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DSSS/VL (DEEP SPACE SURVEILLANCE SATELLITE/VISIBLE LIGHT) ON-BOARD DATA PROCESSING DEFINITION STUDY. VOLUME I. SUMMARY

IBM Federal Systems Division

Prepared for:

Space and Missile Systems Organization

21 November 1975

SAMSO TR NO. 75-260 VOLUME I

FINAL REPORT

DSSS/VL ON-BOARD DATA PROCESSING DEFINITION STUDY

VOLUME I of II

SUMMARY

CONTRACT NUMBER
AF F04701-75-C-0110

21 NOVEMBER 1975

PREPARED FOR

SPACE AND MISSILE SYSTEMS ORGANIZATION

POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CALIFORNIA 90009

PREPARED BY

INTERNATIONAL BUSINESS MACHINES CORPORATION

FEDERAL SYSTEMS DIVISION
2625 TOWNSGATE ROAD
WESTLAKE VILLAGE, CALIFORNIA 91361

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CONTENT AND CLASSIFICATION
APPROVED BY:

Jeff R. Falkner

JEFF R. FALKNER
PROGRAM MANAGER

TECHNOLOGY EVALUATION
IBM DEPARTMENT TE1

Federal Systems Division
INTERNATIONAL BUSINESS MACHINES CORPORATION
Westlake Operations
Thousand Oaks, California 91360

ABSTRACT

This document, Volume I of the Deep Space Surveillance Satellite/ Visible Light On-Board Data Processing Definition Study Final report, contains a summary of the project which encompassed design, implementation and characterization of selected sensor data processing algorithms within a digital simulation system. Subjects include an introduction and background, technical approach, simulation development, characterization results, major conclusions and recommendations.

FOREWORD

This report summarizes the work conducted for the Air Force Space and Missile System Organization under Contract F04701-75-C-0110 for which the period of performance was from March 1975 through December 1975. The scope of work included the design, development and verification of a digital computer simulation of the sensor data stream and associated data processing for candidate Deep Space Surveillance Satellite (DSSS) Visible Light (VL) systems. Also included was a characterization of the candidate on-board processing algorithms using both simulation experiments and hardware parametric analysis. The applicable computer programs were incorporated into the Multi-Optical Sensor Simulation (MOSS) developed under Contract F04701-74-C-0524.

The SAMSO Project Officer was Lt. Carl Deitrick who was proceeded by Capt. David Losh. Of the many Aerospace Corporation contributors to the project, some of the more significant were Kenneth Wayment, Dr. Michael Harris, Monroe Schlessinger, Stanley Marcus, and Charles Crummer. Many ideas were offered by the above individuals; these were discussed and several were subsequently incorporated into the simulation programs.

IBM, as the prime contractor, was supported by the Grumman Aerospace Corporation in a subcontractor capacity. IBM was responsible for requirements analysis and integration; design, development and verifications of deliverable software; and characterization of the simulation programs. IBM was supported by Grumman Aerospace Corporation for the DSSS sensor and on-board hardware requirements. The work was centered at IBM's Federal Systems Division Facility at Westlake Village, California, and was led by the Program Manager, Jefferson R. Falkner. He, in turn, was supported by the following task leaders:

- Task 1 and 2 - David P. Wisemiller (Chief Programmer)
- Task 3 - Dr. Edwin M. Winter
- Grumman Aerospace Corp. Subcontract Project Manager - Raymond Schuhnel

Key IBM contributors included:

- Janice K. Ujihara - Programmer for the Data Stream Generator
- Gerald Loffredo - Analyst for Algorithm Implementation
- Dr. Arthur L. Wright - Analyst for Characterization Study
- Donald R. Van Dam - FPP Programmer

The end deliverables under this contract include a final report consisting of two volumes, the simulation programs via magnetic tapes and program listings, and an update of the MOSS User Manuals (three volumes). The reports are organized as follows:

Final Report

- Volume I	Summary
- Volume II	Verification and Characterization Results

Users Manual

- Volume 1	DSSS User Guide (updated)
- Volume 2	DSSS Program Logic Manual (updated)
- Volume 5	Data Stream Generator Program Logic Manual (updated)

The delivered software simulation consists of four programs:

1. DSSS On-Board Data Processor
2. DSSS Functional Processor Program
3. MOSS Data Stream Generator
4. Output Processor Program

This technical report has been reviewed and is approved.

Carl B. Deitrick

Lt. Carl B. Deitrick

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1. INTRODUCTION

Current Air Force space surveillance plans are focused on developing a capability to detect and track objects in deep space with sensors both at ground-based sites and on space-based platforms. Many spectral bands are under consideration for this task. The objective of the Deep Space Surveillance Satellite/Visible Light Sensor On-Board Data Processing (DSSS/VL ODP) Definition Study was to design, develop and characterize new MTI algorithms which are candidates for use in the DSSS/VL system. Characterization of these algorithms would be accomplished using a digital computer simulation system which simulates the operating environment, sensor system, and on-board data processing algorithms required for the visible light sensing approaches of the Deep Space Surveillance Satellite (DSSS) system. The algorithms would then be characterized by both a hardware analysis and a simulation experiment study.

The CCD sensor model and eight MTI algorithms were designed and incorporated into the Multi-Optical Sensor Simulation (MOSS) to enable comparison, on an equal basis, of all eight candidate MTI algorithms. The study was conducted in a manner making maximum use of applicable computer code from the MOSS project, thus resulting in an overall enhancement of MOSS. The resultant product of this effort was the development of simulation programs consisting of 18,000 lines of new code in the top-down structured discipline, which satisfies the desire for flexibility and modularity to allow for future changes, updates, and growth. These programs include the latest environmental and sensor models, prototype data processing algorithms and a wide range of input/control parameters. With these models, MOSS constitutes an efficient test vehicle for evaluation of system performance. Finally, the programs provide the flexibility to evolve to a prototype demonstration capability.

This volume of the final report begins in Section 2 with a discussion of the Deep Space Surveillance Satellite detection problem and the objectives of the ODP Study, to investigate candidate solutions for DSSS. Section 3 delineates the study technical approach and highlights the capabilities, features and options of the simulation programs. Section 4 summarizes the results of the characterization effort while Section 5 contains the major conclusions and recommendations of the study. Detailed characterization results, on which the conclusions and recommendations are based, may be found in Volume II of this report.

2. BACKGROUND

Space surveillance consists of two aspects. These are the detection and tracking of space objects and the identification of these objects. In accomplishing these functions utilizing a space-based sensor system, the ODP function is a critical item in the development of the DSSS/VL spacecraft with potential impact on every other spacecraft subsystem. Preliminary analysis indicates that a promising solution in terms of cost and flexibility may be implemented by the use of a special-purpose high-speed data preprocessor coupled with an off-the-shelf general-purpose aerospace digital computer. It is vital to the demonstration of DSSS/VL technolo that a breadboard model of the special-purpose high-speed preprocessor be built early in the development cycle. Sensor data processing requirements should be defined early in the development cycle and simulated in MOSS to allow rational partitioning between the elements of the data processing network. The MOSS simulation when coupled with the algorithms implemented during this study, provides a means to determine performance of algorithms in detecting and tracking space objects. The second aspect, Space Object Identification (SOI), was investigated only as a system constraint in this study.

2.1 DETECTION PROBLEM

The problem of detecting a space object in a vast star field is one of locating an object with many characteristics that are quite similar to the stars, except for the following: the range to a satellite is considerably less than that to a star; a satellite moves at a rate considerably faster than that of a star; and the color temperature of a satellite is quite different from a majority of the stars. Each of these differences leads to a different detection method for satellites. The relative short range of a satellite as compared to the star background points toward their detection by a radar system. On the other hand, the relative motion of a satellite against the star background makes its detection by comparison of pictures an obvious method. Thirdly, their color temperature, particularly in infrared, lends credibility to the use of infrared sensors as a means of detecting satellites.

Of the space surveillance sensor systems, two rely on reflected sunlight from the satellite for detection and tracking. These are the:

- Deep Space Surveillance Satellite/Visible Light Sensor (DSSS/VLS) and,
- Ground Electro Optical Deep Space Surveillance (GEODSS) System

Both of these systems were modelled in MOSS. The ODP study continued the effort conducted during MOSS for the DSSS/VL system by supplementing the MOSS DSG sensor model with a Charge Coupled Device (CCD) Detector and adding eight new algorithms to the On-Board Data Processor (ODP). These additions were made without altering the general MOSS simulation capability to model either a ground or space-based system.

The satellite detection problem cuts across sensor, platform control and data processing technologies and must be addressed and solved in order to develop system specifications in terms of Probability of Detection and False Alarm Rate. Several possible concepts (i.e., imaging, photometry, parallax and motion) have been postulated for detecting space objects by employing visible light sensors. Of these, the detection of space objects, namely earth satellites, by their apparent motion against a celestial background looks more promising at this point in time, and for this reason was pursued in this study. Figure 2-1 depicts three different motion discrimination concepts implemented in the various ODP algorithms. The first concept cancels point sources which do not move within the sensor field of view; thus the remaining objects are assumed to include satellites. The second employs a streak formation/detection algorithm to detect satellite motion imbedded in the background. The third (signature) analyzes a pixel time history to recognize signatures.

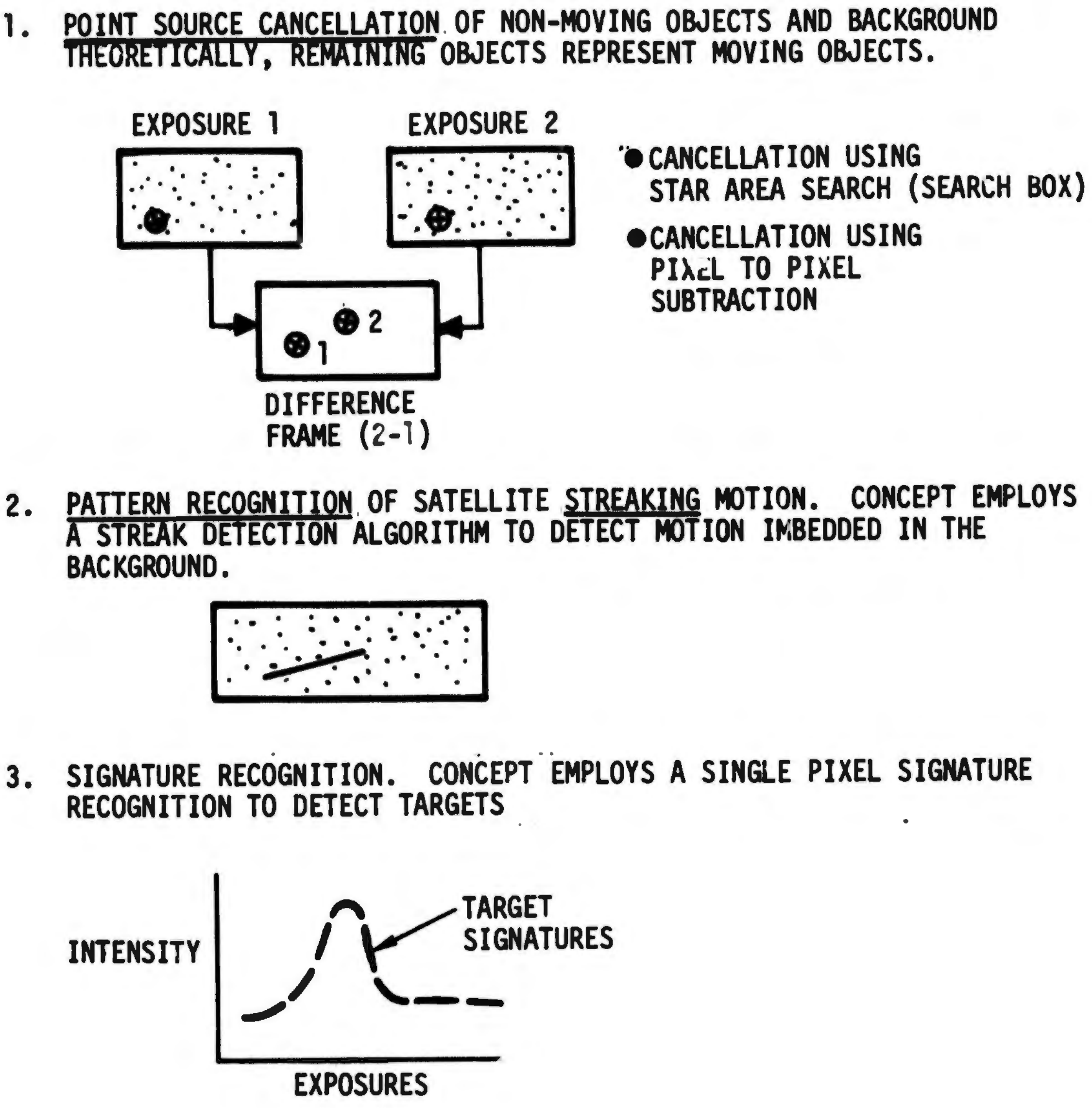
2.2 ODP STUDY OBJECTIVES

The ODP study was a follow-on to the MOSS simulation development contract. During that study, a large flexible electro-optical sensor system simulation was developed. It was the objective of this study to modify that simulation to add:

- Charge Coupled Device (CCD) detectors
- Eight new on-board processing algorithms
- Ground streak processing simulation

All algorithms were then characterized in terms of their performance in simulation experiments, as well as in terms of their hardware implementation feasibility.

Technical advance in the area of visible light sensing has led to changes in the DSSS system. First, the visible light sensor, previously specified to be a Silicon Intensifier Target (SIT) tube, has been changed to be a Charge Coupled Device. With this new sensor specification, and a better understanding of possible noise sources within the sensor and induced by the spacecraft, new algorithms for processing the data have been developed over the past year. These algorithms are much more complex than the original simple pixel-to-pixel subtraction algorithm proposed to eliminate stars for the original space system concept. The new algorithms are developed with the goal of increasing the on-board data processing. It is important at this time to characterize these new algorithms in terms of the new CCD sensor.



1. POINT SOURCE CANCELLATION OF NON-MOVING OBJECTS AND BACKGROUND THEORETICALLY, REMAINING OBJECTS REPRESENT MOVING OBJECTS.

- CANCELLATION USING STAR AREA SEARCH (SEARCH BOX)
- CANCELLATION USING PIXEL TO PIXEL SUBTRACTION

2. PATTERN RECOGNITION OF SATELLITE STREAKING MOTION. CONCEPT EMPLOYS A STREAK DETECTION ALGORITHM TO DETECT MOTION IMBEDDED IN THE BACKGROUND.

3. SIGNATURE RECOGNITION. CONCEPT EMPLOYS A SINGLE PIXEL SIGNATURE RECOGNITION TO DETECT TARGETS

Figure 2.1. Motion Discrimination Concepts

3. TECHNICAL APPROACH AND SIMULATION DEVELOPMENT

The ODP study was organized into three technical tasks aimed at developing the simulations for DSSS and characterizing the candidate algorithms.

Figure 3-1 summarizes the three tasks and depicts their interaction and combination to form the final ODP Software Configuration. The MOSS DSG was enhanced to add a Charge Coupled Device (CCD) detector model and expand its data handling capability from eight to forty exposures. In parallel with the DSG development effort, the eight new algorithms were analyzed and programmed. Following this program development, applicable portions were tested and verified. A broad characterization using MOSS and including hardware analysis then followed.

The three technical tasks are briefly described below:

Task 1: CCD Sensor Modelling included the study and analysis of various sensor/satellite configurations sufficient to update the MOSS Data Stream Generator (DSG) to accomodate the evaluation of the candidate algorithms. Also included was development of a DSG Input Monitor (DIM) to aid in DSG run set-up.

Task 2: ODP Algorithms Development and Integration included the analysis of new On-board Data Processing (ODP) MTI algorithms, sufficient to define the logic, develop the code, and integrate these algorithms into the then existing MOSS ODP and FPP software packages.

Task 3: Algorithm Characterization included the planning, scheduling, and implementing of a comprehensive number of test cases that exercised the candidate algorithms over the required range of parameters. Each of the algorithms was analyzed in terms of performance, design risk and cost.

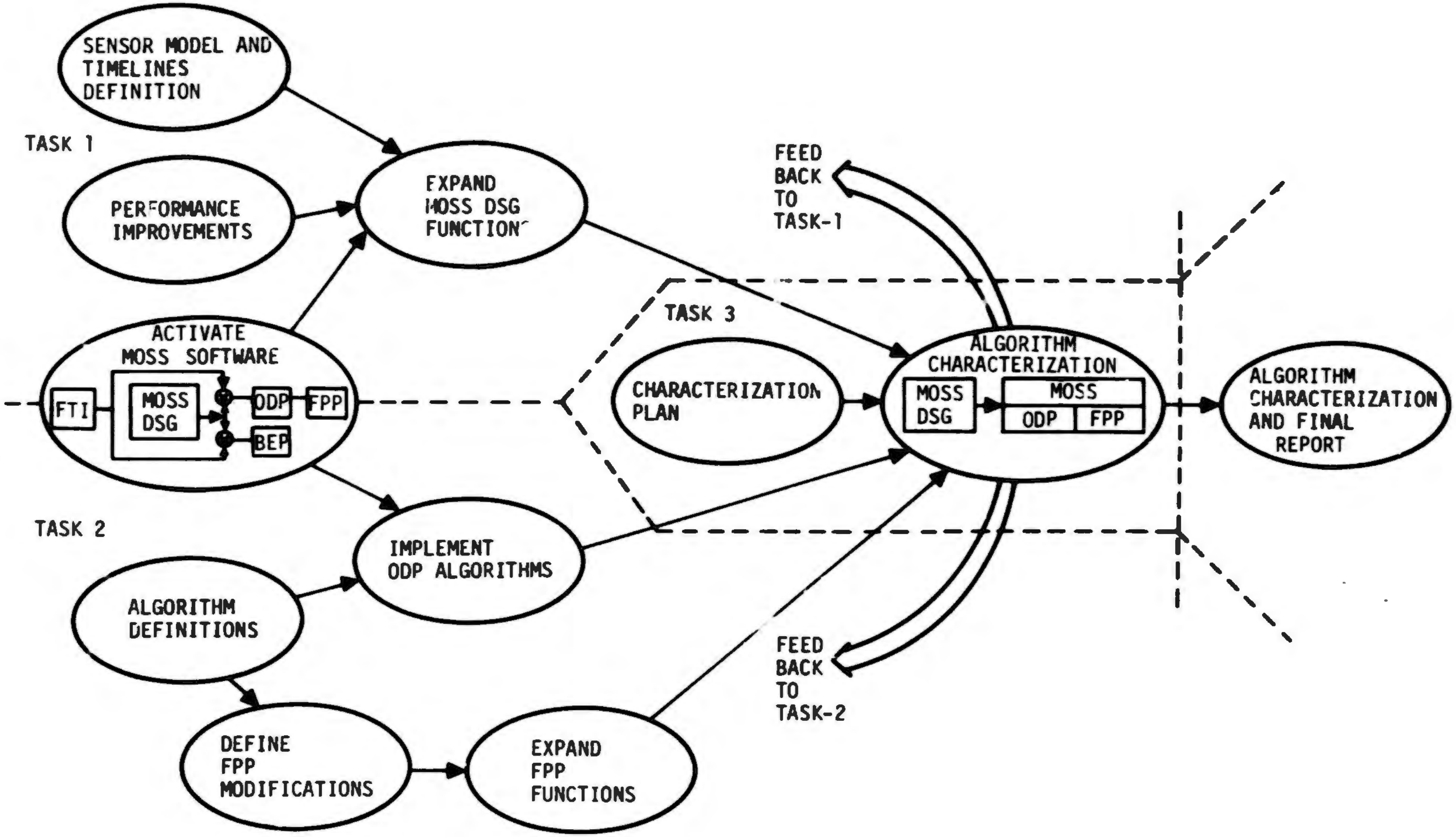


Figure 3-1. DSSS/VL ODP Study Plan

3.1 PROGRAM DEVELOPMENT

Table 3-1 contains a brief description of each of the five major MOSS programs after addition of ODP project code. The program packages for the space portion of MOSS are shown in Figure 3-2. Programs changed or added during the ODP study are indicated by no shading.

3.1.1 DSG Modifications

Certain modifications and additions to the MOSS DSG were required to accomplish the modeling of CCDs. Also, it was desirable to increase the number of exposures per segment from eight to forty to better analyze multi-snapshot algorithms. In addition to these two classes of modification, performance improvements were incorporated to make the MOSS DSG a more efficient tool.

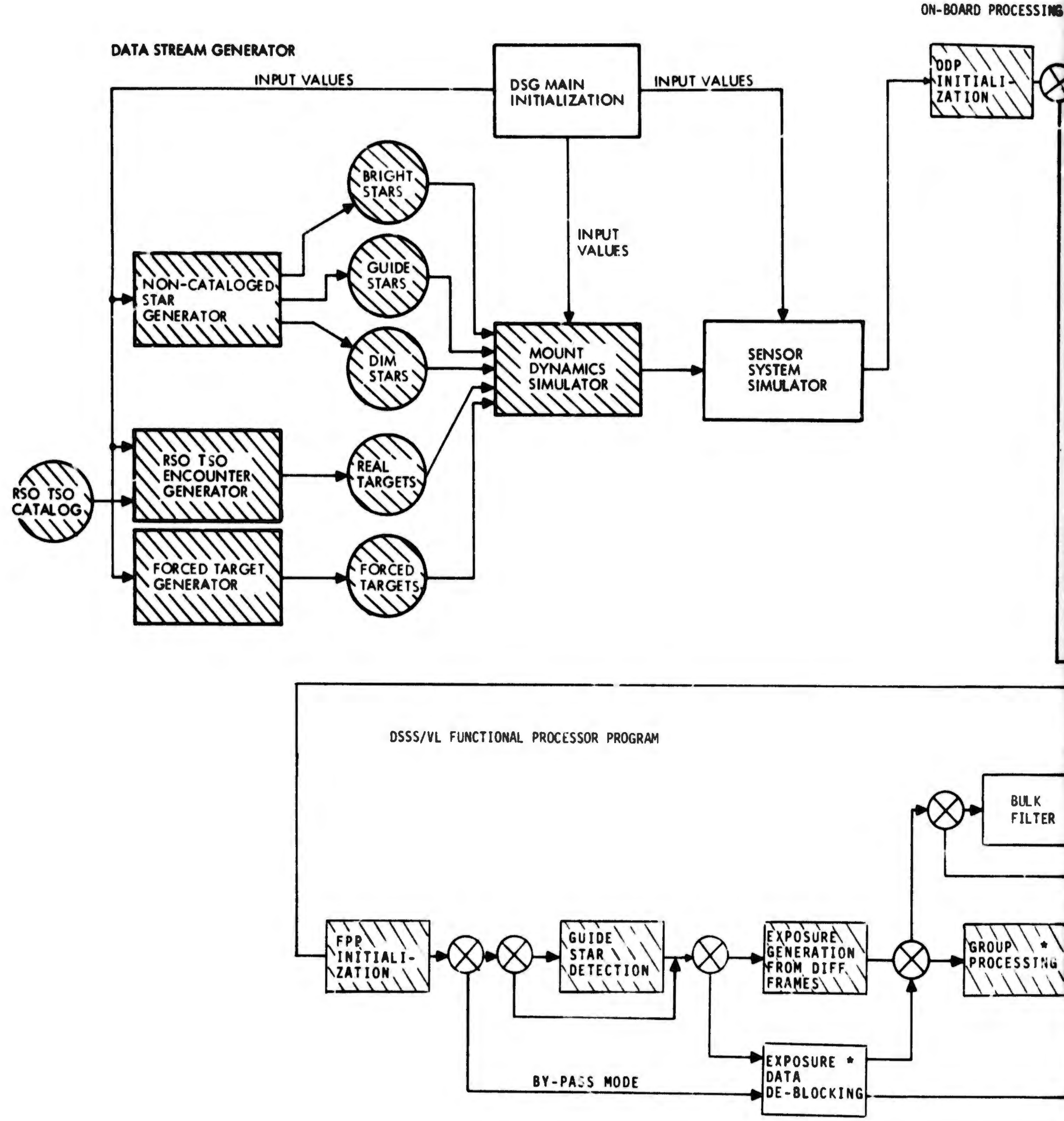
3.1.1.1 Sensor Model Changes

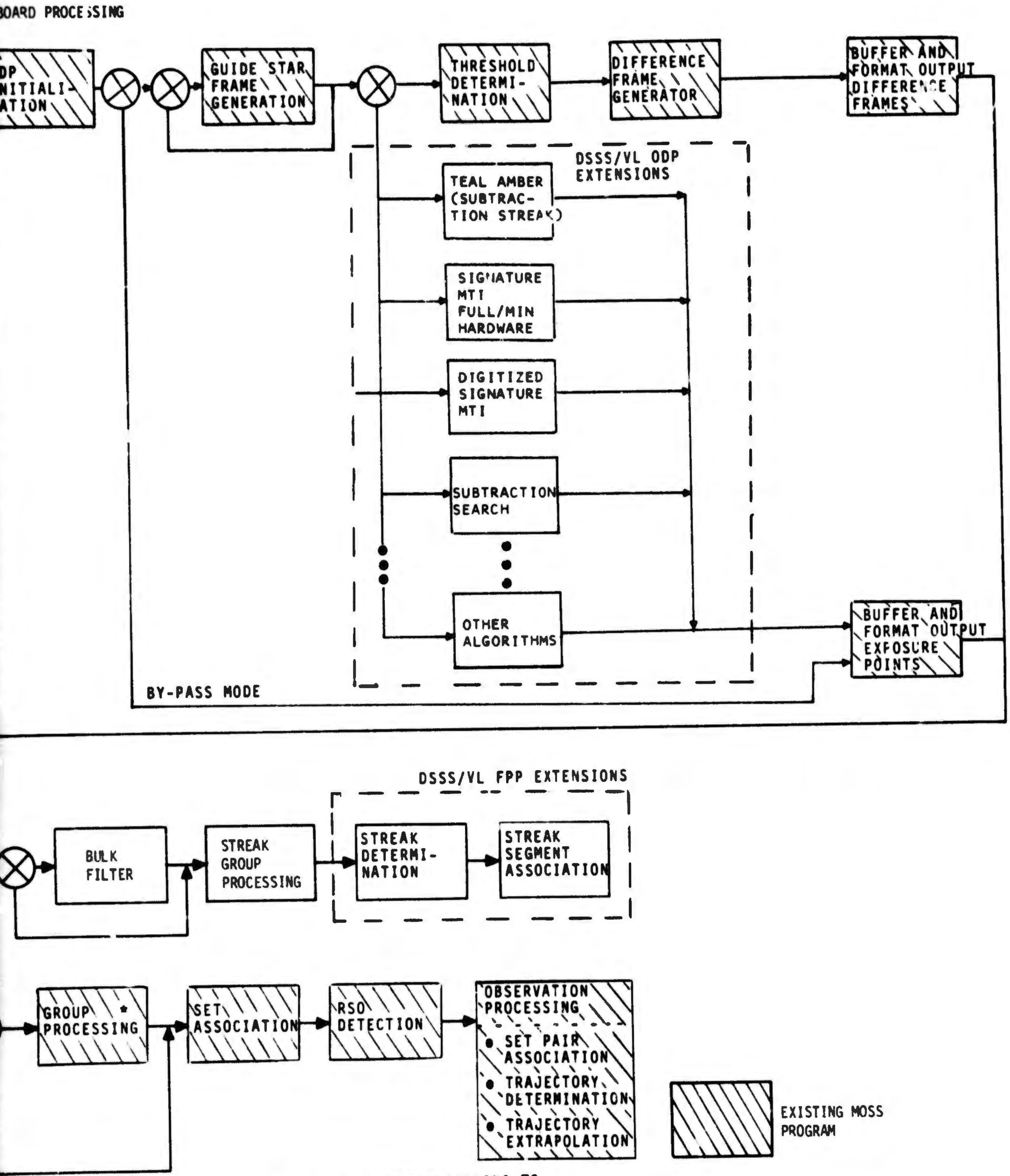
The MOSS DSG is a flexible sensor simulator which was constructed in such a way as to enhance its future utility. An example of this design is the Image Plane Convolution (IPC) Table which is initialized outside of the main stream of the simulation. By initializing the IPC Table outside of the main stream of the simulation, it is more accessible for change. A new CCD sensor IPC Table initialization routine was implemented which can be substituted for the SIT tube initialization at user option. The original SIT tube model was preserved. In addition, the CCD model was made completely compatible with the ground-based sensor simulation operating mode of the DSG.

The principal modification to incorporate a new sensor model for CCDs was required in the IPC Table initialization processor. In

Table 3-1. Glossary of MOSS Programs

NAME	ACRONYM	DESCRIPTION
DATA STREAM GENERATOR	DSG	Produces a data stream with support data which corresponds to the output of a sensor system. It models the environment, orbit dynamics, platform dynamics, and sensor elements.
Ideal Encounter Generator	IEG	Provides ideal coordinates of observables within the sensor's field of view based on the sensor's scan pattern.
Mount Dynamics Simulator	MDS	Simulates error sources in the ground mount or space platform and applies these errors as corruptions to the ideal coordinates of observables.
Sensor System Simulator	SSS	The Sensor System Simulator models the effects of the atmosphere, telescope, and detector on moving targets, stars and the extended light source background. For either a ground or space based sensor.
DSG Input Monitor	DIM	Interactive run setup program.
DSSS PROGRAMS		These programs consist of the onboard and ground data processing programs that are part of a Deep Space Surveillance System.
Onboard Data Processor	ODP	The Onboard Data Processor program simulates the spaceborne portion of the processing function and performs the background elimination function for the space system simulation. Includes the eight new algorithms.
Functional Processor Program	FPP	The Functional Processor Program processes the output of the ODP with the ultimate aim producing satellite trajectories. Option for either point association or streak association.
GEODSS SIMULATION		Consists of the BEP plus options for track processing and tracker feedback simulation.
Background Elimination Processor	BEP	Ground data processing for background elimination and track initiation. The BEP contains four modes of operation under MOSS: Continuous Scan, Intermittent Streak Bulk Filter, Intermittent Streak Pattern Recognition, Hybrid Streak.
FIELD TEST INTERFACE	FTI	Special program to reformat and prepare field data entry to the ODP or BEP.
OUTPUT PROCESSING		
Output Processing Program	OPP	Special interactive or batch program to plot DSG or ODP outputs.


ON-BOARD PROCESSING
DATA STREAM GENERATOR
INPUT VALUES
DSG MAIN INITIALIZATION
INPUT VALUES
ODP INITIALI-ZATION
BRIGHT STARS
INPUT VALUES
NON-CATALOGED STAR GENERATOR
GUIDE STARS
DIM STARS
MOUNT DYNAMICS SIMULATOR
SENSOR SYSTEM SIMULATOR
RSO TSO ENCOUNTER GENERATOR
REAL TARGETS
RSO TSO CATALOG
FORCED TARGET GENERATOR
FORCED TARGETS
DSSS/VL FUNCTIONAL PROCESSOR PROGRAM
BULK FILTER
FPP INITIALI-ZATION
GUIDE STAR DETECTION
EXPOSURE GENERATION FROM DIFF FRAMES
GROUP PROCESSING *
EXPOSURE * DATA DE-BLOCKING
BY-PASS MODE



* = DSSS/VL MODIFICATIONS TO EXISTING CODE

Figure 3-2. Overview of DSSS/VL ODP Programs

B

this processor, the convolution of the image blur circle with the sensor is performed. In the original MOSS DSG, this image plane convolution included a model of the electron beam, which is used to read the target in the Silicon Intensifier Target tube. In the simplest case, the MOSS model could have been changed to include only the integration of the blur circle into a square grid. However, for accurate sensor modelling, the capability of modelling rectangular pixels and inactive areas in the focal plane was provided. In addition, a charge transfer model, a channel bloom model and a CCD noise model were included. For flexibility, these models are user controlled, independent of the IPC initialization chosen.

A detailed discussion of the modelling of CCD imaging sensors is included in the appendix to Volume II.

3.1.1.2 Multi-Snapshot Modification

The original MOSS DSG limited the number of exposures per segment to eight. The evaluation of multi-snapshot algorithms required that this number be increased to forty exposures per inertially fixed position or stare period.

3.1.1.3 Performance Improvements

To facilitate the usage of the DSG as a characterization tool, certain performance improvements were incorporated.

One major improvement which has particularly reduced simulation run time was the addition of a 'fast noise' mode. Noise must be calculated for each of the resolution elements or pixels in the field-of-view regardless of whether the sensor is a CCD or a tube. This is a rather laborious process requiring a considerable portion of the computer time expended in the sensor system simulator. A method of table lookup to obtain Gaussian distributed noise was implemented which eliminated 11 of the 12 calls to the linear random number generator used per pixel, and therefore improved the efficiency of noise modelling in the sensor system simulator.

3.1.1.4 DSG Input Monitor

A terminal based interactive program was developed to aid users in the simulation set-up. DIM can be used either to modify already existing set-ups or to create entirely new runs.

3.1.2 ODP Development

The following MTI algorithms were developed and integrated into the MOSS On-Board Data Processor (ODP) program:

- Digitized Signature
- Pixel Pixel CCD
- Logical OR
- Full Signature
- Window Signature
- Background Signature
- Subtraction Streak
- Subtraction Search

The functions of these algorithms are discussed in Table 3-2 while the individual functional flow diagrams are continued in Volume II.

The algorithms were implemented by extending the existing MOSS ODP and by creating a Standardized MTI Interface. This interface allows for the inclusion of new MTI algorithms into the ODP with a provision for transmitting "exposure" points to the FPP in addition to the "difference frame" points generated in its normal mode of operation. The Standardized MTI Interface allows for the

Table 3-2. Algorithms Investigated on ODP Study

ALGORITHM	CONCEPT
Subtraction Streak	● Difference exposures ● "OR" differences to form composite ● Search for streaks ● "OR" succeeding differences and continue search for streaks
Full Signature	● Find minimum and maximum signal for each pixel for exposure history ● Form composite of those pixels passing test on threshold = K X (max - min) ● Search composite for streaks
Window Signature	● Similar to above except less storage required (not all exposures used to determine min and max). Initial N exposures window used for min/max determination
Background Signature	● Similar to above except a priori min and max used
Digitized Signature	● Form composite based on exposure to exposure changes/threshold crossings and total exceedence count ● Search for streaks
Subtraction Search	● Eliminate stars by subtracting pixel to pixel including nearest neighbors ● Form tracks by linear fit to points remaining
Pixel-Pixel CCD	● Difference exposures and threshold ● Form tracks by linear fit
Logical OR	● Threshold each exposure and "OR" exceedences into composite ● Use last exposure to blank composite ● Search resulting composite for streaks

integration of future algorithms with minimal resources.

3.1.3 FPP Modifications

To allow for the comparison of the new MTI algorithms on an equal basis, the MOSS Functional Processor Program (FPP) was extended to accept and perform track initiation on the exposure data generated by the DSSS/VL ODP. These extensions were incorporated using the existing By-Pass mode interface to the FPP, thereby allowing total compatibility with the existing MOSS system.

The major effect in the FPP was that of incorporating routines to qualify a group of pixels from an exposure (possibly a composite) as a "streaking" object and then to associate streaks from more than one exposure (or composites). These routines and techniques of streak processing were previously included in the MOSS GEODSS system. As indicated in Figure 3-2, minor modifications were made in the Exposure De-blocking and Group Association modules to support the new MTI algorithm data and the streak processing modules.

3.1.4 Algorithm Characterization

The algorithms developed under Task 2 were characterized using both simulation experiments and a hardware parametric analysis. A characterization plan, developed during the initial phase of the study with Air Force approval, was the basis of this study. The characterization itself consisted of an intensive series of production runs and an equally intense analysis effort.

The characterization effort was divided into two phases. In the first phase, all eight algorithms were subjected to an initial performance characterization and to a parametric hardware analysis. Upon review of the initial results by SAMSO, three algorithms were eliminated from consideration in the subsequent phase due to their relatively poor performance. The Phase II study concentrated on a detailed study of the probability of detection. The results of the characterization are summarized in Section 4 and detailed in Volume II.

3.2 MOSS PROGRAM STATUS

In this section, the status of the MOSS programs as modified by the ODP is discussed. Two new programs were added to the MOSS package during the ODP contract: DIM and OPP. Both programs function in an interactive mode (the OPP may also be run in batch mode) under the control of the IBM OS/VS Time Sharing Option (TSO).

Table 3-3 quantifies parameters that describe the size of the programs and operating system characteristics relevant to their use. Work file requirements are in most cases minimal; that is, less than 30,000,000 bytes of online storage. The work files do not include input/output sensor files or printer spooling output files.

Considerable user-oriented flexibility has been incorporated into the MOSS DSSS programs along with many options. The quantity of parameters and control/processing options available to the user numbers over 300 for model/conditions selection in the DSG, while the remaining space system program packages contain over 345 control parameters with comparable numbers existing for the other program packages.

In summary, the DSSS MOSS program packages have been modified and updated with the addition of a considerable quantity of new code. All major program options and features have been successfully tested and no known errors exist in the programs. They provide a realistic and flexible simulation capability that includes the DSSS On-Board and Ground Processing algorithms and can be used as a test bed for evaluating and optimizing system parameters.

Table 3-3. MOSS Program Characteristics (U)

PROGRAM	LINES OF CODE			PROGRAM EXECUTION	
	MOSS DEVELOPED	ODP DEVELOPED	TOTAL*	CORE REQUIREMENTS (BYTES)	WORK FILE REQUIREMENTS
DSG	11,000	2000	13,300	2,200,000	Minimal
ODP	3,000	6500	11,000	650,000	Minimal
FPP	2,000	900	17,500	700,000	Minimal
BEP	9,700	-	10,300	500,000	Up to 100 million bytes
DIM	-	6000	6,000	interactive	Minimal
OPP	-	2600	2,600	interactive	Minimal
FTI	1,300	-	1,300	800,000	Minimal
TOTAL	27,000	18000	62,000		

*Total includes code used which was developed on SADPS and SDPS in addition to MOSS and ODP code.

4. SUMMARY OF CHARACTERIZATION RESULTS

In this section the significant results of the algorithm characterization are summarized. The reader is directed to Volume II of this report for an in-depth treatment of these results. The nominal Data Stream Generator (DSG) run set-up is discussed first along with a typical system configuration. Following this is a short summary of some of the performance measurement criteria used in the study. Included in this section, is a comparison of the algorithms from both simulation performance criteria and hardware analysis.

4.1 NOMINAL DSG CONDITIONS

The purpose of the simulation experiment study was to determine algorithm performance in terms of ability to handle false data and to detect targets. A set of nominal parameters were specified through consultation with SAMSO, Aerospace, Grumman and Rockwell. These nominal parameters were specified in so-called normalized units. A variety of systems could be interpreted in terms of this nominal parameter set.

The nominal input parameters are shown in Table 4-1. The stress data parameters were variations of a factor of two from the nominal in order to investigate a possible algorithm sensitivity to false data at conditions different from nominal.

A 200 x 200 pixel segment of the field-of-view was used for the Phase I characterization studies and all Phase II characterization studies. For Phase I, 40 representative forced targets were placed within this 200 x 200 pixel field of view. These targets had a variety of angular rates and intensities as well as angles of attack. Also included were two pairs of crossing targets. These are considered to be a representative target set in order to determine

Table 4-1. DSG Nominal Values for Phase I and II

pixel size and shape	unit square	
blur circle	0.3 radius	
jitter x	0.047	0.0667 (total)
jitter y	0.047	
shadow geometry	none	
charge transfer model	off	
image persistence model	off	
background	1000 electrons	
target intensity range	100 - 5000 electrons (Phase I)	
target angular rate range	0.1-8 pixels/int. time (Phase I)	
target I/w range	125-8000 (Phase I)	
channel bloom threshold	$5 \cdot 10^5$ electrons	
star intensity range	$20 - 2 \cdot 10^5$ electrons	
star density (focal plane)	5500 above 18.5 Mv	
star density distribution	characteristic of 30° lat.	
forced target acceleration	0	
segment level platform errors	none	
shading	none	
noise	quantum + 35 electron preamp	
adaptive gain	N/A	
FOV gaps	none	

possible effects upon probability of detection. For Phase II, a more dense target population was chosen to allow compilation of significant probability of detection data. The P_D data shown later in this section is based on close to 300 targets near system threshold.

The nominal star density in the 200 x 200 field of view was 5600 stars. For stress runs this number was raised to 10,000. These stars were of 18.5 M_V and less with a density distribution corresponding to that encountered at 30-degree galactic latitude.

The background level of 1,000 electrons was chosen as a nominal case and the variation from this for stress runs consisted of one magnitude brighter (or 2512 electrons). The nominal one-sigma jitter, one fifteenth of a pixel, was varied from the nominal in two ways: zero jitter and twice the nominal jitter. The purpose of this was to explore this important parameter at three different levels. In addition, the blur size, which was nominally 0.3 pixels, was varied to 0.4 pixels for stress runs.

A typical system translation of the nominal values in Table 4-1 is shown in Table 4-2. Since most of the important parameters were varied from nominal, a wide range of system translations can be specified.

4.2 PERFORMANCE MEASUREMENT CRITERIA

Throughout the characterization study, common measurement criteria for the algorithms were required. These standards were needed for simulation performance measurement in terms of false data handling and probability of detection and for characterization of the hardware feasibility, which formed an important part of the overall characterization. In this section, the algorithm measurement

Table 4-2. System Translation

H_o (zero magnitude irradiance)	See Volume II For Classified Data
telescope effective diameter	
optical transmission	
sensitivity (CCD)	
integration time	
resolution (pixel)	
background	
jitter (1 sigma)	
spectral band	
detection goal	

criteria for both the simulation runs and for the hardware implementation study are summarized.

The various performance measurement criteria are shown in Table 4-3. All of these criteria are not applicable for each of the eight algorithms. For example, the number of target points present in the composite is only applicable for those algorithms which form a composite. On the other hand, the number of target detections using a four out of five association rule would only be applicable for those algorithms relying ultimately on Set Association in the FPP (non-streak algorithms).

Table 4-3. Performance Measurement Criteria

CRITERIA:	A SSK	B PPCCD	C LOR	D SSH	E DS	F WS	G FS	H BS	NUMERICAL VALUE
Target Points in Composite	X		X		X	X	X	X	1σ Ideal
Target Detections (3 or more points)			X		X	X	X	X	-
Average TGT Points Per Exposure		X		X					-
4/5 Target Detections		X		X					-
False Points in Composite	*		X		X	X	X	X	<1000
Average False Points Per Exposure		X		X					<30
Streak FPP Output			X		X	X	X	X	<5 False Streaks
Composite	X		X		X	X	X	X	-

*Subtraction Streak is Processed Data

Some of the criteria in Table 4-3 were utilized for quick-look output. Quick-look criteria, such as the target point count in the composite and the average target points per exposure, were important in viewing the overall detectivity sensitivity of the sensor/data processing combination. These were used to rate the ODP independent of the FPP. However, the four-out-of-five target detections and streak FPP output criteria were used to determine probability of detection; and the false point count per exposure and streak FPP output were utilized to determine the false data handling sensitivity. It was only at this level that such diverse algorithms as Subtraction Streak, Pixel Pixel CCD, and Logical OR could be compared.

The algorithms which utilize a point association FPP (Pixel Pixel CCD, Subtraction Search) had to be evaluated in terms of potential number of false points in a full field of view for an operational system. To relate the average number of false points per exposure in a 200 x 200 pixel array run to a value for the number of false tracks output in a full operational system field of view, a data processing sizing had to be accomplished. The sizing for the relationship between false tracks per segments for a 2400 x 2400 pixel field of view and the number of false points in a 200 x 200 characterization array resulted in a maximum tolerable level of 30 false points per exposure in a 200 x 200 array. It should be noted that the false track sensitivity is very steep in this region and that values less than 30 should be encouraged in the characterization runs.

Five of the other six algorithms could be evaluated in terms of the streak FPP output. The Subtraction Streak algorithm did not fit into this type of evaluation, since it contained streak processing within the ODP. However, the output of the Subtraction Streak ODP could be compared to the streak FPP output for the other algorithms. Through several runs of the streak FPP, it was found that a level of about 1,000 false points in the composite resulted in about five false streaks in the 200 x 200 array field of view. Since the streak FPP was not optimized for performance on each of the algorithms, it was felt that this value of five false streaks could be reduced and that a thousand was a tolerable number for false points in the composite.

An additional important performance measurement criterion was the output processor composite output. The composite output consisted of a printed representation of the actual data at the output of the ODP.

Typical composite outputs are shown in Figure 4-1 for a good performing case and in Figure 4-2 for a poor performing case. The DSG input was the same for both runs.

The crossing targets entered in the Phase I study did not present any problem for the algorithms. However, these targets only crossed in the composite and did not cross at the same instance of time. Nevertheless, the streak FPP successfully detected the segments contained in the crossing targets. Previous work on MOSS has shown crossing targets to be no problem for point FPPs.

The hardware characterization was principally in terms of size, weight and power of the on-board processor. Since a high degree of parallel processing is possible on-board the satellite, this is more of a limitation than data rates. A review of applicable literature and contact with manufacturers led to the following standards:

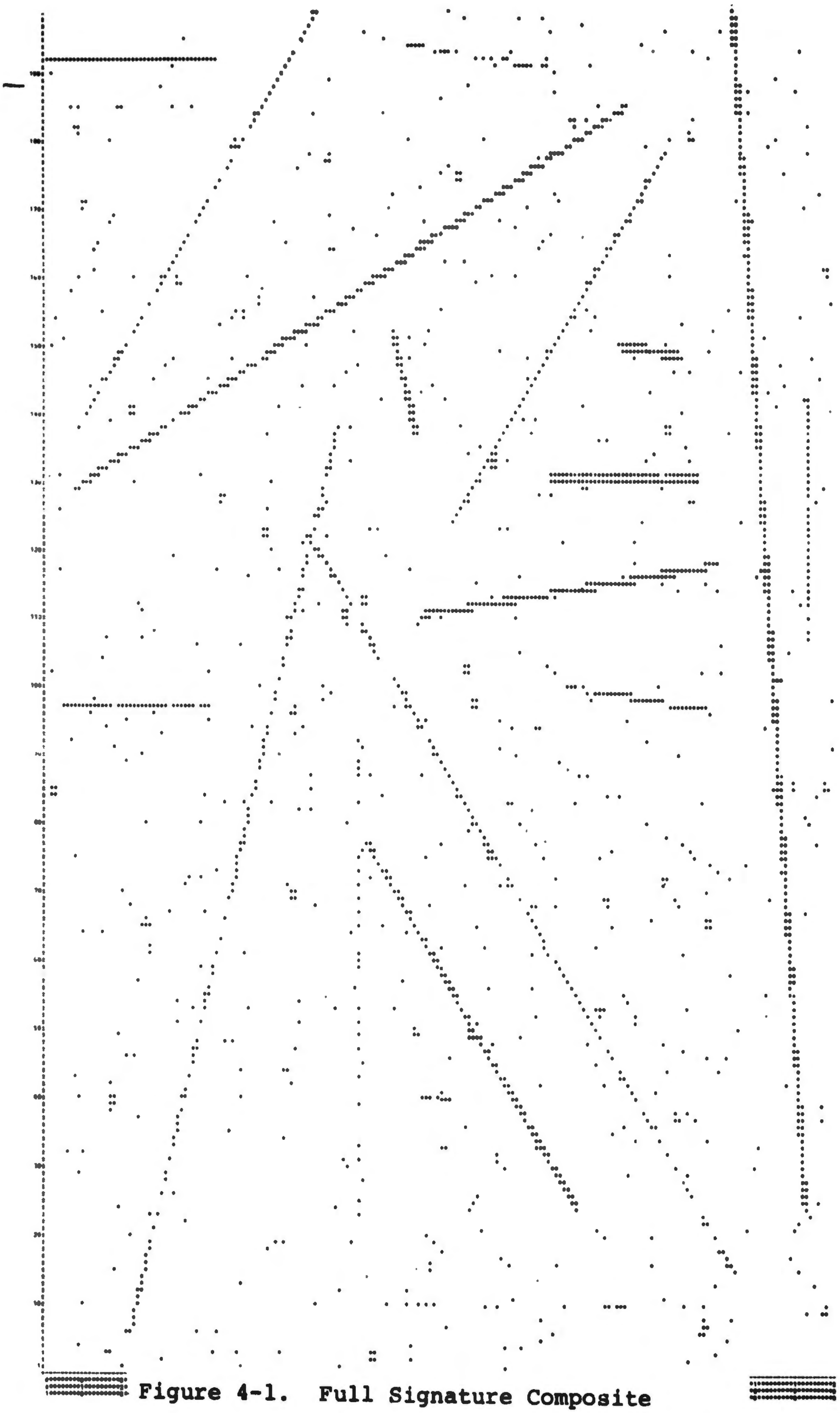


Figure 4-1. Full Signature Composite

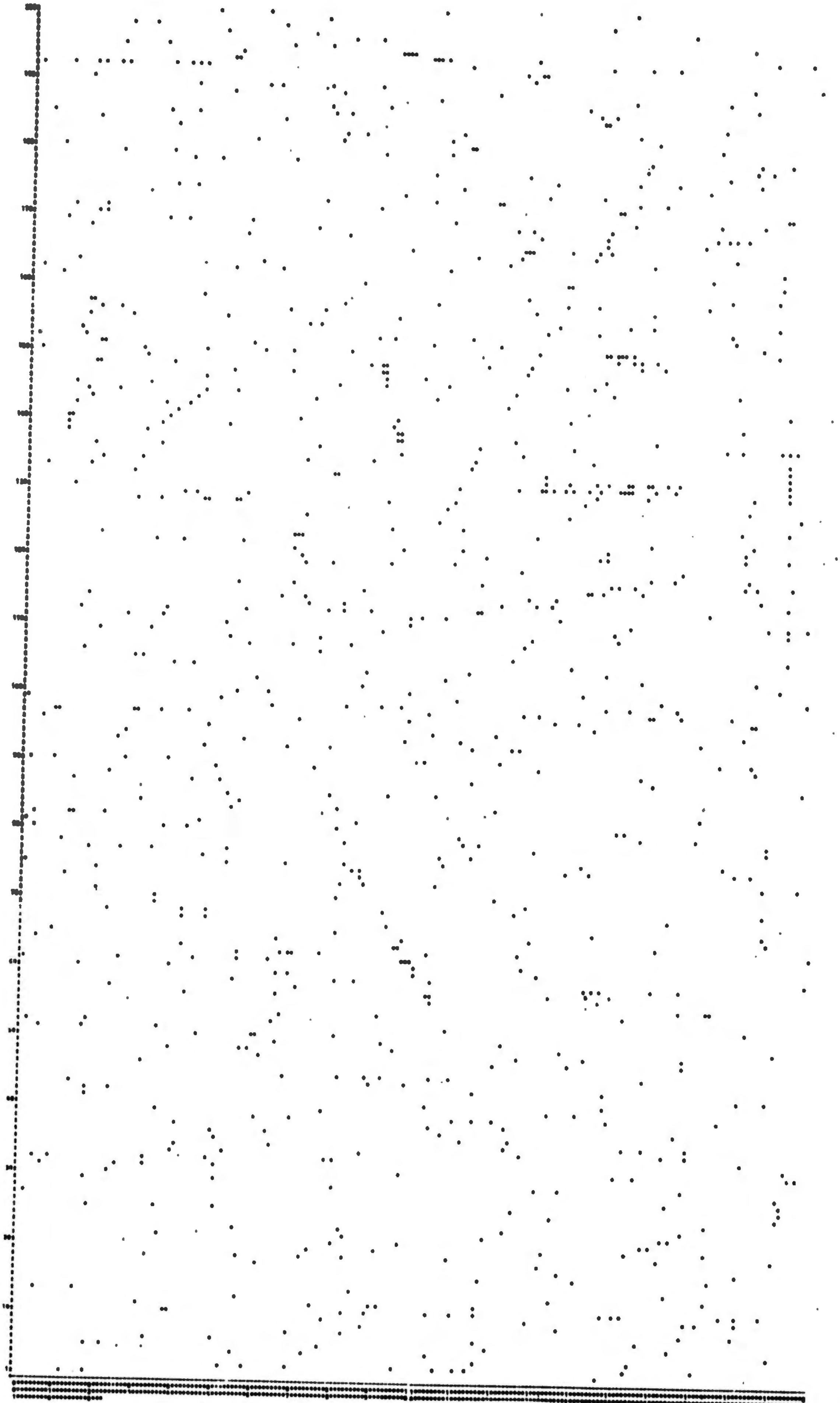


Figure 4-2. Digitized Signature Composite

- **Size**

  - Analog 250 in^3/megel (million elements)
  - Digital 90 in^3/megabit

- **Weight**

  - Analog 6 lb./megel
  - Digital 3 lb./megabit

- **Power**

  - Analog 15 w/megel
  - Digital 1.5 w/megabit

To analyze an algorithm, a hardware implementation had to be configured for each algorithm based on a 2400 x 2400 pixel array sensor. With this available, the memory requirement could be sized. A typical hardware configuration (the Logical OR algorithm) is shown in Figure 4-3.

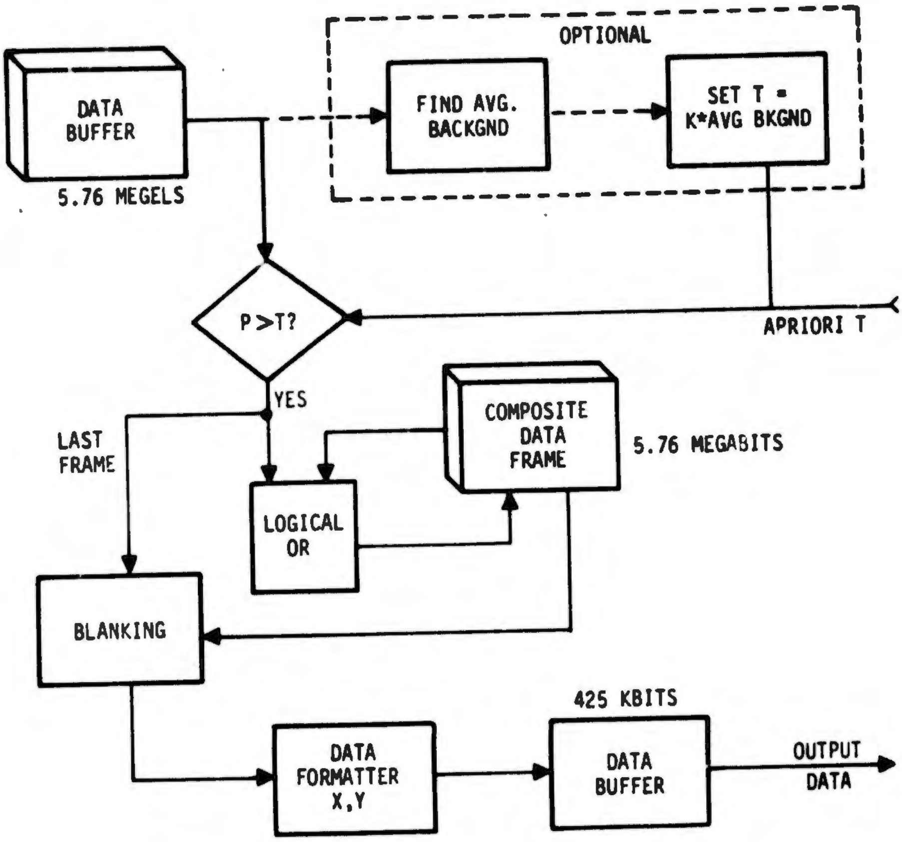


Figure 4-3. Logical OR Algorithm

4.3 ALGORITHM DECISION HISTORY

Before discussing the actual results of the characterization phase, it is important to discuss the algorithm decision history. In Figure 4-4 is a history of the various algorithms treated during this study. There are in total eleven algorithms. This includes, in addition to the algorithms characterized, the Subtraction Streak Two Composite algorithm and the Continuous Add/Subtract algorithm. There were, therefore, nine algorithms characterized. Of these nine algorithms, two were variations of Pixel Pixel CCD. The first of these was the original specified Pixel Pixel CCD algorithm which had unequal exposures. This algorithm was evaluated during the early phases of this study and at that point it was decided to also evaluate Pixel Pixel CCD with equal exposures. The Pixel Pixel CCD algorithm with equal exposures is significantly different from Pixel Pixel CCD with unequal exposure since it requires a thresholding function.

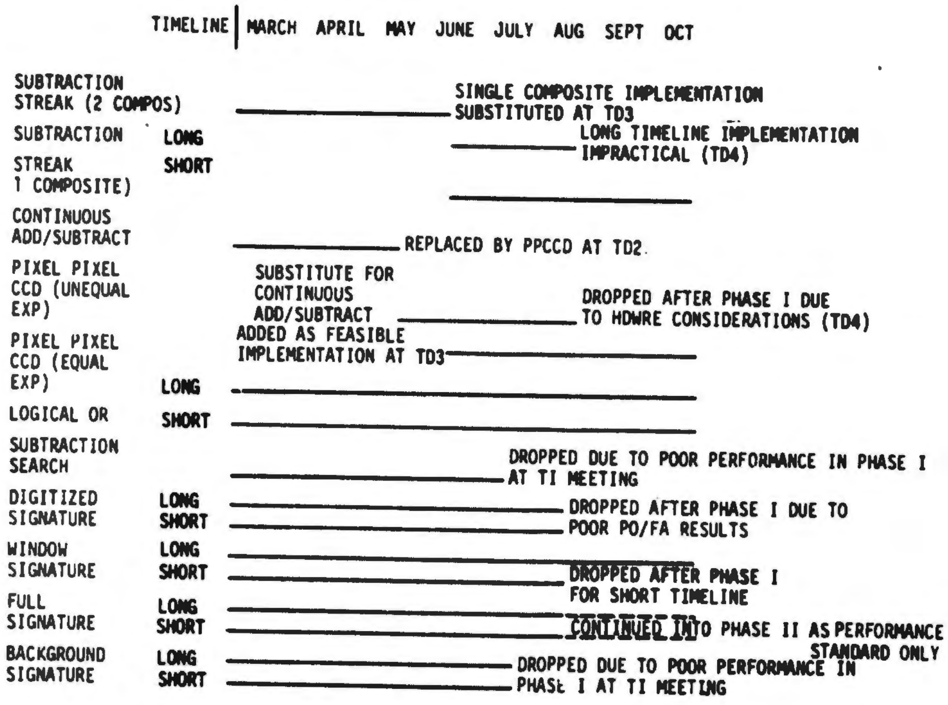


Figure 4-4. Algorithm Characterization History

In addition to the various algorithms, the possibility for long and short time-lines results in the need for seventeen characterizations. The degree of characterization is shown in Figure 4-4. For example, the Continuous Add/Subtract algorithm was studied during the early phases of this program but was not implemented into computer code. It was replaced by the Pixel Pixel CCD algorithm at the second Technical Direction meeting. The Subtraction Streak Two-Composite algorithm was treated during the first three months of this study. It was replaced by the single composite implementation at the third Technical Direction meeting. Several algorithms were dropped during Phase I: Subtraction Search and Background Signature. These algorithms were dropped early in Phase I at a Technical Interchange meeting.

At the fourth Technical Direction meeting, several important decisions were made. First, the Subtraction Streak algorithm for a long time-line implementation was considered to be impractical, because it was not a two-composite algorithm. The two-composite algorithm would be feasible for a long time-line implementation. This point is discussed further in Volume II. Also, the Pixel Pixel CCD algorithm with unequal exposures was dropped after the Phase I characterization, due primarily to hardware considerations. This algorithm performed as well as the equal exposure implementation of Pixel Pixel CCD, but was considered to be nonimplementable, because realistic CCD and sky backgrounds have shading across the field of view, making the use of the exposure time ratio as a thresholding function impractical.

The Digitized Signature algorithm was dropped after Phase I characterization due to relatively poor probability-of-detection and false alarm results. Also, Window Signature was considered impractical for a short time-line after Phase I experimentation.

The Full Signature Algorithm was considered impractical for implementation based upon the hardware study. This was simply because the algorithm requires a large quantity of on-board memory. However, it was continued into Phase II as a performance standard to evaluate the Window Signature algorithm.

The algorithm characterization history presented in Figure 4-4 serves to show some of the decisions which were made during the course of the project. In addition to variations shown in Figure 4-4, other possible implementations were considered for hardware. For example, Window Signature was considered with different quantization levels. It was evaluated in both the simulation runs and in the hardware study for different numbers of levels.

4.4 COMPARISON OF ALGORITHMS

In this section, different methods for comparing the algorithms are examined. First of all, many of the algorithms can be compared in terms of their ODP output alone. The comparison in terms of the ODP output has an advantage in that the algorithm is compared without any further processing. However, there is a disadvantage since some algorithms cannot be compared at this output point. The second point of comparison in the simulation results is in terms of the FPP output. This basis is quite useful in that several algorithms can be compared together. The final comparison discussed in this section is in terms of the on-board and ground hardware complexity. These comparisons all form a basis for an algorithm trade-off matrix.

4.4.1 ODP Output Comparison

Only certain of the algorithms can be compared at this level. For example, since the Subtraction Streak ODP algorithm includes a streak processing operation, it cannot be compared with signature algorithm outputs. Also, it is difficult to relate the output of a point association algorithm (Subtraction Search and Pixel Pixel CCD) with the output of any of the composite formation algorithms. Thus, in this section, only comparisons between the signature algorithms and the Logical OR are discussed.

Also in comparing the ODP output, comparisons are made between various 9-exposure (short time-line) algorithms and 38-exposure (long time-line) algorithms. For nine exposures, the ODP output of Logical OR and Digitized Signature will be compared. The ODP output of Logical OR, Full Signature, Digitized Signature, and Window Signature will be compared for 38 exposures.

In order to effect a better comparison, the ODP runs were examined in an attempt to find a run for each algorithm with approximately the same false alarm rate. By this means the fraction of the target pixels detected could be examined closely. The runs (ODP run numbers are shown) selected for comparison are shown in Table 4-4. In this table, four 38-exposure runs for each of the four composite formation algorithms and two 9-exposure runs are compared. The comparison is in terms of fraction of the target pixels detected in a common DSG run.

Three of these 38-exposure runs have approximately the same false alarm rate. These runs, C310C8, C310F10 and C331G1, have a false alarm rate of approximately 0.0092. The Digitized Signature has a slightly higher false alarm rate although it is close to the other three. In terms of the fraction of the target pixels detected, the Digitized Signature algorithm is much lower then the other three algorithms. The Window Signature algorithm and the Logical OR algorithm are close in performance while the Full Signature algorithm appears superior when measured against this criteria.

Table 4-4. Comparison of Algorithms Based on ODP Output Only – Compared to 1 Sigma Composites

	Algorithm	Fraction of Target Pixels Detected	False Alarm Rate
Thirty Eight Exposures	Logical OR (38) C310C8	0.348	0.0098
	Window Signature (38) C310F10	0.331	0.0092
	Digitized Signature (38) C310E9	0.157	0.012
	Full Signature (38) C331G1	0.464	0.0092
Nine Exposures	Logical OR (9) C332C2	0.3513	0.0115
	Digitized Signature (9) C310E1	0.186	0.0172

The comparison of the two 9-exposure runs, C332C2 and C310E1, is more difficult. Here the false alarm rates are different. However, even with a higher false alarm rate, the Digitized Signature algorithm for nine exposures is far worse in performance relative to target points than the Logical OR algorithm for the same exposure time-line.

In summary, on the basis of Table 4-4, the Full Signature appears to be the best algorithm for 38 exposures followed almost equally by Window Signature and Logical OR. The Digitized Signature appears to be eliminated from consideration for both the 38-exposure and the 9-exposure time-line. These results are in line with the analysis of Phase I.

Of course, the ODP output of the various signature algorithms and Logical OR can be compared in terms of their composites. The composites for two of these algorithms are in a previous section. An assessment on the quality of those composites shows the Digitized Signature algorithm to be inferior in performance to the others.

4.4.2 Comparison of FPP Output

The FPP allows a comparison of algorithms which cannot be related at the ODP output stage. Using the FPP, point association algorithms can be compared to streak algorithms and all can be compared to the Subtraction Streak algorithm at the same point in the processing. It is possible to plot probability of streak detection as a function of the signal-to-noise ratio of the target.

The best comparison in terms of the FPP output for each of the algorithms is available from the output of the T340, T350 and T360 series of runs, which had many targets. Each of this series of runs was put through the applicable FPP processor.

The results for the 9-exposure time-lines are shown in Figure 4-5. In this figure the probability of target detection is plotted against the target intensity. The data in this figure is based upon detection data for close to 300 targets in the intensity reqion near the threshold and an angular rate region near the minimum. It represents the most detailed probability of detection study of algorithms.

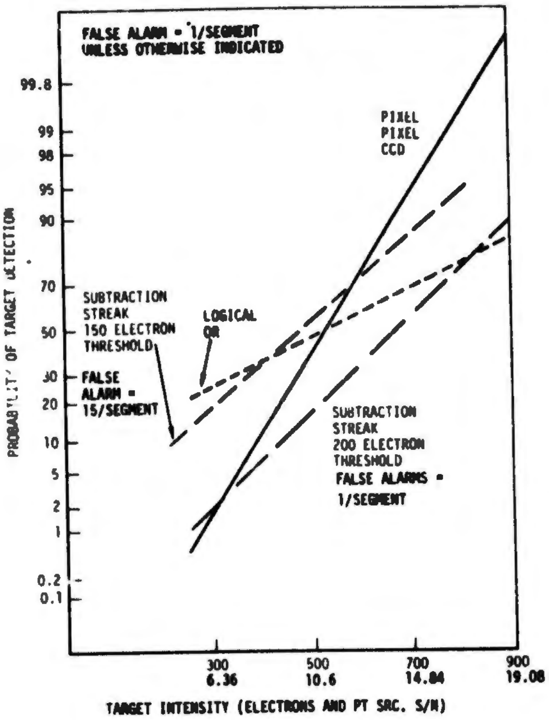


Figure 4-5. Probability of Target Detection — 9 Exposures

The Subtraction Streak algorithm is plotted for two conditions: one for a 150 electron threshold and the second for a 200-electron threshold. As it was discussed above, this algorithm was carried through the Phase II characterization with two thresholds. The false alarm rate at the 150-electron threshold is above the tolerable level as measured for the other algorithms. However, future algorithm enhancement, possibly a minimum velocity test, could allow the algorithm to perform at this threshold.

There is a considerable difference between slopes of the curves of each of the three algorithms. The slope of the Pixel Pixel CCD curve is steeper than that for the Subtraction Streak or Logical OR algorithms. Thus, while the Pixel Pixel CCD curve has a relatively low probability of detection at the lower intensity, it has a very high P_D at the highest intensities. Of the three algorithms, the

Logical OR algorithm shows the worse probability of detection at the high intensities. This is due to the P_D roll phenomenon discussed in Volume II.

From the results shown in Figure 4-5, the Logical OR algorithm for nine exposures and a Subtraction Streak algorithm appear to be legitimate contenders. The Pixel Pixel CCD algorithm however should not be dismissed because of low probability of detection at low target intensities. The Pixel Pixel CCD algorithm does have the best record as far as repeatable probability of detection.

The 38-exposure time-line algorithms are compared to Figure 4-6. Again, these results are the results of the extensive Phase II probability of detection run series. They represent the compilation of over 230 targets in the region of interest. All three algorithms performed adequately in this comparison.

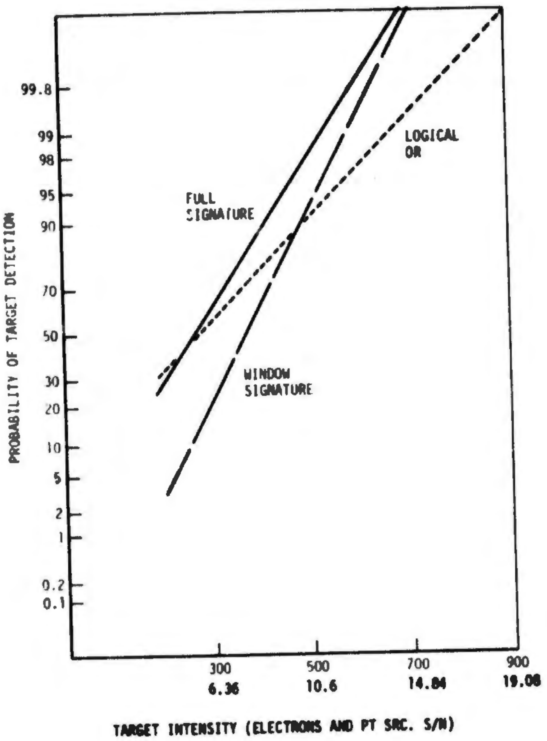


Figure 4-6. Comparison of Algorithms – 38 Exposures

4.4.3 Hardware Comparisons

The data on the possible vehicle impace in terms of ODP estimated size, weight and power are summarized in Table 4-5. It is obvious that the Full Signature algorithm with 1520-pound weight and 3,801-watt power estimates is out of line with the other seven algorithms. The other seven algorithms can be placed into three levels of vehicle impact based upon the size, weight and power estimates. In the first level is Logical OR, followed by Subtraction Streak, Subtraction Search and Background Signature. The estimated weights of these algorithms are all under 100 pounds, and the estimated power is in each case under 200 watts. In the third hardware feasibility category are Window Signature, Digitized Signature and Pixel-Pixel CCD.

None of these algorithms have any significant technology impact with the possible exception of Subtraction Streak. The Subtraction Streak algorithm requires the development of an on-board streak correlation routine. For this reason there is some exposure in vehicle impact for the Subtraction Streak algorithm.

The data rates for each of the algorithms are all less than 18 kbps for the same false point count. Except for Subtraction Streak (1 kbps), there was no significant difference between the algorithms. However, the data rate in each case is so low that this should not be a significant algorithm-to-algorithm discriminate.

Ground computer complexity is defined as a qualitative measure of the level of complexity of: the ground data processing hardware; the ground data processing alogrithms; and the consequent ground data processing cost. For example, if the on-board processor produces high quality streaks with accurate lengths, the ground computer complexity required is less than one which produces segmented streaks. An accurate estimate of velocity will significantly

Table 4-5. Vehicle Impact Summary

Algorithm	Analog Memory (Megels)	Digital Memory (Megabits)	Estimated		
			Size (in^3)	Weight (Pounds)	Power (Watts)
Subtraction Streak	11.52	5.79	3,400	86.5	181
Full Signature	253.44	0.425	63,400	1520	3801
Window (Analog) Signature	23.04	0.320	5,790	139	345
Window Signature (Digital)	5.76	63.36	7,000	225	181
Background Signature	11.52	0.425	2,925	71	173
Digitized Signature	17.28	6.185	4,928	125	269
Subtraction Search	6.336	5.86	2,111	55.6	103.8
Logical OR	5.76	6.185	1,996	35.9	95.7
Pixel-Pixel CCD	17.28	0.050	4,320	103.7	259

aid the trajectory initiation process. For these algorithms, four levels of ground processing complexity are defined. At level one, the least complex, is the Subtraction Streak algorithm. This is because this algorithm required only Streak Association in the ground processor and no streak detection in background elimination. At the second level of complexity are the signature algorithms. The signature algorithms all produced a good quality streak. Thus, a streak detection algorithm on the ground similar to the FPP used in this study is possible. At the third level, complexity is the point association algorithms. These algorithms, Pixel Pixel CCD and Subtraction Search, require a FPP which uses Track Initiation and not streak processing. Because this type of FPP is in general more sensitive to false points, the complexity requirement for this set of algorithms is greater than for the signature algorithms. The most complex ground processing situation is offered by the Logical OR algorithm. This is because the Logical OR algorithm results in streak breaking of the output composite streak. Some presently undeveloped algorithm would be needed to better associate the components of a detected streak. It is important that the components of a detected streak be associated and not eliminated since mere detection that a streak is present is often not enough. A good estimate as to the velocity of the target is needed for many DSSS/VLS system applications, and the velocity estimate is based upon the length of the streak.

No algorithm should be eliminated on the basis of ground computer complexity unless that complexity is outside the present realm of the technology. However, the Logical OR algorithm, since it requires further algorithm development in the FPP must be examined closely for a final decision.

4.4.4 ODP Algorithm Tradeoff Matrix

A tradeoff matrix for the ODP algorithms for 38 exposures and for 9 exposures is shown in Figures 4-7 and 4-8, respectively.

There are the four performance measurement criteria in these tradeoff matrices. They are simulation performance, the vehicle impact in terms of size, weight and power, the ground data link, and the ground processing complexity. A ranking of the algorithms based upon the characterization results is shown for each of these criteria. For example, while the Full Signature algorithm's performance at 38-exposure was better than Logical OR and Window Signature, its vehicle impact was not acceptable. Thus there are

	SIMULATION PERFORMANCE	VEHICLE IMPACT	DATA LINK	GROUND PROCESSING COMPLEXITY
SUBTRACTION STREAK	NOT APPLICABLE	2	1	1
PIXEL PIXEL CCD	NOT APPLICABLE	3	2	3
LOGICAL OR	2	1	2	4
SUBTRACTION SEARCH	NOT APPLICABLE	2	2	3
DIGITIZED SIGNATURE	NOT ACCEPTABLE	3	2	2
WINDOW SIGNATURE	3	3	2	2
FULL SIGNATURE	1	NOT ACCEPTABLE	2	2
BACKGROUND SIGNATURE	NOT ACCEPTABLE	2	2	2

NOTE: WITHIN EACH GROUP, 1 IS BEST

Figure 4-7. ODP Algorithm Trade-off Matrix — 38 Exposures

	SIMULATION PERFORMANCE	VEHICLE IMPACT	DATA LINK	GROUND PROCESSING COMPLEXITY
SUBTRACTION STREAK	2	2	1	1
PIXEL PIXEL CCD	2	3	2	3
LOGICAL OR	1	1	2	4
SUBTRACTION SEARCH	NOT ACCEPTABLE	1	2	3
DIGITIZED SIGNATURE	4	3	2	2
WINDOW SIGNATURE	NOT ACCEPTABLE	3	2	2
FULL SIGNATURE	3	NOT ACCEPTABLE	2	2
BACKGROUND SIGNATURE	NOT ACCEPTABLE	2	2	2

NOTE: WITHIN EACH GROUP, 1 IS BEST

Figure 4-8. ODP Algorithm Trade-off Matrix — 9 Exposures only two candidates for 38-exposure implementation, Logical OR and Window Signature. A tradeoff is necessary between the Logical OR simulation performance and relatively low vehicle impact versus the computer complexity for the ground processing present with Logical OR.

A similar tradeoff is shown in Figure 4-8 for the nine exposure case. In this case the Logical OR algorithm had the best simulation performance of the nine exposure algorithms; however, its ground computer complexity is considerably higher than that of Subtraction Streak.

In summary, there is no ultimate algorithm resulting from the ODP characterization. Rather, several algorithms have been pointed out to be relatively good performers on the basis of the simulation. The system designer thus can use the trade-off data presented in this report, and summarized in the trade-off matrices as part of the choice in configuring a system.

5. RECOMMENDATIONS

In this section, recommended future activity using the MOSS simulation is summarized. These recommendations include: ground experiment simulation; satellite signature input; CCD sensitivity variation modelling; Spatial Correlation Logical OR (SPALOR); and hybrid algorithms; and FPP improvements.

5.1 GROUND EXPERIMENT SIMULATION

The majority of the issues which affect the sensor data processing for the DSSS/VLS system can be tested using ground based experiments. This includes critical sensor parameter settings, performance against integrated background light, star rejection in the face of jitter, and data processing algorithms through the initiation of tracks. Field data gathered from two locations has been used to test out algorithms for visible light systems. The MOSS programs are available with a ground observer input to simulate the ground environment. Capabilities exist to use the ground observer programs developed under MOSS to aid in the effective design of ground experiments. These programs are also available for the processing of the data from these experiments as part of a systematic evaluation of ground experiments. The need to emulate the space environment, particularly as far as jutter and sensor background is concerned, can also be examined. Indications from MOSS are that the simulation of space observer with a ground telescope is not only feasible, but in many ways preferable to a probe or satellite experiment.

Many of the problems encountered by an orbiting spacecraft can be modelled in a ground-based sensor. Thus, MOSS DSG operating in a GEODSS mode can be used to simulate candidate field test set-ups and compare these results to simulated space runs. An interface between the MOSS GEODSS output (with CCD detector model) is required to allow data flow into the simulated space ODP.

The MOSS programs as they exist, with both a ground observer portion and a space observer portion, can provide a unique aid in the design of field test experiments. A field test experiment design procedure is shown in Figure 5-1. The main flow lines are shown in this chart. One processing line is the MOSS/ODP simulated operational configuration. This consists of the use of the MOSS DSG as a space platform with corruptional effects such as would be found from a space observer.

This data stream, a simulated space data stream, is sent to the MOSS ODP and FPP programs for evaluation. The results of these runs, expressed in terms of probability of detection of a target and expected false track rate, can be correlated to the operational configuration selected. It is against these results that an experimental design for ground emulation of a space-based observer can be tested. The experimental design in terms of resolution, field-of-view, atmospheric environment factors, integration time, etc., serves as an input to the MOSS DSG operating as a ground observer. In this case, parameters characteristic of a selected test site, such as scintillation, air glow, and atmospheric seeing are used to corrupt the measurements. The corrupted DSG measurements would then be input to the MOSS ODP/FPP programs for evaluation. These results can then be compared to the simulated spacecraft run previously made. The comparison then can serve to modify the experimental design. With this method the simulation can be used as a design tool and as an evaluation tool.

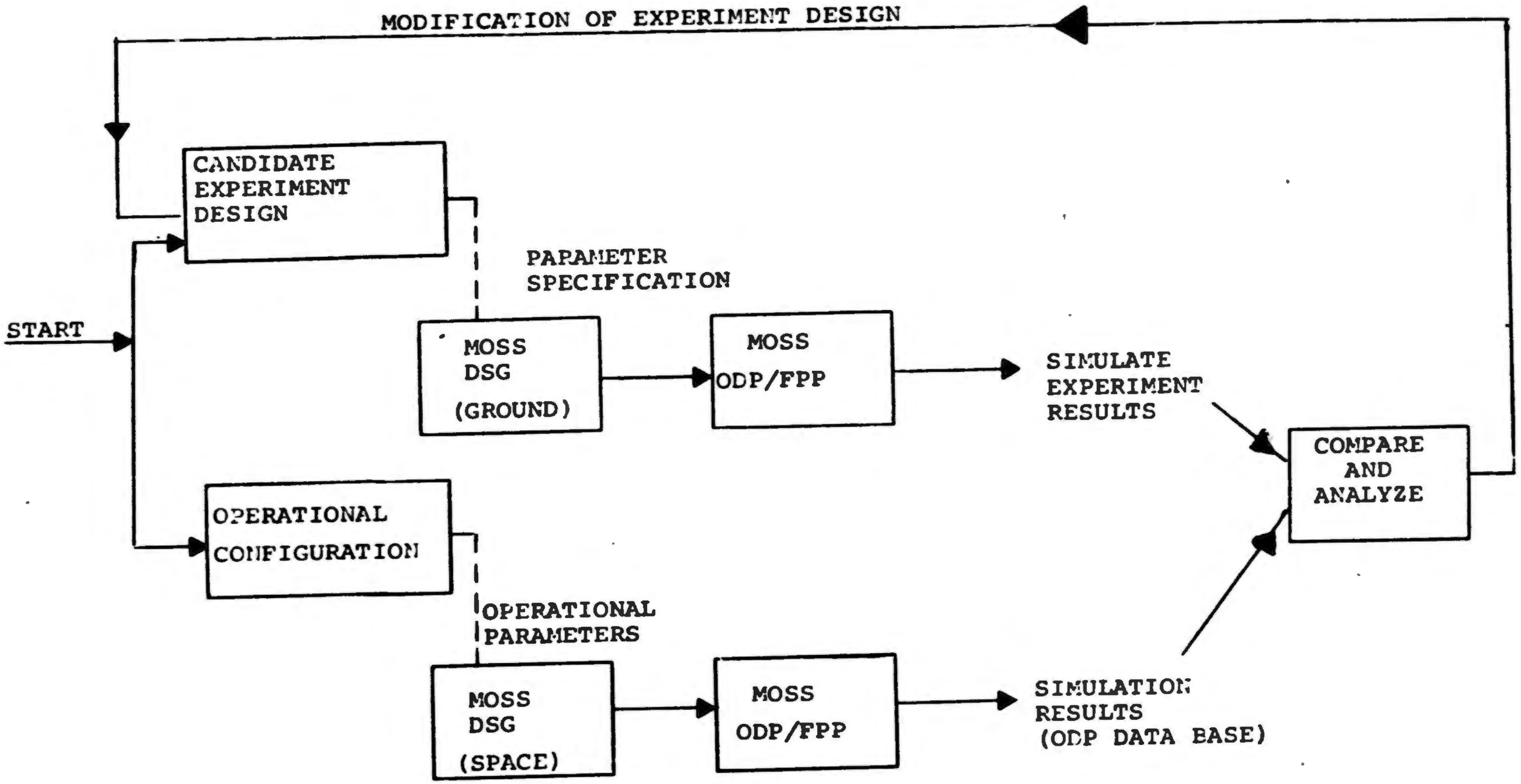


Figure 5-1. Field Test Design Approach

5.2 SATELLITE SIGNATURE INPUT

An interface to a satellite signature generator program would allow the replacement of the present Ideal Encounters generated by the MOSS RSO/TSO Encounter Generator (RTE). At present, this program produces focal plane encounters for orbital objects. These encounters are a series of x,y, and intensity measurements during the detector integration time. Through parallel program set up (i.e., common observer and threat orbital elements, epochs, etc.) a signature program produced intensity series will replace the RTE-produced intensity series. This intensity series could then be sent for further processing in the MOSS Platform Dynamics and Sensor System Simulator.

An overview of this approach is shown in Figure 5-2. Naturally, the relatively long integration periods and the finite detector geometry will smooth the signatures. It is important to include this capability for two reasons. First, the unexpected effect of spatial jitter has shown that high frequency information (in that case spatial frequency) can, in conformance with the sampling theorem of digital signal processing, create difficulties (false jitter point leakage) at much lower spatial frequencies. A similar possible aliasing effect may be caused by high frequency intensity variations. For example, scintillations in intensity of a dim target may create gaps within a streak. Thus, DSSS/VL ODP-selected MTI algorithms can be evaluated against real target signatures. Secondly, the SOI potential of MTI algorithms, and the DSSS system as a whole, should be investigated. Particularly important is the amount of SOI information available from the MTI process itself.

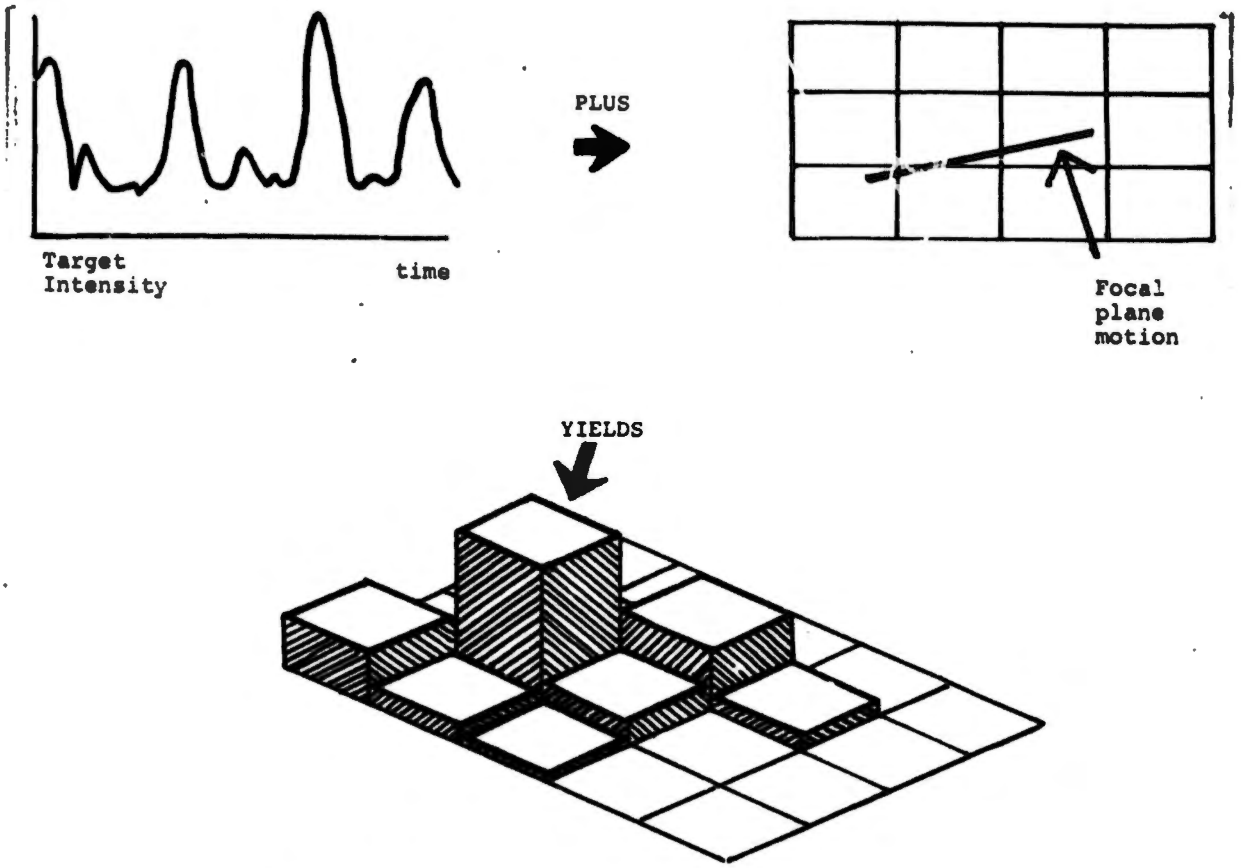


Figure 5-2. Signature Input to MOSS

5.3 CCD SPATIAL VARIATIONS OF SENSITIVITY

Experimental data obtained from CCD measurements have shown that there is significant pixel-to-pixel variation in sensitivity. This variation results from a variety of sources and is seen by the CCD user as pattern noise. Measured sensitivity variations are shown in Figure 5-3. These measurements were made using a small light spot focused on a Texas Instruments CCD. Two types of variation are seen. First, within a given pixel there is a variation due principally to the geometric distribution of energy. There is also a definite pixel-to-pixel variation. Since sensitivity variation is an important property of a real CCD, the selected ODP algorithms should be evaluated against this phenomenon. Streak-based algorithms, in particular, may be more sensitive to this effect than point association algorithms. Sensitivity variations on a dim target may cause gaps in the streak similar to target scintillation effects.

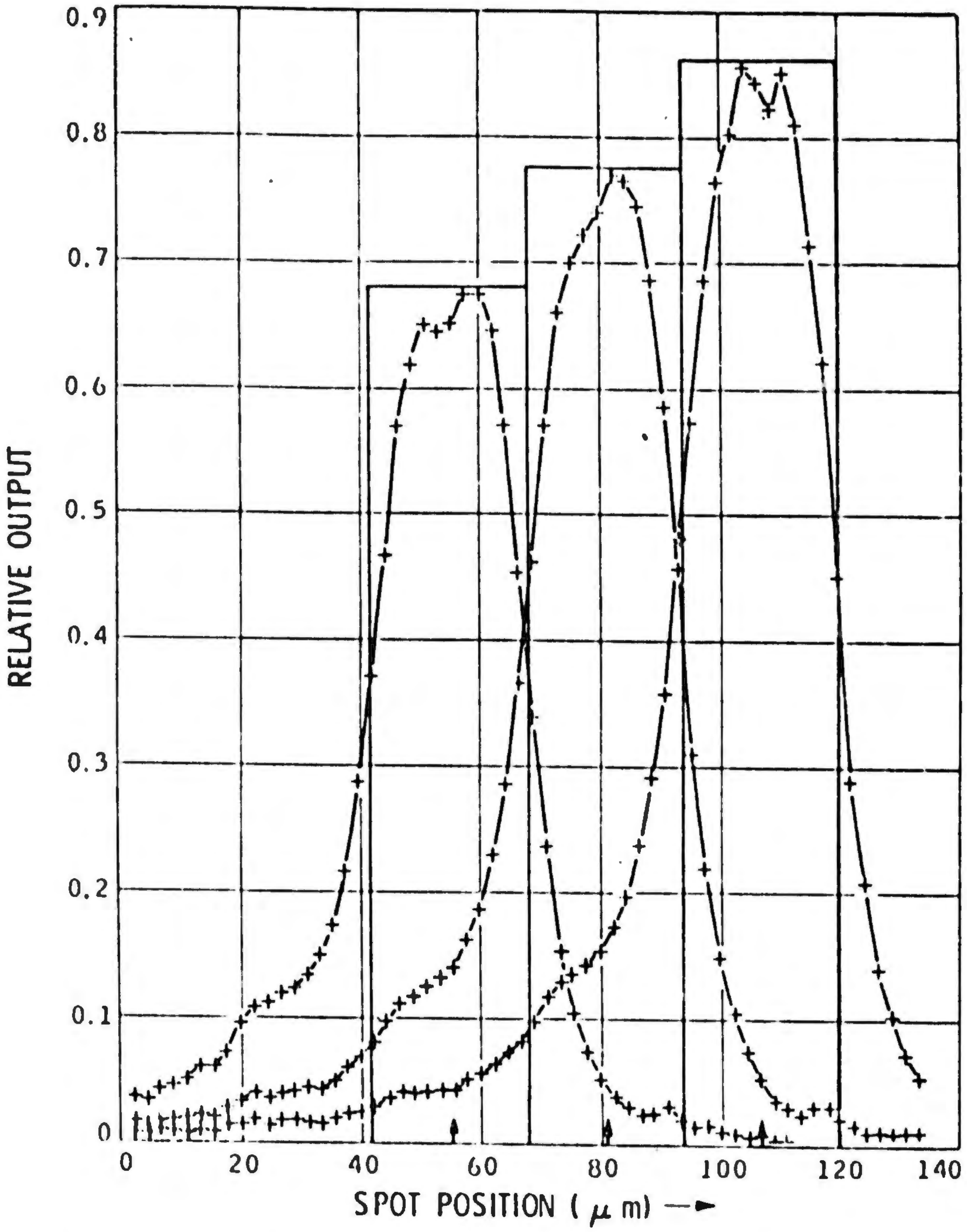


Figure 5-3. Sensitivity profile for three adjacent pixels (blue filter) (scan 1 to vertical channel) Reference: Ando, K. "MTF and Point Spread Function for a Large Area CCD Imager," Proceedings Symposium on Charge-Coupled Device Device Technology for Scientific Imaging Applications, JPL SP43-21, Jet Propulsion Laboratory, Pasadena, CA 1975

CCD sensitivity variations can be included in the present MOSS sensor simulation to augment the present shading model. An implementation concept for sensivity variation is shown in Figure 5-4. By developing a sensitivity matrix during initialization, the running time should not be significantly increased.

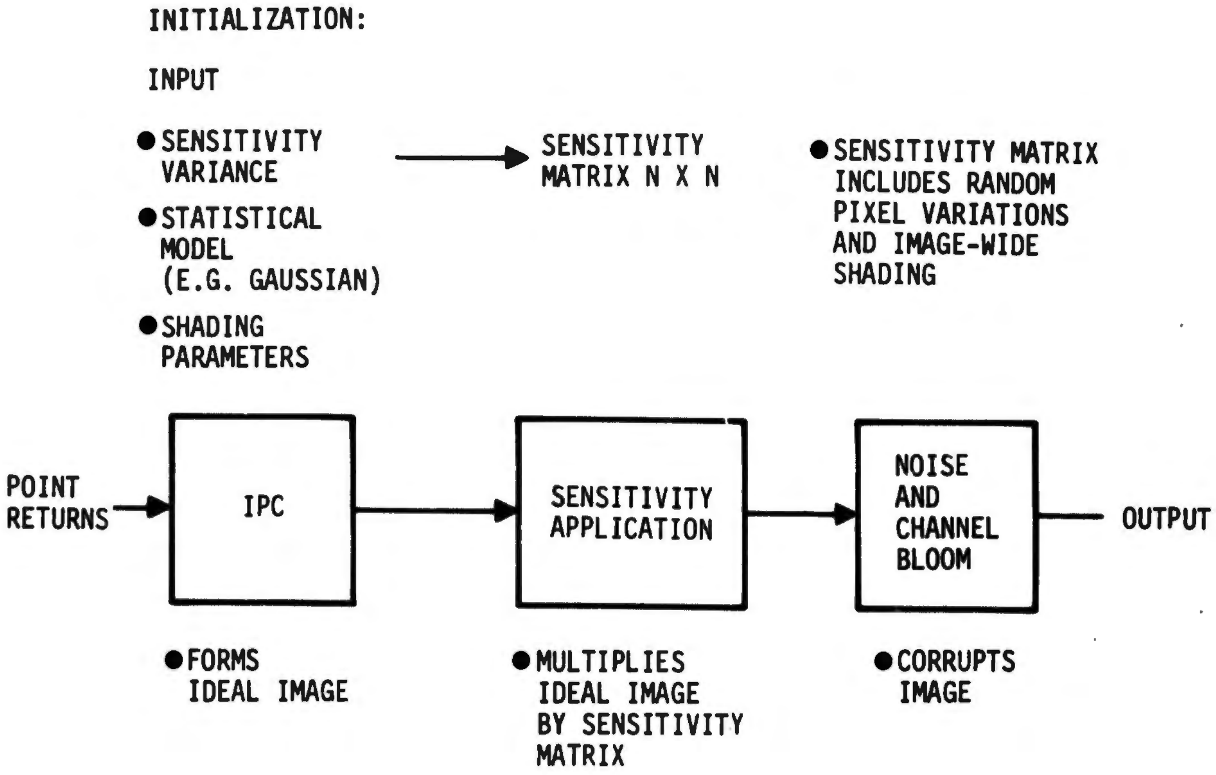


Figure 5-4. MOSS Modification To Model CCD Pixel Level Sensitivity Variations

5.4 SPATIAL CORRELATION LOGICAL OR (SPALOR)

The SPALOR algorithm combines features from one of the most promising DSSS/VL ODP study algorithms, Logical OR, with the concept of spatial correlation. Its principal advantage is in the enhancement of the intensity target returns before threshold. Because of target motion during the integration period, a target will spread its energy even if the integration time and pixel size have been optimized for slow target detection. This "streaking" phenomenon when included with the optical/material blurring, reduces detectivity. By performing a limited spatial correlation, the target signal can be enhanced. This algorithm will improve the low intensity detectivity capability of the Logical OR algorithm.

The SPALOR functional flow is shown in Figure 5-5. The spatial correlation function is really a complex thresholding based on neighboring pixels. Each pixel's intensity is first tested against the self-correlation threshold T_1 and the intensity in the pixel is added to (or multiplied by) each of the neighboring pixels and tested against respective thresholds. Successful correlations are ORed into a composite in the same manner as Logical OR.

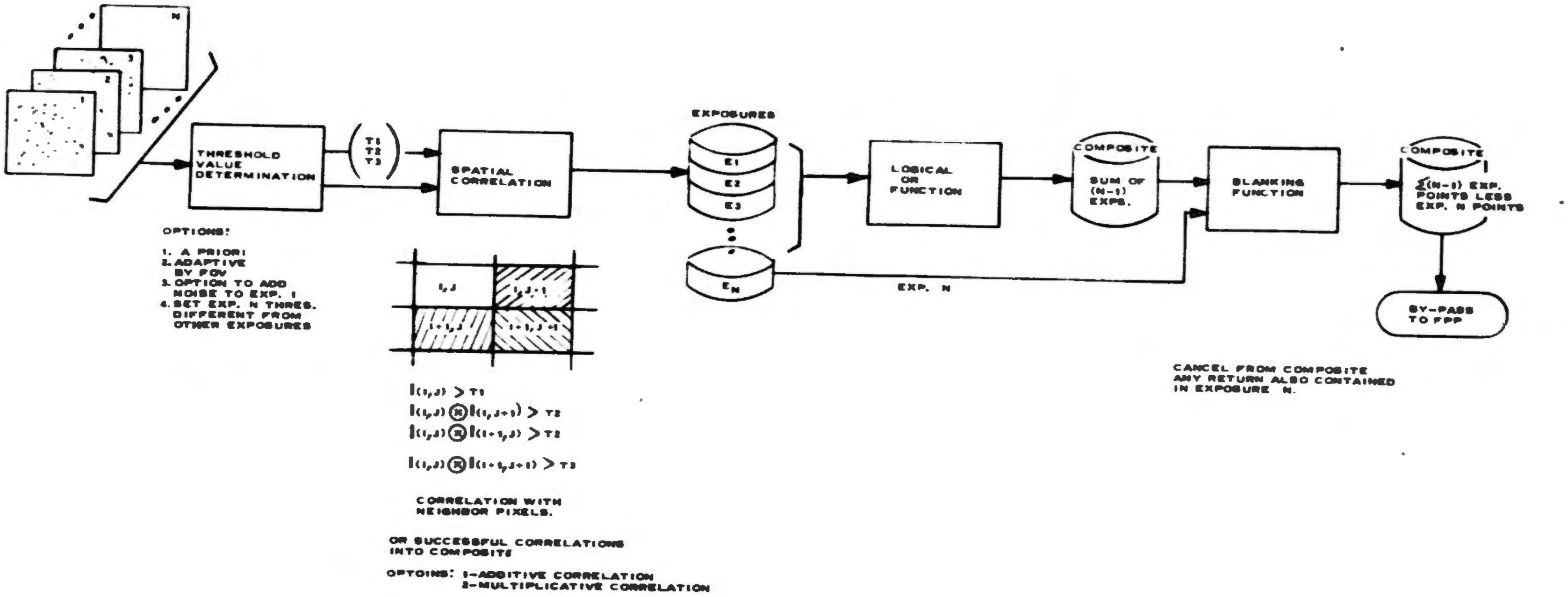
5.5 HYBRID ALGORITHMS

Hybrid algorithms, combining good features of the various ODP algorithms, should be studied further. Since the ODP was programmed in a modular fashion, the combination of such features is relatively simple.

One particularly interesting hybrid would combine the composite output of Logical OR with the rotating vector of Subtraction Streak. This algorithm would combine on-board implementation through track initiation with relatively low risk.

5.6 STREAK FPP IMPROVEMENTS

The present MOSS FPP is not optimized for all candidate algorithms. For example, the FPP performance on the output of the Logical OR algorithm is not optimized. Since the Logical OR algorithm results in significant streak segmenting, gross mis-estimates of target velocity are possible (see Figure 5-6). Also missed targets



OPTIONS:

1. A PRIORI
2. ADAPTIVE BY FOV
3. OPTION TO ADD NOISE TO EXP. 1
4. SET EXP. N THRES. DIFFERENT FROM OTHER EXPOSURES

$I(i,j) > T1$

$I(i,j) \circledR I(i,j+1) > T2$

$I(i,j) \circledR I(i+1,j) > T2$

$I(i,j) \circledR I(i+1,j+1) > T3$

CORRELATION WITH NEIGHBOR PIXELS.

OR SUCCESSFUL CORRELATIONS INTO COMPOSITE

OPTOINS: 1-ADDITIVE CORRELATION
2-MULTIPLICATIVE CORRELATION

CANCEL FROM COMPOSITE ANY RETURN ALSO CONTAINED IN EXPOSURE N.

Figure 5-5. Spatial Correlation Logical OR (SPALOR)

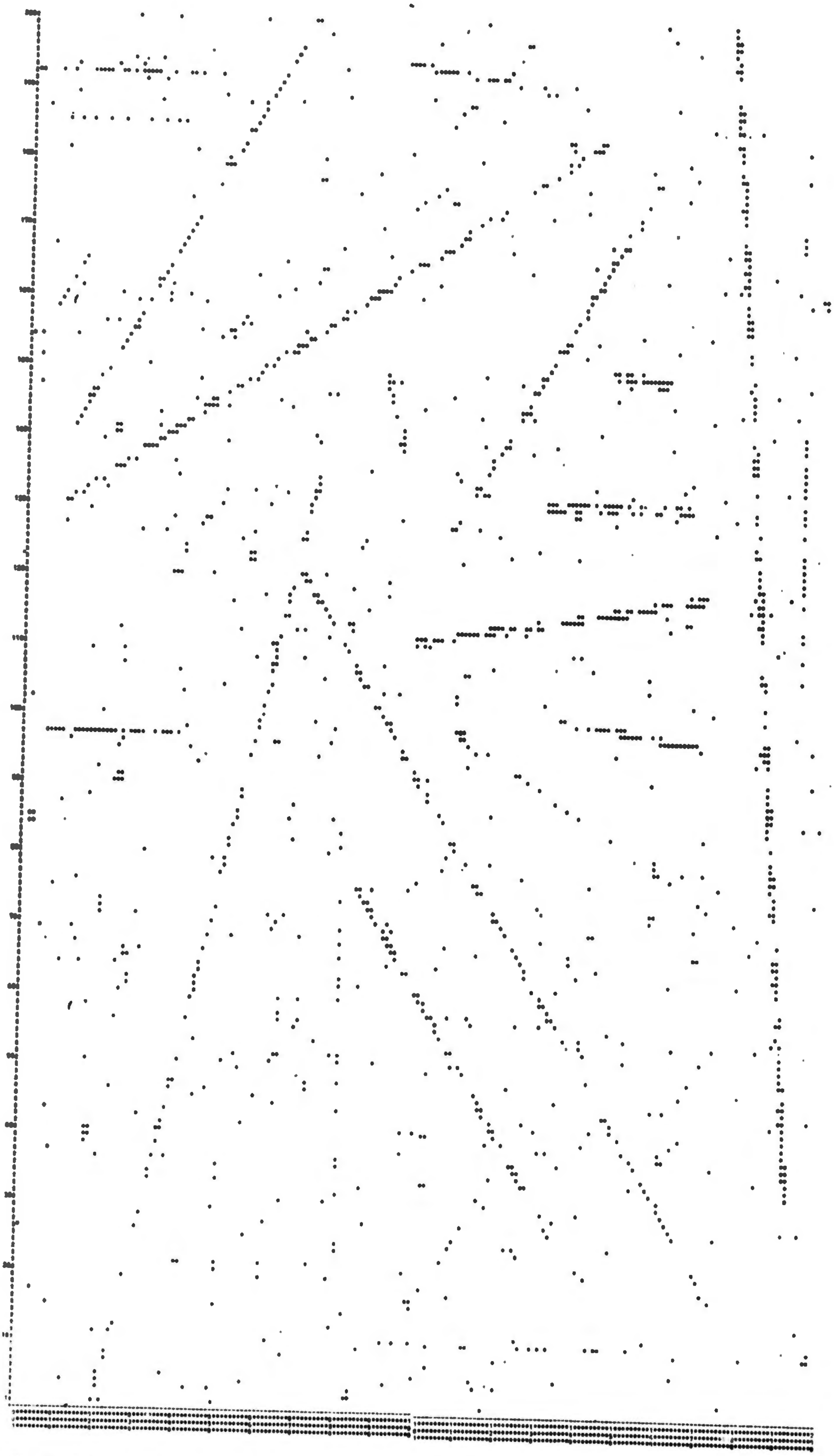


Figure 5-6. Streak Segmenting Examples from Logical OR ODP Run

is a high possibility because of the loss of individual streak components. This problem is reflected to some extent in all the algorithms studied under the DSSS/VL ODP study.

It is desirable to study more fully alternative FPP configurations for associating streak segments and implement these in MOSS for evaluating the best candidate.

Several approaches to the FPP should be examined. These include non-contiguous centroiding, frequency domain pre-filtering, and segment initiation. Many of these can be implemented in the same FPP and do not necessarily represent alternatives.

> <u>Non-Contiguous Centroiding</u> - The present MOSS streak FPP associates points into groups on a contiguity test (see Figure 5-7). Pixels passing the ODP detection criteria and not touching another pixel are immediately discarded. It is proposed that the impact of non-contiguous association be explored in terms of P_D and expected increase in false streaks.
>
> <u>Frequency Domain Pre-Filter</u> - There exist many isolated singlets and doublets which are not part of a target streak. However, any simple test discriminating against isolated singlets and doublets will also discriminate against singlets and doublets which are part of a broken target streak. It is proposed that digital filtering using Fourier transforms be explored as a means of preferential discriminating against isolated singlets and doublets.
>
> <u>Streak Segment Initiation</u> - To better link streak segments and to include those pixels which may not individually pass streak recognition test, it is proposed that the present streak association criteria be modified as follows. A stricter length to width test would be used to find initiator streak segments. The orientation of these segments would be used to associate segments which need only pass a less stringent length-to-width test (see Figure 5-8).

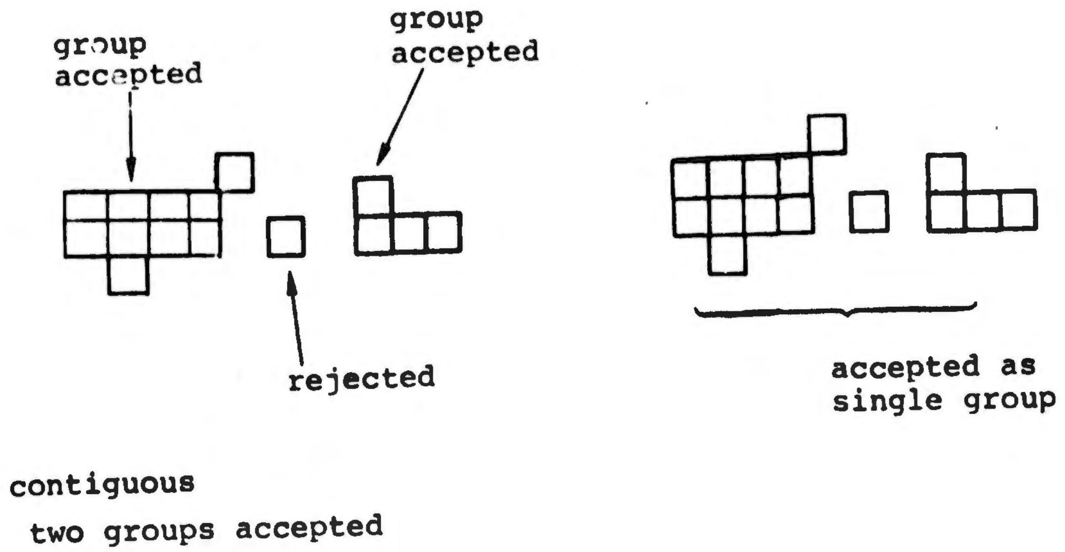


Figure 5-7. Group Association Criteria

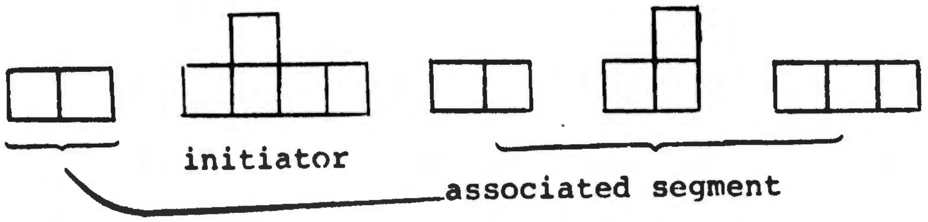


Figure 5-8. Streak Segment Initiation

The above technique should be analyzed in detail and the promising ones implemented in MOSS. Candidate ODP algorithm outputs could be used to evaluate the FPP modifications.