of the range bin in which the reply exists to obtain 1/8-nmi accuracy.

12. After processing all replies, the remaining range bins are updated with zeros.

13. Code validation processes are simulated in the CD model for modes 2, 3, and C. Validation for modes 2 and C is done automatically, switching past the statistical detection routine. The following steps are taken:

a. The target record is checked to see if the mode has already been validated.

b. If not, the code of the incoming reply is compared with the code received on the last interrogation of that mode, if a reply was received.

c. If these codes match, and the garble flags of both replies are set to zero, the code for that mode is validated.

d. The code validation information is added to the target report printout.

14. The leading-edge flag is reset to zero, and a target report is printed including:

a. Range bin (nmi)
b. Start azimuth (ACP's, degrees)
c. Center azimuth (ACP's, degrees)
d. End azimuth (ACP's, degrees)
e. Code validation information.

ARTS III Processor Model

The only substantial changes made to the original simulation of the ARTS III beacon processor were the inclusion of garble-sensing and code-validation routines. The inputs to the ARTS simulation and the performance outputs are listed in TABLE 3. The operation of the model is as follows:

1. The BDAS portion of the ARTS beacon processor is simulated by bracket-and-code-pulse-detection coding similar to the ten-channel decoder model. The array of reply pulses is examined for pulse spacings of 20.3 (± 0.1 or 0.2) μs. The intervening pulses in the array are checked to determine if they occur in code pulse positions of the reply.

2. When a 20.3-μs bracket pair is detected that overlaps a previously detected pair, the model determines whether code-pulse positions have been entered by the overlapping reply. If so, both replies are flagged as garbled.

3. The ARTS routine first checks the mode of interrogation. If not mode A or C, the number of replies is set to zero. Otherwise, processing continues normally.

4. The maximum number of in-process targets is 45. Target records are kept in an old-target register, and when updated, the result is stored in a new-target register.

5. If a reply is received which begins a new target, a target record is created at the reply range, and the hit, sweep, and "sumh" counts are set equal to one. (See Section 2 for a description of the ARTS III Processor). Also, the miss count and leading-edge flags are set to zero. The new target is then transferred to the old-target register.

6. On each interrogation, the incoming reply ranges are compared with the range recorded in the old-target register. If the incoming range is within ± 1/16 nmi of the record range, the reply is recorded as a hit. All existing targets which are not recorded as hits are updated with a miss. When a hit is recorded the miss count is set to zero, the "sumh" count is incremented by the interrogation number, and the interrogation count is incremented.

7. After each update, the target-detection thresholds are compared with the appropriate counts. If the leading-edge flag is still zero, the hit count is checked against the target-start threshold and the miss count is checked. The flag is set if the specified number of replies for leading-edge declaration has been received before a specified number of consecutive misses.

8. If the leading-edge flag has been set and a miss occurs, the number of consecutive misses in the register is checked against the target-end threshold to determine if the trailing edge has been reached.

9. Before a target is declared, the total number of hits is compared with a minimum-run-length threshold.

TABLE 3

ARTS III PROCESSOR MODEL/TRANSIENT EFFECTS PPM
INPUT AND OUTPUT VARIABLES

Inputs
Target Detection Parameters (see TABLE 1)
Reply Ranges
Reply Codes
Garble Status
Outputs
Target Range
Corrected Center Azimuth
Sweep Count
Hit Count
Sum-H Count
Strong Target Label
Reported Code
Code Validation Number

10. The run length of the target is also compared against another threshold which, if exceeded, causes a strong-target azimuth confidence label to be included in the target report.

11. The number of interrogation sweeps over which a target continues is compared with a ringaround threshold which, if reached before target end, causes the target to be declared ringaround (i.e., the target does not end, creating a circle of replies on a PPI). The record is then deleted from the register.

12. Code validation is performed for both mode A and mode C.

13. A validation number for each mode is contained in the target report. For mode A, the code bits and garble status of consecutive replies from that mode are compared and a corresponding validation number assigned. Validation level zero is assigned if all replies have garble tags, level one if one reply is ungarbled, level two if one is ungarbled and the decoded code bits match, and level three if consecutive ungarbled replies with matching codes are received.

14. Mode C validation levels are checked in the same manner, with validation level zero meaning no mode C replies received. Level one is assigned if all replies are garbled and level two if a single reply is ungarbled. Level three is assigned if two consecutive ungarbled replies occur with identical codes.

15. The output from the ARTS III simulation consists of the following:

a. Range
b. Center azimuth
c. Sweep count
d. Hit count
e. Sum-H count
f. Strong-target azimuth confidence label, if reached
g. Mode A code validation number and code
h. Mode C code validation number and code.

AN/TPX-42 Processor Model

The simulation of the AN/TPX-42 processor is similar to the ARTS III simulation in that, in both processors, the reply ranges are merged with an in-process target array in which incoming ranges are compared with the record range of the most recent reply. The Common Digitizer compares incoming reply ranges with the recorded range at the time of declaration of target leading edge. The TPX-42 employs a sliding-window detector similar to that of the CD, as opposed to the more complex algorithm used by the ARTS III processor.

The model of the TPX-42 used with the Transient Effects PPM is the same as the one included in the TSC simulation, with the exception of the following:

1. Programming of the sliding-window function is different.
2. Simulation of the Reply Detection Unit includes code-pulse recognition.
3. Code-validation functions are simulated.

A list of input and output variables is provided in TABLE 4. The flow of the TPX-42 computer model is as follows:

1. The incoming-reply pulse array is analyzed for pulses arriving with a spacing of 20.3 ± 0.15 μs. Each time that spacing is sensed, the intervening pulses are tested to determine which pulses are located in code pulse positions as measured in 1.45-μs (± 0.1 μs) intervals from the first framing pulse.
2. If two other pulses in the array are found to be 20.3 ± 0.15 μs apart, and they are detected before the occurrence of the second framing pulse of the first detected bracket pair, the model switches to the garble sensing routine. A garble flag is set for both of these replies if the second reply overlaps a pulse position of the first. The garble flags and reply codes are used later in the program for code validation purposes.
3. All replies are processed by the TPX-42, regardless of the interrogation mode. A maximum of 20 replies can be processed on one interrogation.
4. When the first reply in the array is processed and no target records exist in the register, a new record is inserted. The range (nmi) and azimuth (ACP's) of the reply is recorded, and a "one" is inserted into the first bit in the sliding window.
5. As replies are received on subsequent interrogations, the reply ranges stored in the reply array are compared with the recorded ranges in the existing-target register. If a reply range is within the range tolerance (usually ± 1/16 nmi) of an existing recorded range, the reply is entered as a hit in the sliding window. For targets for which no reply exists on a given interrogation, a zero will be inserted into the window.
6. After the receipt of a valid hit, the mode of interrogation is checked. If a mode 3/A interrogation had been transmitted, the confidence count is increased by one.
7. After receipt of a hit, the number of "ones" in the sliding window is compared with the target leading-edge threshold to determine if target start has been achieved. If a miss has occurred, the program checks to determine if the number of "ones" in the sliding window has been reduced to the value of the target trailing-edge threshold. If trailing edge is detected, and the leading-edge flag had been previously set, the target will be detected provided the mode 3/A confidence-count threshold has been reached.

TABLE 4

AN/TPX-42 PROCESSOR MODEL/TRANSIENT EFFECTS PPM
INPUT AND OUTPUT VARIABLES

<u>Inputs</u>
Window Length
Target Leading Edge Threshold
Target Trailing Edge Threshold
Reply Ranges
Reply Codes
Garble Status
<u>Outputs</u>
Target Start Azimuth
Target Stop Azimuth
Corrected Center Azimuth
Target Range
Reported Code
Code Validation Number

8. The center azimuth of a detected target is calculated by adding the number of ACP's at leading and trailing edge, dividing by two, and subtracting a bias value. The target range is the value of the last recorded reply range.

9. Code validation is accomplished by using information from the routine which performs code-pulse recognition and garble sensing. Validation numbers are calculated by comparing the codes and garble status of consecutive mode 3/A or mode C replies. Numbers are assigned corresponding to the following conditions: level zero when no replies are received on that mode, level one when only garbled codes are reported, level two when a non-garbled reply is received, and level three when two consecutive non-garbled replies with identical codes are received on the indicated mode.

10. A target report from the TPX-42 computer model consists of the following:

a. Range
b. Start azimuth
c. Stop azimuth
d. Center azimuth
e. Confidence check (number of 3/A replies)
f. Code validation number and reported code.

AIMS PPM/EQUIPMENT MODELS

All of the beacon processor models developed for the AIMS PPM use the technique of random sampling to predict equipment performance. Predictions of reply probability and fruit rate from the AIMS PPM are entered into a Monte Carlo type of event generator. Random numbers are generated and applied to the probabilities of reply and garble to dictate the occurrence of a hit, a miss, or a garbled reply. For the analog equipment, the probability of display of a correctly coded reply is generated, and the digital processor simulations predict the probability of target detection and the probability of code validation. The number of trials used is a compromise between minimal error and excessive computer run time.

Defruiter/Decoder Model

In the process of improving the appearance of the PPI display by reducing the amount of fruit, defruiter action also 1) eliminates the first reply received on each mode, 2) increases the number of missing replies, and 3) passes incorrectly coded replies to the processor. All of these factors are taken into account in the computer simulation of the defruiting and decoding equipment.

The defruiter model used with the AIMS PPM accepts the following inputs:

1. Reply probability of the transponder-equipped aircraft.
2. Fruit per second at the interrogator of interest while the mainbeam is pointed at the aircraft.
3. Hits per victim-interrogator mainbeam width.
4. Mode interlace.
5. Average number of code pulses in a reply.
6. Acceptance gate of the defruiter.

As output, the simulation generates a new reply probability and the probability of garble resulting from defruiter action. With the decoder switch on, the subroutine generates the probability of displaying a correctly coded reply.

The defruiter and decoder simulations operate as follows:

1. The number of correlated replies is initialized to zero. The defruiter storage flag is set to zero.
2. The probability of a garbled code is calculated from the following equation:

$$P\ (\text{Garble}) = \left[\left(1 - e^{-\lambda t}\right)^2\right] \cdot \frac{NG}{t}$$

λ = fruit rate/second

t = SIF[a] reply length = 20.3 μs

N = number of empty pulse positions

G = acceptance gate providing minimum usable pulse to the decoder.

The above equation is based on the assumption that fruit replies are Poisson distributed. In addition, the occurrence of fruit on consecutive sweeps in an empty pulse position of a valid reply is required for a garble condition to pass a defruiter. Therefore, the probability of at least one overlap of a valid reply by fruit is squared and then limited by a factor determined by the available pulse positions. The expression $(1 - e^{-\lambda t})$, developed in Reference 1, evaluates the probability of at least one overlap in a specified period, t.

3. A random number between zero and one is selected and compared with the transponder reply probability. If the random number

---

[a]Selective Identification Feature.

is less than that value, a reply is assumed to have been received. If not, a miss is assumed, the defruiter storage flag is set to zero, and processing continues with the next sweep.

4. If the analog decoder is the beacon-code detection unit to be analyzed, the routine checks for a possible garble condition by selecting another random number and comparing it with the probability of code garble. If a garble occurs, the hit count for correctly coded replies is reduced by one.

5. A check is made to determine if a reply is in storage from the last interrogation of the present mode. The incoming reply sets the flag in storage for the next sweep of that mode.

6. If a flag exists in storage for the last interrogation of that mode, the hit count is increased by one. The routine then proceeds to the next sweep.

7. A new probability of reply is calculated by dividing the number of received replies by the number of trials.

8. The decoder function is switched on in the defruiter routine. The output is the probability of display of a correctly coded reply.

9. If the ARTS III or TPX-42 processors are to be analyzed, the reply probability after the defruiter is passed to the digital processor routine. The probability of garble is also passed to the processor subroutine.

ARTS III Processor Model

The simulation of the ARTS III beacon processor is also based on a Monte Carlo technique of event generation. The inputs to the ARTS model consist of calculations from the AIMS PPM and ARTS target-detection parameters which are read into the subroutine. The inputs are listed in TABLE 5.

TABLE 5

ARTS III SIMULATION INPUT PARAMETERS

Reply Probability
Fruit Rate
Hits Per Mainbeam Width
Mode Interlace
Leading Edge Threshold
Consecutive Misses For Fruit Discard
Minimum Target Run Length
Strong Target Run Length

The flow of the ARTS III subroutine is as follows:

1. The hit and miss counts are set to zero. The code validation levels are also set to zero.
2. A random number is generated and applied to the reply probability to determine whether a hit or a miss has occurred in the reply sequence.
3. If a hit occurs, the hit count is increased by one and the miss count remains at zero.
4. If a miss occurs, the miss count is incremented. If the leading-edge threshold has not been reached and the threshold of consecutive misses for a fruit discard is reached, the hit count is reduced to zero, and the target record is erased.
5. After receipt of a hit, the subroutine checks to see if the leading-edge threshold has been reached. The leading-edge flag is set if target start occurs. Processing continues, and code validation processes begin.
6. The program continues to process replies until the trailing edge of the mainbeam is reached. Each time a valid hit is detected, the run length of the target record is incremented.
7. The code validation processes simulated are the third-level validations of modes A and C. A description of the ARTS III code validation routine is contained in Section 2. After the leading-edge threshold has been reached, the model checks each time a hit is detected to see which mode has been interrogated. If validation has already occurred for that mode, processing continues. If not, the simulation checks to see if an ungarbled reply occurred on the previous interrogation of that mode.
8. The present reply is checked for a garble condition by selecting a random number and comparing it with the probability of garble. The probability of garble is calculated in the defruiter routine if the defruiter is switched on. If not, the probability of garble is calculated in the ARTS III routine by the following equation:

$$P\ (\text{Garble}) = \left(1 - e^{-\lambda t}\right) \frac{NT}{t}$$

where

λ = Fruit per second

t = SIF reply length = 20.3 μs

N = Number of empty pulse positions in a received reply

T = Pulse position tolerance.

The above equation is based on the assumption of a Poisson distribution of fruit replies.

9. If two consecutive replies are received in the same mode and neither reply is garbled, validation has been obtained for that mode and the validation count is incremented.

10. After all replies in the mainbeam have been checked, the run length of the target is compared against the minimum run length criterion to determine if a valid target exists. The run length is also compared against the strong-target threshold to determine the degree of confidence in the target azimuth.

11. The number of occurrences of correct code validation is divided by the number of trials to produce the probability of code validation for each mode. The probability of valid-target detection and the probability of strong-target detection are produced in the same way.

AN/FYQ-47 Common Digitizer Model

The simulation of the sliding window detector function of the Common Digitizer utilizes a Monte Carlo sampling process similar to the ARTS III model. The operation of the statistical detector, when the mainbeam of the interrogator-of-interest (I_o) scans a target with a known reply probability, is simulated by a series of experiments utilizing a random number generator. The fruit rate at the beacon processor while a target is interrogated is an input to the model, along with the hits per beamwidth and mode interlace of the associated interrogator. Inputs to the model that are not derived from the basic AIMS PPM are the sliding window parameters such as window size, leading-edge threshold, and begin-validate threshold. The model flow is as follows:

1. The mode of interrogation is checked. If mode 3/A has been interrogated, control is passed to the target-detection routine. If mode C or mode 2 has been interrogated, the program goes directly to the code-validation routine.

2. If the mode of interrogation was 3/A, a random number is compared to the reply probability to determine whether a reply has been received. If a reply is received, a "one" is inserted into the first slot in the sliding window. The contents of the sliding window are shifted back in the memory. If a miss is received, a "zero" is placed in the first slot.

3. When the number of replies received reaches the begin-validation threshold, the program checks to see if code validation has already been obtained for that mode. If the code for that mode has not been validated, a check is made to determine if the last mode 3 interrogation elicited an ungarbled reply.

4. If an ungarbled reply is in storage, the present reply is tested for a garble condition. This is done by selecting a random

number and applying it to the probability of garble. Garble probability is calculated by determining the probability of a fruit reply overlapping a pulse position of a valid reply. This probability is calculated using the following equation:

$$P\ (\text{Garble}) = \left(1 - e^{-\lambda t}\right) \frac{NT}{t}$$

where

λ = Fruit rate per second received at the I_o while the mainbeam is pointed at the target aircraft

t = SIF reply length = 20.3 μs

T = Pulse position tolerance for the Common Digitizer Beacon Reply Group

N = Number of empty pulse positions in the received reply.

5. In order for the validation count to be incremented, a reply to the last interrogation of that mode must exist in storage, and both that reply and the incoming reply must be garbled.

6. The number of "ones" in the sliding window is compared to the target-start threshold after each mode 3/A interrogation. When the number of hits received equals the threshold, the target detection count is incremented. Processing continues until the target ends or code validation occurs, whichever is first.

7. The outputs of the model are calculated by dividing the number of times that an event occurs by the total number of trials. The outputs generated are the probability of target detection and the probability of code validation for each mode.

AN/TPX-42 Processor Model

The sliding-window detector functions of the TPX-42 are similar to those of the Common Digitizer. The simulations of the two processors used with the AIMS PPM are nearly the same except that the TPX-42 uses all replies received for target detection regardless of the interrogation mode. A confidence check on mode 3/A is used to complete target detection. The target-detection parameters of the AN/TPX-42 differ from the Common Digitizer and that is accounted for in the simulation. The flow of the TPX-42 model is as follows:

1. The model simulates the actions of the TPX-42 for the condition when the mainbeam passes a particular target. This is done for

a large number of trials to obtain the probability of target detection and code validation. The simulation uses Monte Carlo techniques similar to those used to model the ARTS III processor and Common Digitizer.

2. As the simulation processes a series of interrogation-reply sequences, a random number is generated and compared with the transponder reply probability to produce a hit or a miss at the processor. If a valid reply is received, a "one" is inserted in the sliding window. A missed reply causes a "zero" to be inserted in the sliding window. The remaining contents of the window are shifted back in the memory and the information in the last slot is eliminated.

3. The number of hits in the sliding window is totaled after each interrogation and compared with the minimum number needed to reach target start. This number is the leading-edge threshold. Attainment of target start initiates the code validation functions of the TPX-42.

4. The mode of interrogation is checked, and the confidence check count is incremented if the mode is 3/A.

5. After the receipt of a valid reply, once leading edge is established, a check is made to determine whether the reply has been garbled by fruit. The probability of garble is determined as follows:

$$P\ (\text{Garble}) = \left(1 - e^{-\lambda t}\right)^{\frac{NT}{t}}$$

where

λ = Fruit per second received at the I_o while the mainbeam is directed at the target aircraft

t = SIF reply **length** = 20.3 μs

T = Pulse position tolerance of the AN/TPX-42 processor

N = Number of empty pulse positions.

6. The incoming reply is compared with the reply elicited by the last interrogation on that mode. If a reply exists in storage, and both replies are ungarbled, the code for that mode of reply is assumed to be validated. Code-validation level three, as defined in Section 2 for the TPX-42, is the level for which the probability of occurrence is calculated.

7. Once the leading edge threshold has been exceeded and the confidence-check threshold has been met, the target is considered to be detected and the target-detect count is incremented. The simulation continues for a large number of trials to minimize error.

8. The outputs of the TPX-42 simulation are the probability of target detection and the probability of code validation for each mode. These probabilities, respectively, are the number of occurrences of valid target detection divided by the number of samples, and the ratio of the number of code validations to the number of samples.

SECTION 4

SUMMARY

Computer simulations of ATCRBS equipments have been developed for use with the AIMS and Transient Effects PPM's. These computer programs include models of FAA defruiting and decoding equipment and digital processors such as the ARTS III, AN/FYQ-47 Common Digitizer, and the AN/TPX-42 processor. The models developed for use with the AIMS PPM provide probabilistic interpretations of processor performance as a function of the ATCRBS environment. The simulations developed for use with the Transient Effects PPM are applicable to a variety of specific problems whose solutions depend on analysis of pulse-by-pulse operation of the processors.

The results of this study have been and will be useful to the FAA and DoD for the purpose of analyzing the impact of new systems, such as the Automated Terminal System (ATS), and the U.S. Army Very Lightweight Air Traffic Management Equipment (VLATME) on ATCRBS processing equipment performance.