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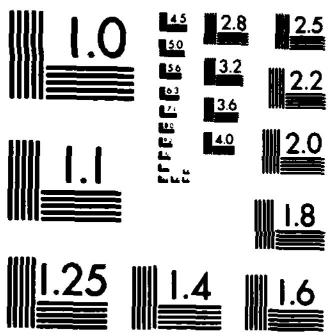
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(17)

En Route Moving Target Detector (MTD) II Test and Evaluation

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Prepared By
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16. Abstract

The moving target detector (MTD) II is a sophisticated signal processor designed to provide improved radar detection of aircraft in the air traffic control environment, particulary in areas of heavy radar clutter. The MTD II was installed on one channel of the FPS-67B en route surveillance radar at Bedford, Virginia. The objective of this testing was to compare the operational performance of the the MTD II with that of the common digitizer (CD) operating with the other radar channel. This report covers performance relative to percentage of target detection, false alarm rate, interference reduction, processor improvement factor, subclutter visibility, system dynamic range, velocity response, and flight testing of the MTD II and CD equipped radar channels.

The results of the test show that the MTD II provides performance superior to that of the CD.

17. Key Words
Moving Target Detector
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Radar Processor

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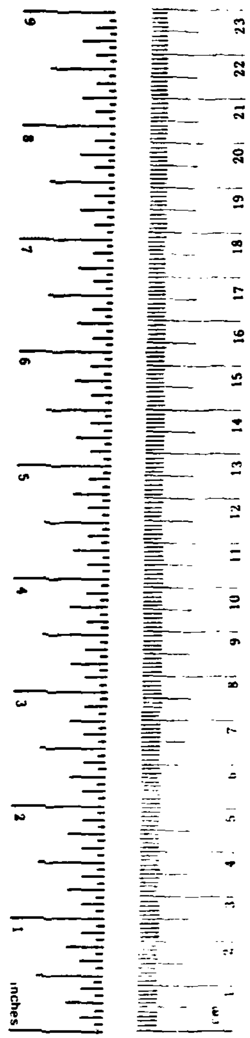
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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



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

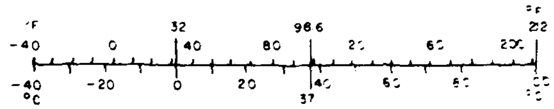


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ACRONYMS

A/D	Analog-to-digital
ACP	Azimuth change pulse
ARP	Azimuth reference pulse
ARSR	Air Route Surveillance Radar
ATC	Air traffic control
CW	Continuous wave
CD	Common digitizer
C&I	Correlation and Interpolation
CPI	Coherent processing interval
CFAR	Constant false-alarm rate
dB	Decibel
IEEE	Institute of Electrical and Electronic Engineers
FAA	Federal Aviation Administration
FIR	Finite impulse response
FFT	Fast Fourier transform
FPS	Fixed radar detector (military designation)
IF	Intermediate frequency
I&Q	In phase and Quadrature
LP	Linear Polarization
MLT	Mean level threshold
MTD	Moving target detector
MTI	Moving target indicator
MIT	Massachusetts Institute of Technology
NAS	National Airspace System
nmi	Nautical mile
P_d	Percentage of detection
P_{fa}	Probability of false alarm
PM	Processing module
PMP	Parallel microprogrammed processor
PPI	Plan position indicator
PRF	Pulse repetition frequency
RAG	Range azimuth gate
RF	Radiofrequency
rms	Root mean square
SCV	Subclutter visibility
SGP	Single gate processor
SP	Surveillance processor
STC	Sensitivity time control
TTG	Test target generator
μs	Microsecond
ZVF	Zero velocity filter

INTRODUCTION

PURPOSE.

The purpose of this project was to test and evaluate a moving target detector (MTD) radar processor system in an en route air traffic control (ATC) radar environment and to determine its capability to improve upon the radar processing function now performed by the current radar system and common digitizer (CD) combination. The primary area of concern was the ability of the MTD II to improve the performance of the en route radar system in areas of high level radar clutter.

BACKGROUND.

The MTD II was developed for the Federal Aviation Administration (FAA) by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory under contract DOT-FATQWAI-679. Like the MTD I (reference 1), the MTD II was designed to improve radar aircraft detection in clutter. The en route version of the MTD II was installed at the fixed radar detector FPS-67B radar site near Bedford, Virginia. This report presents the results of the evaluation of this MTD II system.

DESCRIPTION OF EQUIPMENT.

A simplified block diagram of the MTD II system is shown in figure 1. In order to provide the required clutter rejection, the MTD II utilizes wide dynamic range, coherent signal processing, velocity filtering, and adaptive thresholding. The MTD II receiver is a linear receiver with a dynamic range of 54 decibels (dB). The output of the receiver consists of the in-phase (I) and quadrature phase (Q) video signals which are sent to two 10-bit analog-to-digital (A/D) converters. Data from the A/D converters are processed in the parallel microprogrammed processor (PMP) in groups of eight radar sweeps, referred to as coherent-processing-intervals (CPI's). There are 512 CPI's per antenna scan, each of which represents 0.703° in azimuth. The 192-nautical mile (nmi) range of the processor is divided into 1,536 range gates, each processed through a bank of eight finite impulse response (FIR) Doppler filters. The total number of range-azimuth-Doppler cells for the 192-nmi range of the processor was 6,291,456 per antenna scan.

The correlator and interpolator (C&I) processor correlates all threshold crossings into targets and centroids them in range and azimuth. After C&I processing, all the targets can be subjected to independent geographical and Doppler adaptive thresholds to maintain the false alarm rate going into the surveillance processor (SP) at 1×10^{-5} per scan.

The targets are then subjected to additional filtering in the SP which uses scan-to-scan correlation to reduce the false alarm rate to the design goal of approximately one false alarm per antenna scan. The resulting correlated targets are then outputted for display. Nonscan correlated targets can also be selected for display both for maintenance and operational purposes. A complete system description is given in references 2 and 3.

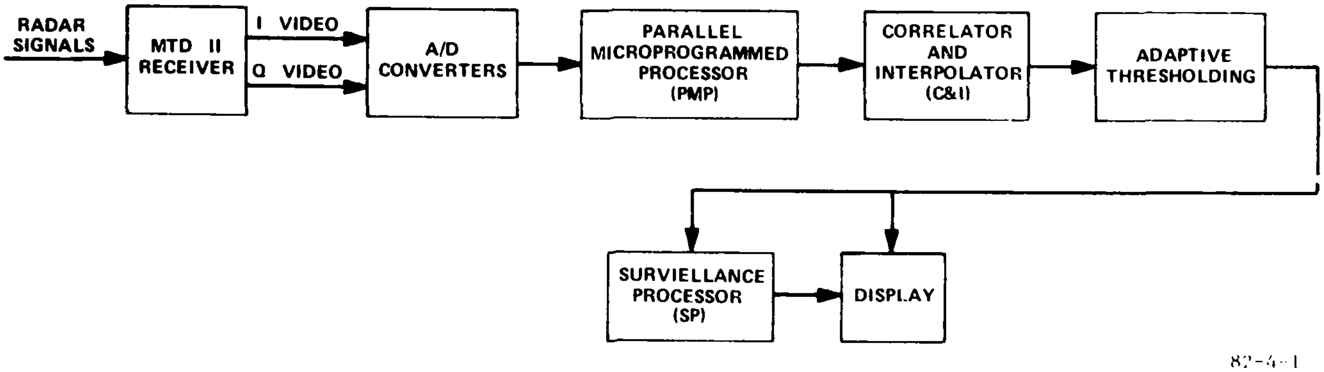


FIGURE 1. MTD II SIMPLIFIED BLOCK DIAGRAM

DISCUSSION

The basic philosophy followed in testing was to compare the capabilities of the MTD II processor when used in an en route environment to that provided by an operational radar processor; in this case, the combined FPS-67B and CD system. The Bedford FPS-67B radar site was chosen for these tests since it provides an extended, high amplitude ground clutter environment.

Standard radar system performance factors were tested and data from flight test targets of opportunity were collected to determine overall system performance. Except for the "Flight Tests" section, the testing described deals primarily with investigation of the MTD II's performance. Since comparative FPS-67B/MTD II and FPS-67B/CD cotesting was accomplished using aircraft targets, it is discussed in the Flight Tests section. Hereafter, the FPS-67B/MTD II will be referred to as the MTD II and the FPS-67B/CD will be referred to as the CD.

SYSTEM TEST AND RESULTS

TEST CONFIGURATION.

The MTD II was installed on channel 2 of the FPS-67B radar (figure 2). Cross-channel blanking was provided between channels to eliminate mutual interference. The MTD II also included a provision for delaying its trigger, when necessary, in order to prevent the simultaneous firing of both radar transmitters.

Channel 2, the MTD channel, was modified by replacing its stalo with a crystal controlled, phase-locked oscillator to improve stability. The receiver preamplifier was also replaced with a solid-state unit of wider bandwidth and improved sensitivity. The increased sensitivity was necessary because the MTD II channel's transmitter pulse width was decreased from 6 microseconds to 2.3 microseconds. This provided a larger number of independent data samples per each nmi of range to aid in weather clutter resection since weather is generally considered homogeneous only over intervals up to 1 nmi in extent. The approximate 4.0 dB loss in transmitter signal average power was to be made up by an increase of 4.0 dB in receiver sensitivity.

The three basic connections between the radar and the MTD II were triggers, coho signals, and the receiver preamplifier outputs.

The MTD II's radar control unit provided the basic timing and control of the radar system. It provided triggers to the radar transmitter, receiver, and the A/D converters. Pulse repetition frequencies (PRF's) of 347 and 417 were used. The output from the A/D converters was sent to the PMP, which consisted of six processing modules (PM). Each module processed 32 miles of range. The maximum system range was 192 miles.

The output of the PMP, which consisted of primitive target reports and weather information, was sent over the Institute of Electrical and Electronic Engineers (IEEE) 488 bus to the post-processor for correlation and interpolation and scan-to-scan correlation of the primitive targets. This function was implemented with a Data General Eclipse S-130 computer. The outputs of the post-processor were the target reports in the standard CD format for transmission over modems to the Technical Center. The Megatek display, together with it's processor, provided a means to display MTD II detected radar targets for maintenance purposes and for onsite testing. A plan position indicator (PPI) presentation of targets and clutter could also be produced on this display to aid in monitoring system performance. Onsite recording of the MTD II system outputs was also provided. Data were collected by photographing the Megatek display.

Simultaneous beacon, MTD II, and CD data were recorded on tape at the Technical Center and used in analyzing the performance of the MTD II equipped channel versus that of the CD equipped channel. A brief description of the recording and analysis function is given in appendix B.

SYSTEM NORMALIZATION.

For comparative system testing, the two radar channels were to provide equal transmitter/receiver loop gains. When normalized, any difference in performance between the MTD II and the CD channels could be attributed to system merit.

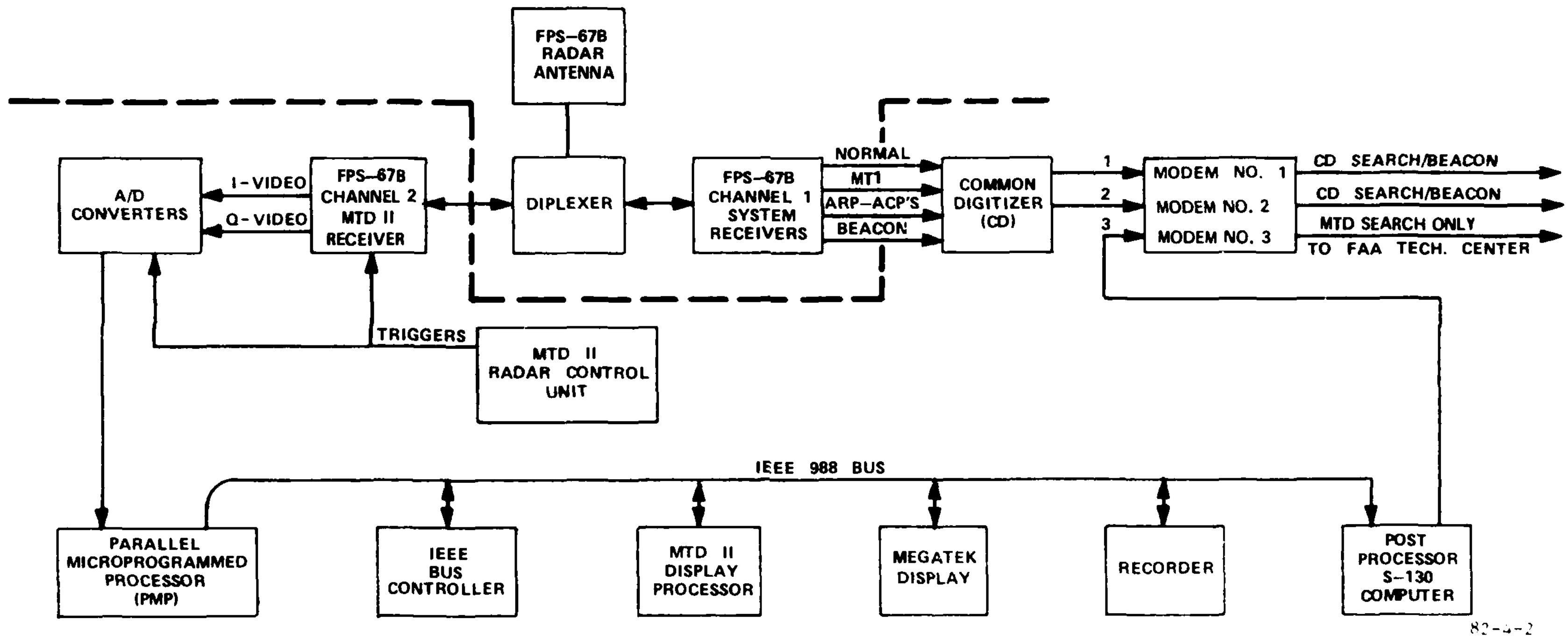


FIGURE 2. TEST CONFIGURATION

In pretest investigations of loop gains, two disparities were discovered. First, due to incomplete transmitter modification of the MTD II radar channel (reference 3), it developed 1.0 dB less peak power than expected. Second, as discussed previously, the MTD II channel was modified by the incorporation of a low noise preamp to increase the systems sensitivity by 4.0 dB. However, only a 2.5 dB increase in receiver sensitivity was achieved.

Due to these factors, the MTD II radar channel had 2.5 dB less gain than the CD channel when compared with its log normal video output. Correspondingly, both channels had equal gains when the CD channel's MTI video was used for comparison. Therefore, the MTD II channel suffered approximately 15 percent loss in long range detection capability. The Bedford radar is operated in the MTI mode for the first 70 (minimum) to 116 (maximum) nmi due to the extended ground clutter. The range of the MTI/log normal crossover varies as a function of the range extent of the ground clutter at a particular azimuth.

PERCENTAGE OF FALSE ALARMS ($P_{f}a$).

This test was conducted to determine the false alarm rate characteristics of the MTD II system and to compare its performance to that of the CD system.

Two areas of testing were accomplished. The false alarm rate in thermal noise of the MTD II was first determined and is discussed in this section. Data were subsequently taken on the MTD and CD system's performance when processing ground and weather clutter signals. These tests are discussed later under "Flight Testing."

PURPOSE OF TEST. This test was conducted to determine if, while processing only receiver thermal noise signals, the desired false alarm rate was obtainable at a low noise level resulting in maximum system dynamic range. The MTD II was designed to operate with a false alarm rate of approximately 1×10^{-5}. Since there are 6,291,456 opportunities for false alarms for each antenna scan, this corresponds to approximately 63 false alarms per antenna scan. In addition, the false alarm rate was to vary less than a factor of 2 as the noise level (as measured at the A/D converters inputs) was varied upward from 1 least significant bit (reference 3). This was to prevent the increase in the thermal false alarm rate with increasing noise level as experienced with the MTD I.

The adaptive thresholds (mean level thresholds) for filters 1 through 7 used to maintain a constant false alarm rate (CFAR) in noise and weather were formed by summing the eight range gates before and seven range gates after the range cell of interest, with the cells adjacent to the cell of interest being subtracted from the sum. This sum (13 cells) was then multiplied by three-eighths to provide a threshold value equal to 13.8 dB above mean noise level and a $P_{f}a$ of 1×10^{-5}. This number is in agreement with theoretical values (reference 4). Whereas, filters 1 through 7 use a sliding window range-averaged CFAR threshold, filter 0 uses a time averaged CFAR threshold. Its threshold was set to 15.6 dB above mean noise to achieve the desired false alarm rate.

The root mean square (rms) noise level, which results in the desired false alarm rate, should be equal to one A/D converter least significant bit (2 millivolts). This provides the maximum obtainable system dynamic range (the difference in amplitude between the system noise level and a limit level signal).

Test Data Collection. This test was made by varying the receiver noise level into the A/D converters from 1 to 16 millivolts and using the Megatek maintenance display system to provide a count of the resulting number of false alarms occurring per scan as a function of the noise level. Photographs were taken of the display to record the false alarm rate information.

Results of Test. With the normal operating rms receiver noise level of 2 millivolts as measured at the A/D converters inputs, the system thermal false alarm rate was measured to be 6×10^{-6}. This equals 37 false alarms per antenna scan. At higher noise levels (4 to 14 millivolts) the false alarm rate increased slightly to 8.5×10^{-6}, corresponding to 52 false alarms per scan. Therefore, the desired false alarm rate was approximately provided and processor quantization noise problems encountered with the MTD I (reference 1) were not present in the MTD II. In addition, since the desired false alarm rate was obtained with an rms noise level of 2 millivolts, full dynamic range was maintained. The system parameters of the CD channel at Bedford were normally set to provide a 1×10^{-5} P_{fa} when processing thermal noise signals.

PERCENTAGE OF DETECTION (P_d).

PURPOSE OF TEST. This test was conducted to determine the P_d characteristics of the MTD II system. With an MTD II processor, a 50 percent P_d should be obtained at a signal level of approximately 7 dB above rms noise level (reference 3).

Test Data Collection. The P_d for the MTD II system in thermal noise was determined using a test target generator (TTG). The system was operated with a 8.5×10^{-6} P_{fa} corresponding to a receiver noise level equal to 1 A/D converter least significant bit (LSB). The test targets were set to be nonfluctuating and were moved in range at a rate approximately equal to that of an optimum speed target, and in azimuth at one azimuth change pulse (ACP) each antenna scan. These targets were varied in amplitude in 1 dB steps, using an attenuator, from below noise level to the point where 100 percent detection was obtained. The pulse width was set to 2.3 microseconds (μs). The TTG target run length was set to equal the two-way 3 dB antenna run length at the pulse repetition rate of the radar system. The system was operated in dummy load. The TTG variable velocity control was set to provide the near optimum speed targets.

The following method was used to determine the signal-equal-to-noise point. First, the receiver intermediate frequency (IF) noise level was measured using an rms voltmeter. Then a continuous wave (CW) signal was injected into the receiver and increased until the signal-plus-noise power level of the receiver output was 3 dB above that of the noise alone. This TTG signal output level corresponded to a signal-to-noise ratio of approximately unity. The percentage of targets output to the Megatek maintenance display at various test signal-to-noise ratios was recorded (see figure 3).

Test Results. As shown in figure 3, 50 percent detection was obtained at a signal-to-noise ratio of 7 dB. The system was, therefore, providing the desired performance. Detection performance at other test target radial velocities is shown in the section on "Velocity Response" testing.

For comparison purposes, the log normal (LOG)/CD and MTI/CD systems at Bedford provided a 50 percent detection at signal-to-noise ratios of approximately 6 and 10 dB, respectively.

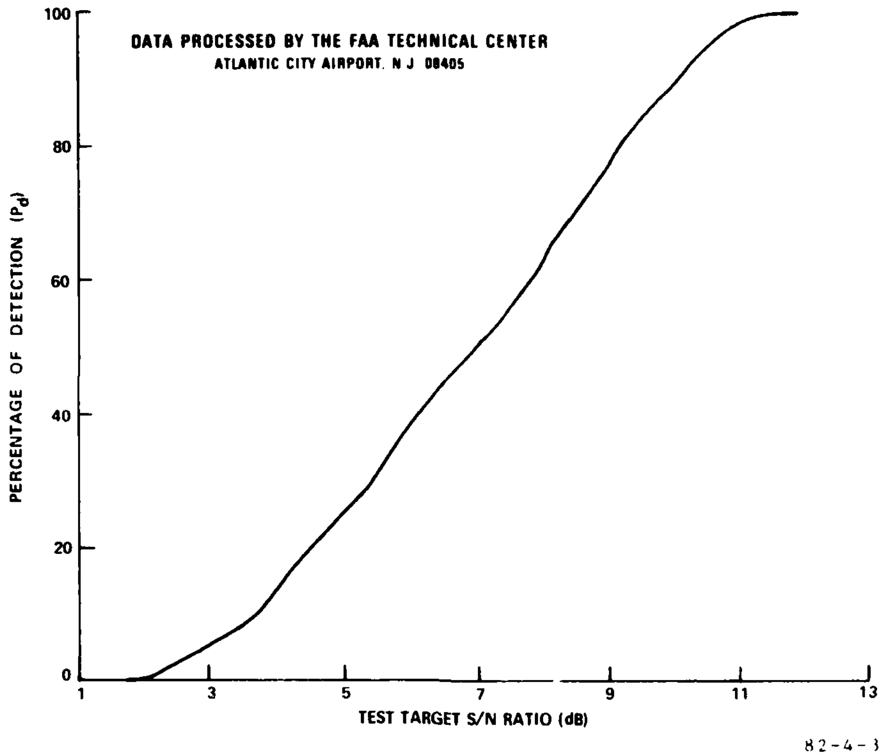


FIGURE 3. MTD II PERCENTAGE OF DETECTION

SYSTEM STABILITY.

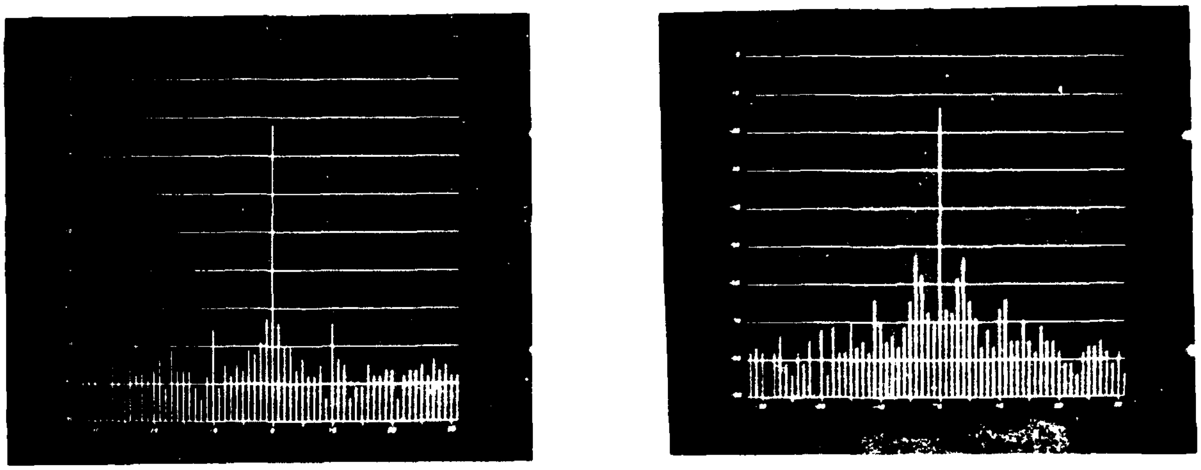
PURPOSE OF TEST. This test was performed to determine the level of stability provided by the MTD II system when used with an FPS-67B radar system.

Various time and phase instabilities contribute to the after-cancellation clutter residue, resulting in the lessening of the system's subclutter visibility performance. When the stability provided is less than the ground clutter amplitude by an amount equal to the Doppler filter mean level threshold, spurious signals of sufficient amplitude to produce false primitive targets will occur. It is desirable that the system provide the maximum possible stability. The following system stability tests, therefore, provide information for determination of system target-over-clutter detection capability. This is discussed more fully in the next section, "Subclutter Visibility," which deals with system target detection in clutter performance.

Test Data Collection. To test the stability, the antenna was spotlighted on a fixed clutter target and the MTD II single gate processor (SGP) fast Fourier transform (FFT) analysis routine was performed. The SGP routine provided a graphics output on the Megatek maintenance display of the relative zero velocity/ nonzero velocity components of the fixed target echo. The graphics display was photographed for subsequent analysis. Data were collected for both staggered and nonstaggered PRF's.

Test Results. Figure 4 shows the system stability data. The center of the horizontal scale in each photograph represents zero frequency. Negative Dopplers are to the left of zero, and positive Dopplers are to the right. The 64 segments of the horizontal axis mark the 64 outputs of the FFT (64 points). These 64 points cover the unambiguous Doppler range of the radar; zero Doppler is at the center, and optimum Doppler at both edges of the display. The frequencies of responses seen can be determined by interpolation. The figure of merit in this test is the difference in amplitude between the desired fixed-target zero-Doppler response and any spurious frequencies generated in the radar system. For the nonstaggered transmitter case, the difference between the zero velocity component and the average of the noise and residue peaks is approximately 45 dB (after subtracting 18 dB for coherent processing gain). Similarly, the staggered transmitter PRF case provided approximately a 42 dB difference. A klystron system, such as the FAA Technical Center's ASR-8, is capable of providing a stability of greater than 50 dB. The degraded performance obtained at Bedford was due to instabilities in the transmitter resulting from incomplete power supply modifications (reference 3). In either staggered or nonstaggered operation, some ground clutter target amplitudes exceeded the stability levels. An algorithm was developed by the contractor to eliminate the resulting false target information. This is discussed under the section which deals with system "Subclutter Visibility" performance.

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405



(A) FIXED PRF (B) STAGGERED PRF

82-4-4

FIGURE 4. FPS 67B/MTD II SYSTEM STABILITY

SUBCLUTTER VISIBILITY.

PURPOSE OF TEST. This test was conducted to determine the capability of the MTD II system to detect test targets in clutter. Since no "angel" or large amplitude weather clutter was observed during the test period, these tests deal only with subclutter visibility (SCV) over ground clutter. The system improvement factor (I), which is the ratio of the signal-to-noise out of the processor to signal-to-noise into the processor, is also discussed in this section. The improvement factor is equal to the SCV plus the system visibility factor (7 dB for the MTD II).

Test Design. To measure the system SCV, a variable phase test target generator signal was superimposed on a fixed phase signal generated by the radar site's echo box. The echo box signal, which varied in amplitude from receiver noise level to limit level as a function of range, provided the clutter levels necessary for the test. The test target, which was adjusted to provide an optimum speed target, was superimposed over a portion of the echo box signal that was approximately equal to receiver limit level. The test target was then adjusted in amplitude until a 50 percent detection was obtained, as seen on the Megatek display. The difference in amplitude between the echo box signals and the test target signals at this point was the system's SCV. For this portion of the test, the transmitter was operated in constant PRF and into the system's dummy load to eliminate spurious signals.

Due to antenna scanning residue, the low radial velocity filters (1, 2, 6, and 7) have a higher clutter residue-to-noise ratio than the midband filters (3, 4, and 5). For high amplitude clutter, this residue can exceed the processor's mean level thresholds and result in false target declarations. To compensate for this effect, the contractor developed an algorithm (combined thresholding) which increased the 1, 2, 6, and 7 filters' mean level thresholds in high clutter areas by an amount proportional to the clutter amplitude.

To determine the effects of antenna scanning modulation on the system's SCV for the low velocity filters, the system was operated into the antenna and the parameters of the combined thresholding algorithms were adjusted to provide the optimum compromise between system SCV and clutter rejection in the low velocity filters. The clutter level which activated the resulting thresholding became the maximum "I" obtainable.

Results of Test. From the preceding section on "System Stability," the maximum system stability for transmitter nonstaggered PRF operation was 45 dB. This is also the system improvement factor when in dummy load operation. Since the echo box SCV test was also conducted in dummy load, the SCV could, therefore, be expected to be 38 dB. It was measured to be 38 dB.

For the lower Doppler velocity filters that experienced degraded operation due to antenna scanning modulation, the SCV was measured to be 29 dB. This measurement was accomplished by operating the system with the antenna rotating and adjusting the thresholding algorithm sensitivity to obtain a 1×10^{-5} false alarm rate. The resulting thresholds were determined to be activitated by any clutter signal greater than 36 dB in amplitude. This was the improvement factor (7 dB above the system SCV). These figures agree with those obtained during the evaluation of the terminal MTD II system (reference 2).

The FPS-67B/MTI system provided a subclutter visibility of 15 dB which was measured using the echo box/signal generator technique. The MTI system utilizes a three pulse canceller configuration.

VELOCITY RESPONSE.

PURPOSE OF TEST. This testing was conducted to determine the system response as a function of target radial velocity. Tests were performed to show the overall response of the seven nonzero filters and to investigate the depth of the staggered PRF's blind speed null at the frequency corresponding to the transmitter's average PRF (first blind speed). The individual filter responses are presented in reference 2. The contractor provided theoretical responses are shown in appendix A for comparison purposes. The MTI velocity response of the FPS-67B system, which was used for comparative system testing as described in later sections of this report, was that of a three-pulse canceller and can be obtained from the FPS-67B technical manuals.

Test Data Collection. The velocity response was determined by introducing pulsed radiofrequency (RF) test signals from the TTG into the system, and observing their resulting response on the Megatek maintenance display.

To determine the overall response, the PRF of the test signal was varied in frequency from 0 to 347 hertz (Hz), which corresponds to the first nonstaggered blind speed. The test signal was simultaneously varied in amplitude so as to maintain a 50 percent target detection. The transmitter was operated at a fixed PRF into the dummy load.

In order to measure the depth of the staggered PRF desensitization null at the frequency equal to the average transmitter PRF, the system was operated with staggered PRF and the TTG PRF was adjusted to the average transmitter PRF. Again, the test target amplitude was adjusted to produce a 50 percent target detection.

Test Results. The system velocity response with nonstaggered transmitter PRF is shown in figure 5. The system exhibits increased sensitivity at the velocities corresponding to the center frequencies of the 1, 2, 6, and 7 filters. Since filters 1, 2, 6, and 7 virtually overlap each other and have a 1.2 dB increase in coherent gain over that of filters 3, 4, and 5 (appendix A), an increased sensitivity results. In the center portion of the plot, Doppler filter straddling losses between filters were offset by the increased sensitivity afforded by the two filter combinations, resulting in a virtually flat response. The overall response was in close agreement with the theoretical values.

The depth of the staggered PRF desensitization null at a frequency equal to the average transmitter PRF was measured to be 17 dB. This agrees with the value that was obtained with the terminal MTD II (reference 2) and indicates normal staggered PRF performance.

INTERFERENCE REDUCTION.

PURPOSE OF TEST. This test was conducted to determine the capability of the MTD II to reduce nonsynchronous interference such as that caused by another radar. If not eliminated, false target declarations can occur resulting in degraded system operation. To reduce interference, the MTD II uses an amplitude discrimination

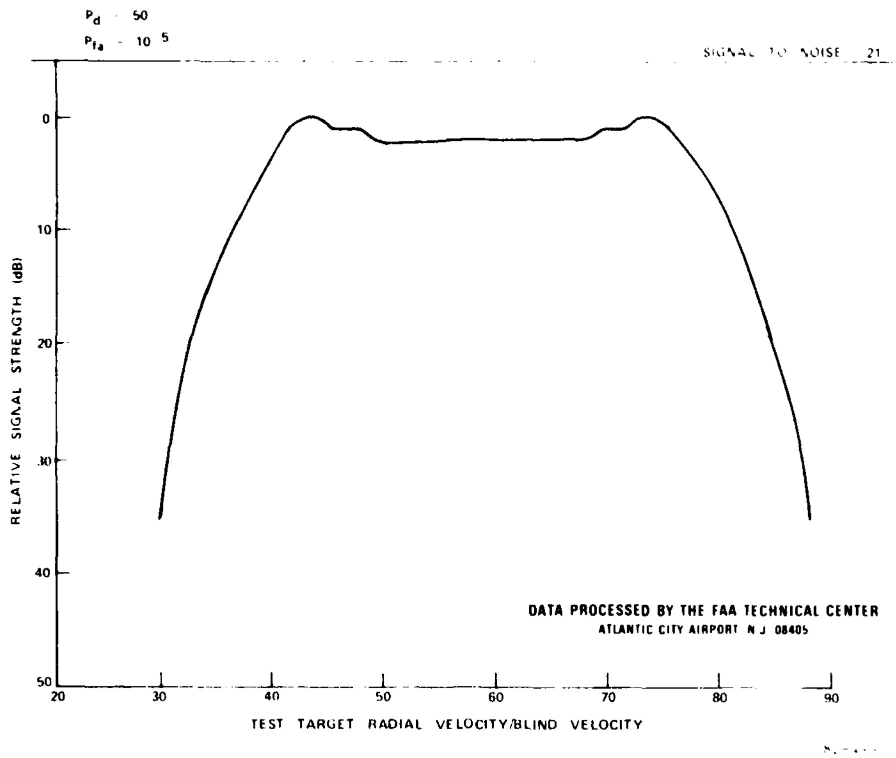


FIGURE 5. MTD II FIXED PRF VELOCITY RESPONSE FOR FILTERS 1 THROUGH 7

technique. If a pulse is determined to be more than three times the average amplitude of other signals in the same range/CPI cell, it is considered to be interference and the entire range/CPI cell is inhibited from being processed further.

Test Data Collection. To test the interference elimination capability of the system, a free running (random) test signal was produced by the TTG for processing by the MTD II. As the number of these simulated interference pulses were varied from 0 to 360 pulses per second (the approximate PRF of an en route radar system), the Megatek display was observed for any resulting false targets. For this test, the TTG output was adjusted to provide an output level sufficient to provide a 99 percent detection of the pulses. The MTD II radar channel was operated on dummy load.

Test Results. This test showed that no additional target declarations occurred due to simulated interference. Therefore, the interference rejection algorithm was operating correctly. It was noted during the evaluation period that target declarations varied from 1,500 per antenna scan with the other radar channel turned off, to 2,500 per scan when it was turned on. This was probably caused by clutter reflections from the CD channel not being entirely eliminated by the system diplexer. Synchronizing the channels would eliminate this problem.

In the MTD II system, the scan-to-scan correlation function was used to eliminate the resulting false targets, which increased the processing load on the scan-to-scan correlator and also increased the chance of false target declarations.

FLIGHT TESTING.

GENERAL. Flight testing was conducted using targets of opportunity. Tests were designed to measure system sensitivity (target detection capability), subclutter visibility, tangential target detection over clutter, and relative system false alarm rates. A limited amount of low level weather was present during the test period and system subclutter (weather) visibility is briefly discussed.

The MTD II system included a scan-to-scan correlator, as discussed earlier. This feature contributed to the cleaner display exhibited in the following MTD II display presentations when compared to the CD presentation. Since the scan-to-scan correlator required three detections before a target was displayed and no coasting function was provided, the MTD II system percentage of detection was correspondingly degraded. The test philosophy followed was to provide the full system outputs in both MTD II and the CD cases for display and analysis, and not to test individual components of the processors (such as the scan-to-scan correlator). Such an analysis was beyond the scope of the project and will be performed later as a part of the terminal MTD II system enhancements work being done at the Technical Center.

In the following discussion, a wedge containing no usable data exists from 75° to 135° since an Air Route Surveillance Radar (ARSR)-3 tower was being installed adjacent to the FPS-67B site. Due to the close proximity of the ARSR-3 tower and the resulting FPS-67B system operation degradation due to blockage of the antenna radiation pattern, the data in the affected area were suspect, and, therefore, not included in the analysis of either system.

The data from the MTD and CD equipped channels were collected simultaneously, with the radar set being operated in the polarization diversity mode. The data shown were recorded at the Technical Center for subsequent analysis (appendix B). To facilitate data reduction and analysis, software was also developed for the Technical Center's Honeywell general purpose computer for the generation of the statistical and display data that are presented in the following sections.

The CD system was operated with the MTI/normal gate controlled by the automatic clutter eliminator (ACE), which varied the MTI/log normal crossover range between 70 and 116 nmi, depending on clutter conditions.

Persistent correlated false alarms were produced by moving ground traffic and by limiting ground clutter. To eliminate these false alarms, a thresholding/censoring map feature was incorporated into the MTD II. It consisted of a map of range/CPI cells with a resolution of 0.5 nmi by four CPI's. These were called range azimuth gate (RAG) cells. The RAG-1 cells attenuated (thresholded) targets by 11 dB to eliminate the false alarms, while the RAG-2 cells were completely censored.

The threshold/censoring map used at Bedford is shown in figure 6. To more clearly show the examples of individual RAG cells, an expanded portion of the map is shown in figure 7. Correlated MTD targets are also shown in this figure. Note the effect of the RAG thresholding on the aircraft shown. When the aircraft entered the threshold area, its output was inhibited since it didn't have sufficient

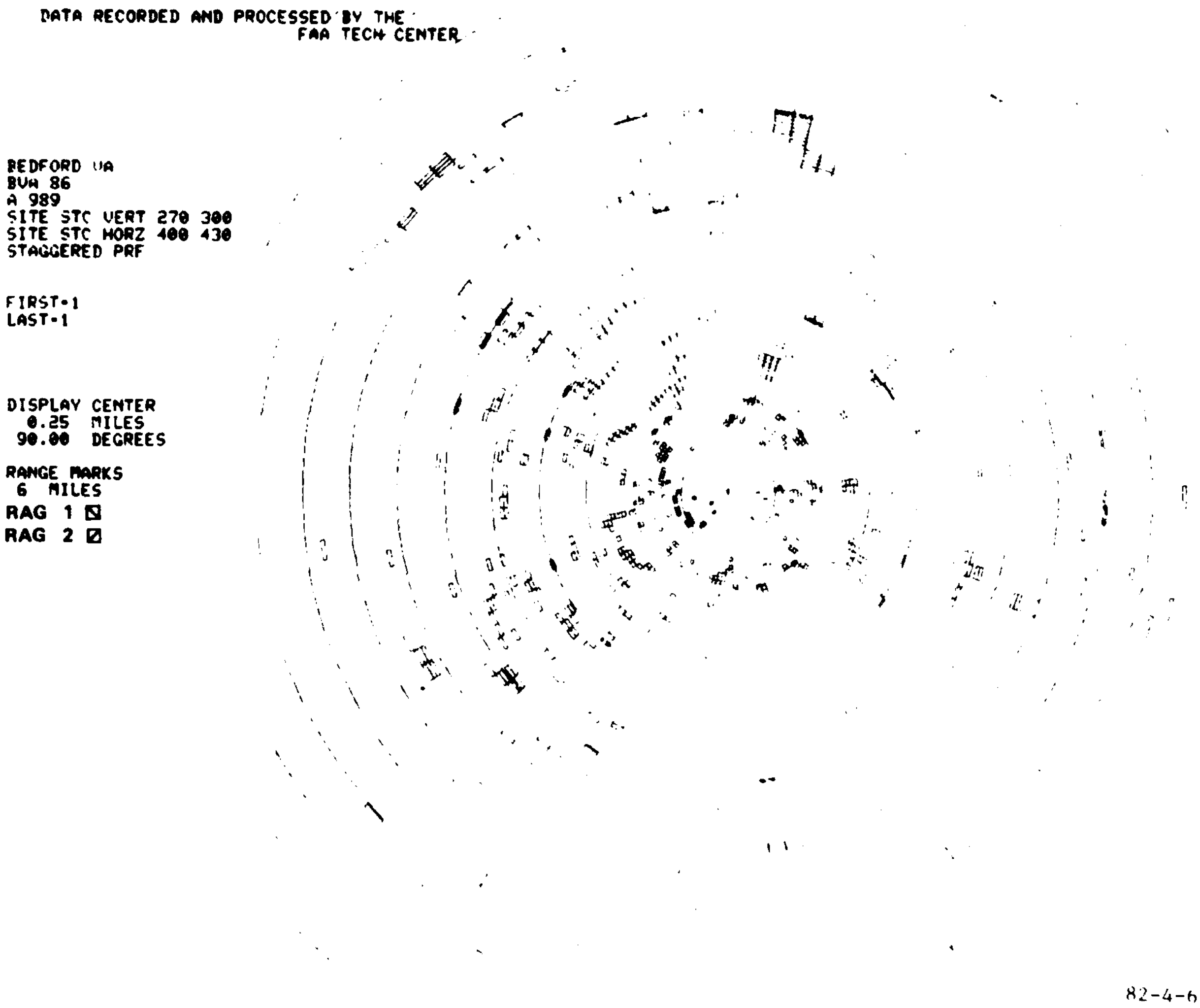


FIGURE 6. MTD II THRESHOLD/CENSORING MAP

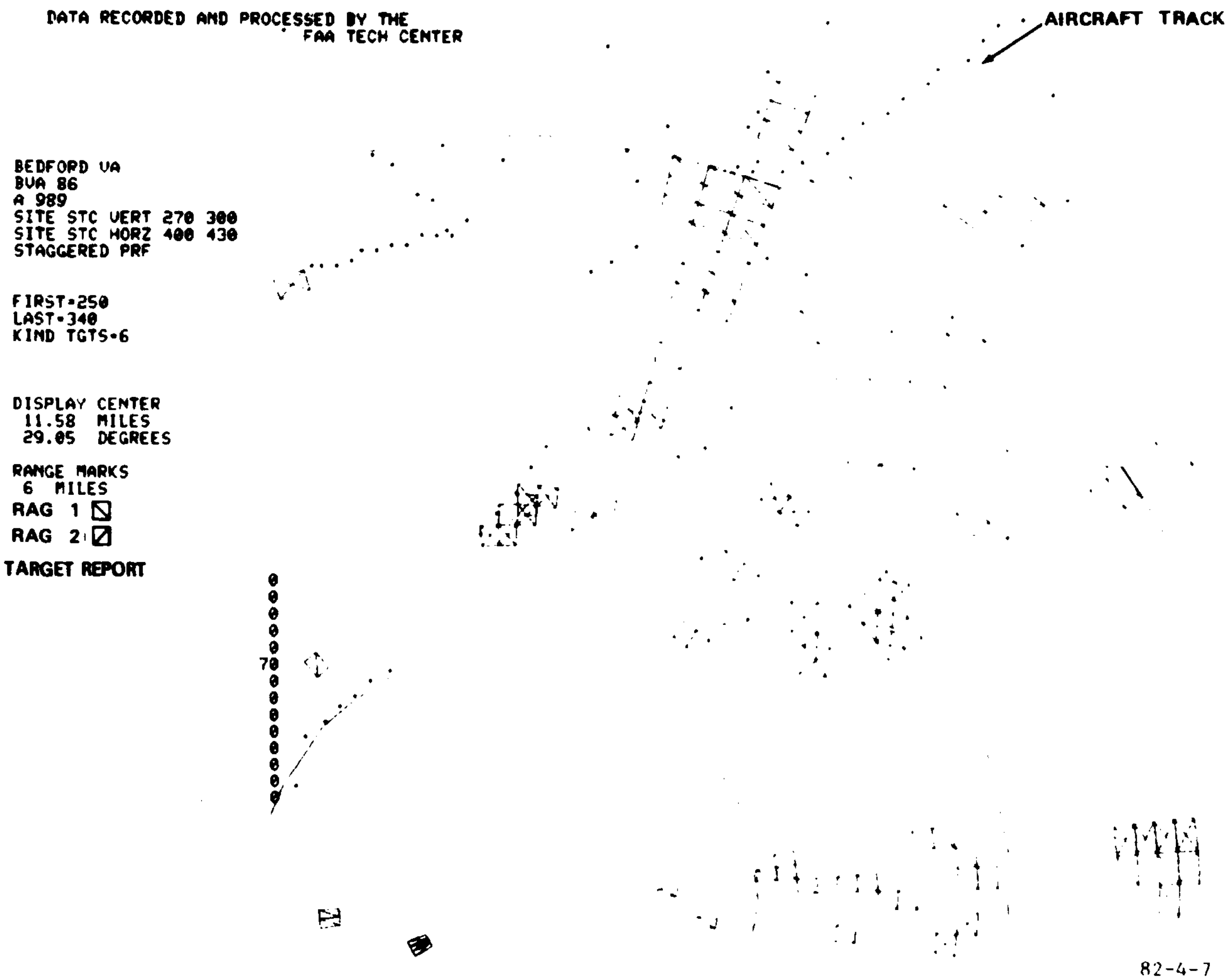


FIGURE 7. EXPANDED MTD II THRESHOLD/CENSORING MAP

amplitude to exceed the RAG-1 threshold. On emerging from the threshold area, its track was again displayed on the third hit (scan-to-scan correlator initiation requirement). Some loss of target detection resulted from use of the threshold/censoring map. Second level thresholding (adaptive area thresholds) was not provided as an alternative for eliminating these false alarms as in the MTD I.

To eliminate direct interference from the CD channel's radar transmitter (the two radar channels were not synchronized), the MTD processor was blanked during the CD channel transmissions. A 12 μs blanking gate was used. This resulted in the blanking of eight range/CPI cells for each CD transmitter pulse and, therefore, 33,312 blanked range/CPI cells (347 transmissions per second times 12 seconds per antenna revolution times eight cells) each antenna scan. This represents approximately 4 percent of all the range/CPI cells. This blanking, therefore, resulted in a loss in the MTD channel's detection capability.

The MTD II scan-to-scan correlator used during this test was developed for the airport surveillance radar MTD II at Burlington, Vermont, and was not optimized for an en route operation. Improved operation could be expected to result from a greater development effort.

The data reduction system provided the graphics in figures 8 through 15. The data presented in these figures are typical of that obtained in other data segments and are used to describe relative system performance in the following sections.

Figure 8: A PPI representation of 50 scans (240 to 290) of MTD II data recorded during actual operation. The MTD II reported 6,620 total returns. Note that the MTD II processor maximum range is 192 nmi.

Figure 9: A PPI representation of the same 50 scans of CD data. The CD system reported 13,357 returns. The CD system provided a maximum range of 200 nmi.

Figure 10: Filtered Beacons — a PPI representation of Mode C (altitude reporting) beacon equipped aircraft filtered during data reduction so that only aircraft "visible" to the radar are shown. This altitude filtering, as noted on figure 10, was performed to remove the effects of the beacon systems broader antenna beam width. In this processing, only aircraft between elevation angles of 45° (the radar antenna beams upper limit) and 0° (with a 4/3 correction for refraction due to the earth's atmosphere) were used for correlation purposes. A correction of 4,000 feet for the radar sites altitude was also included. The data produced can more easily be used to determine performance that might be expected at a typical radar site. The filtering algorithms are given in appendix C. The large number of false alarms to the east were due to reflections from the ARSR-3 tower as previously discussed.

Figure 11: This line graph relates the percent of the aforementioned filtered beacon aircraft that either the MTD II or CD system reported in each 10-mile wide range segment during 200 scans.

Figure 12: A line graph relating the average number of returns for 200 scans that each system reported in each 10-mile range segment.

Figure 13: A PPI representation of a 30-mile square area magnified 16 times taken earlier in the day of weather with MTD II data only.

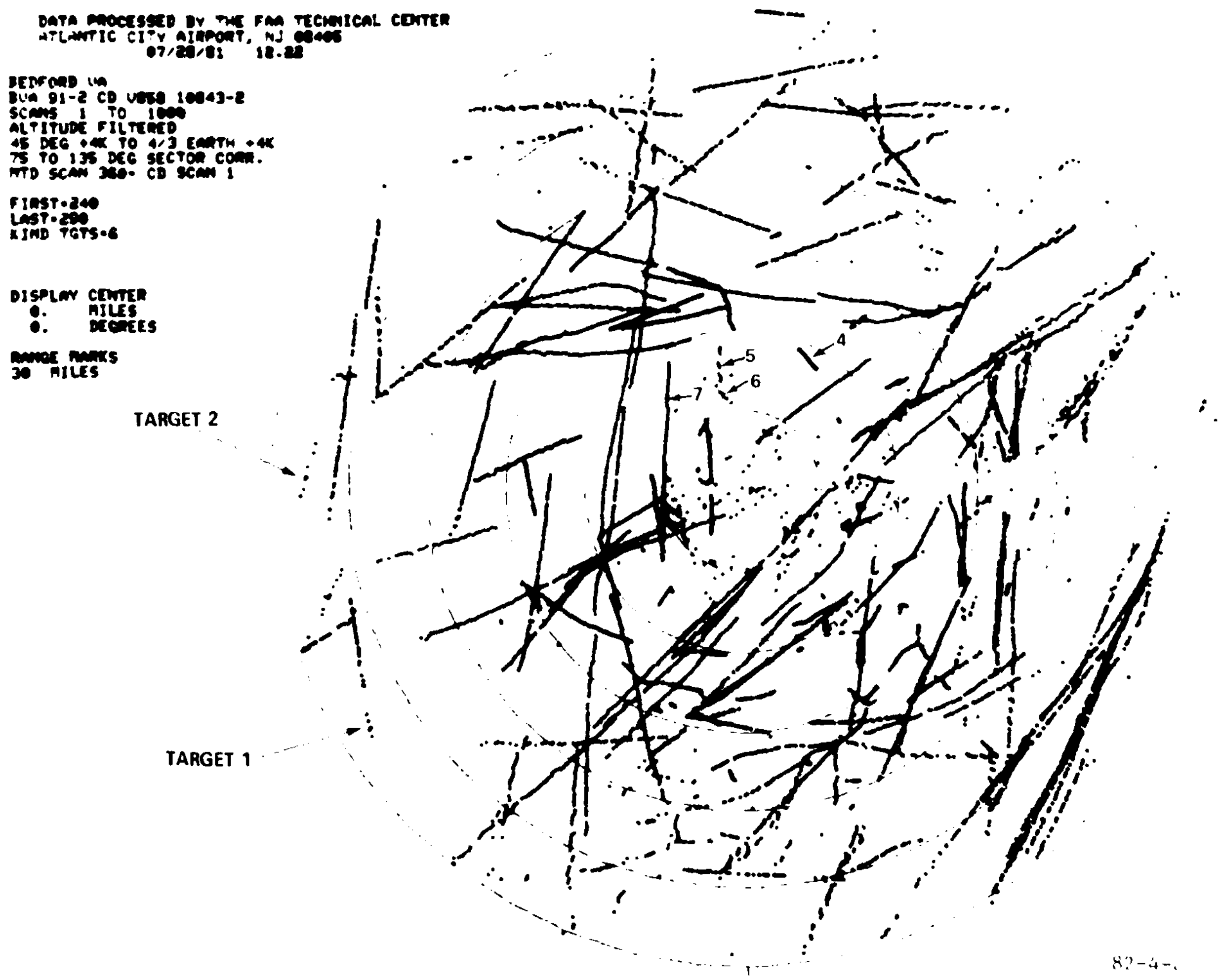


FIGURE 8. MTD II DISPLAY PRESENTATION

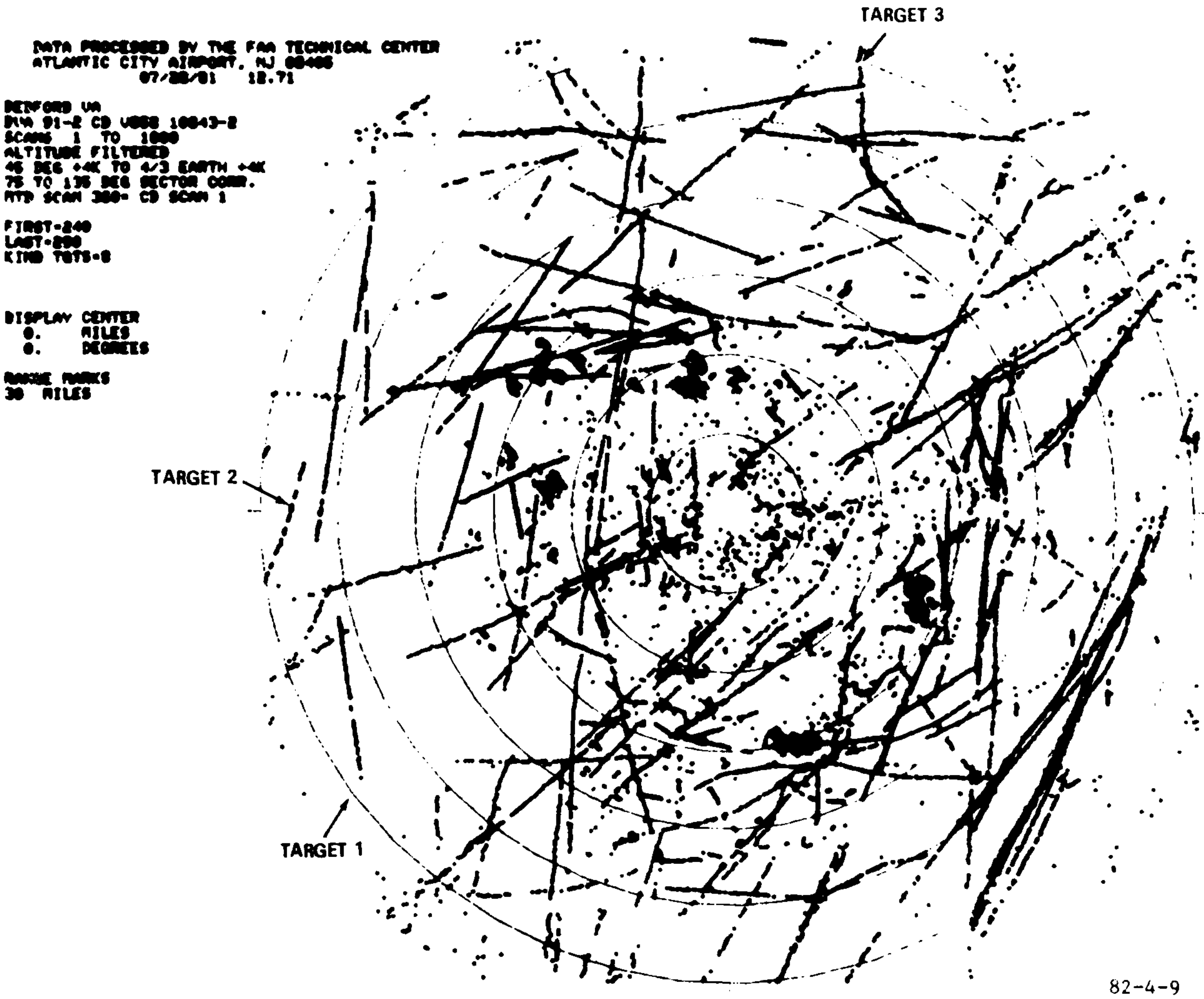


FIGURE 9. CD DISPLAY PRESENTATION

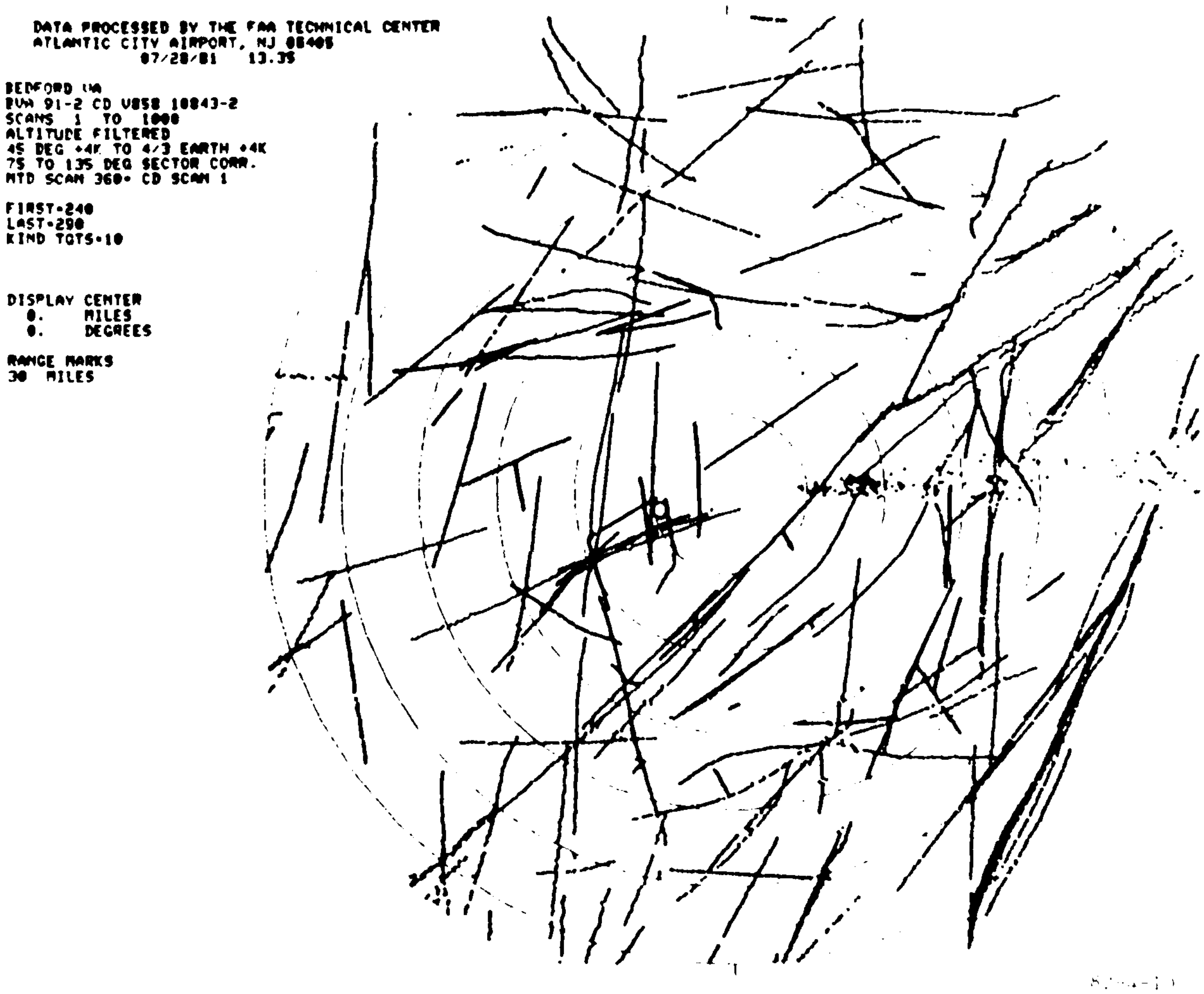


FIGURE 10. BEACON TRACKS PRESENTATION

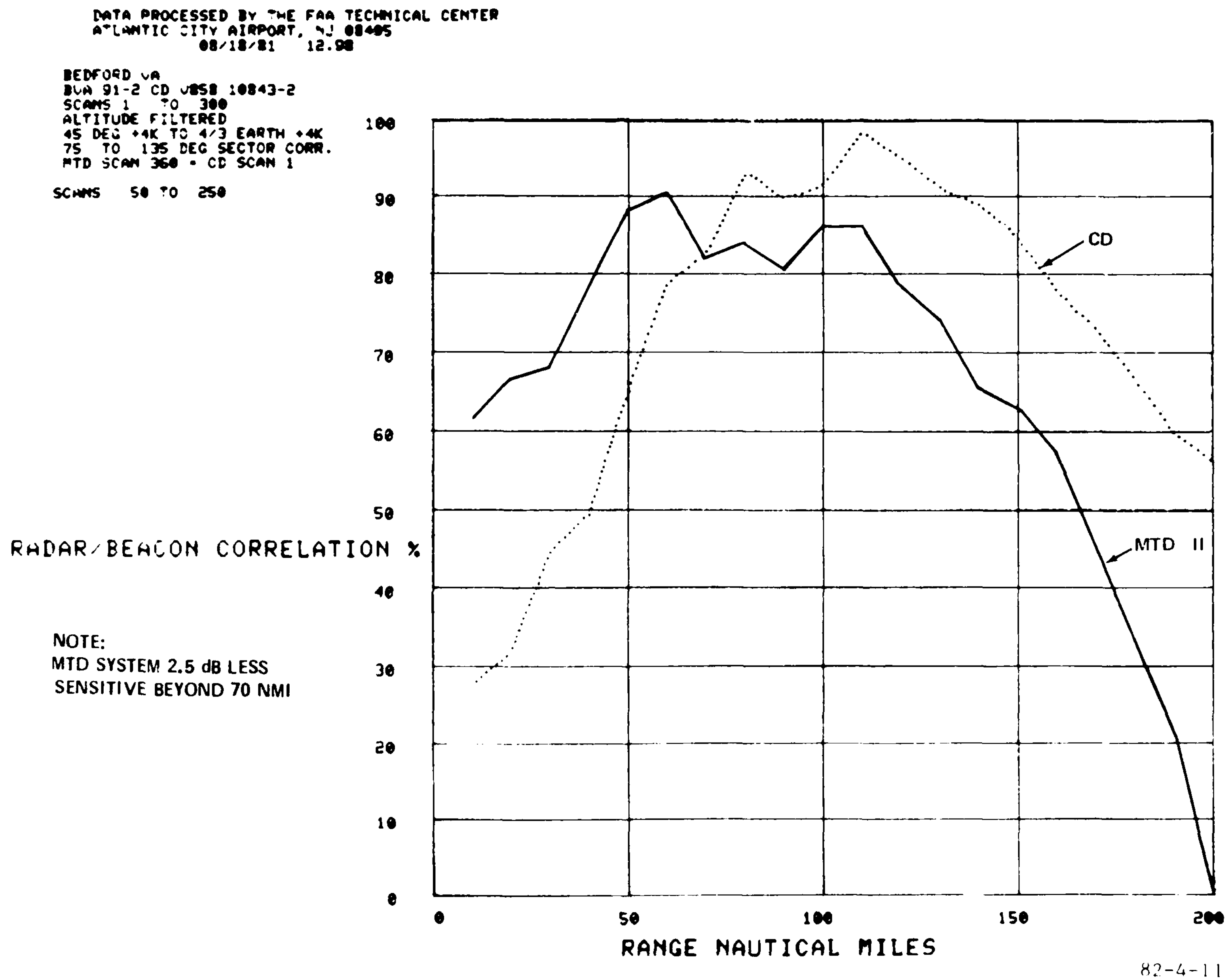


FIGURE 11. RADAR/BEACON CORRELATION, MTD II AND CD EQUIPPED SYSTEMS

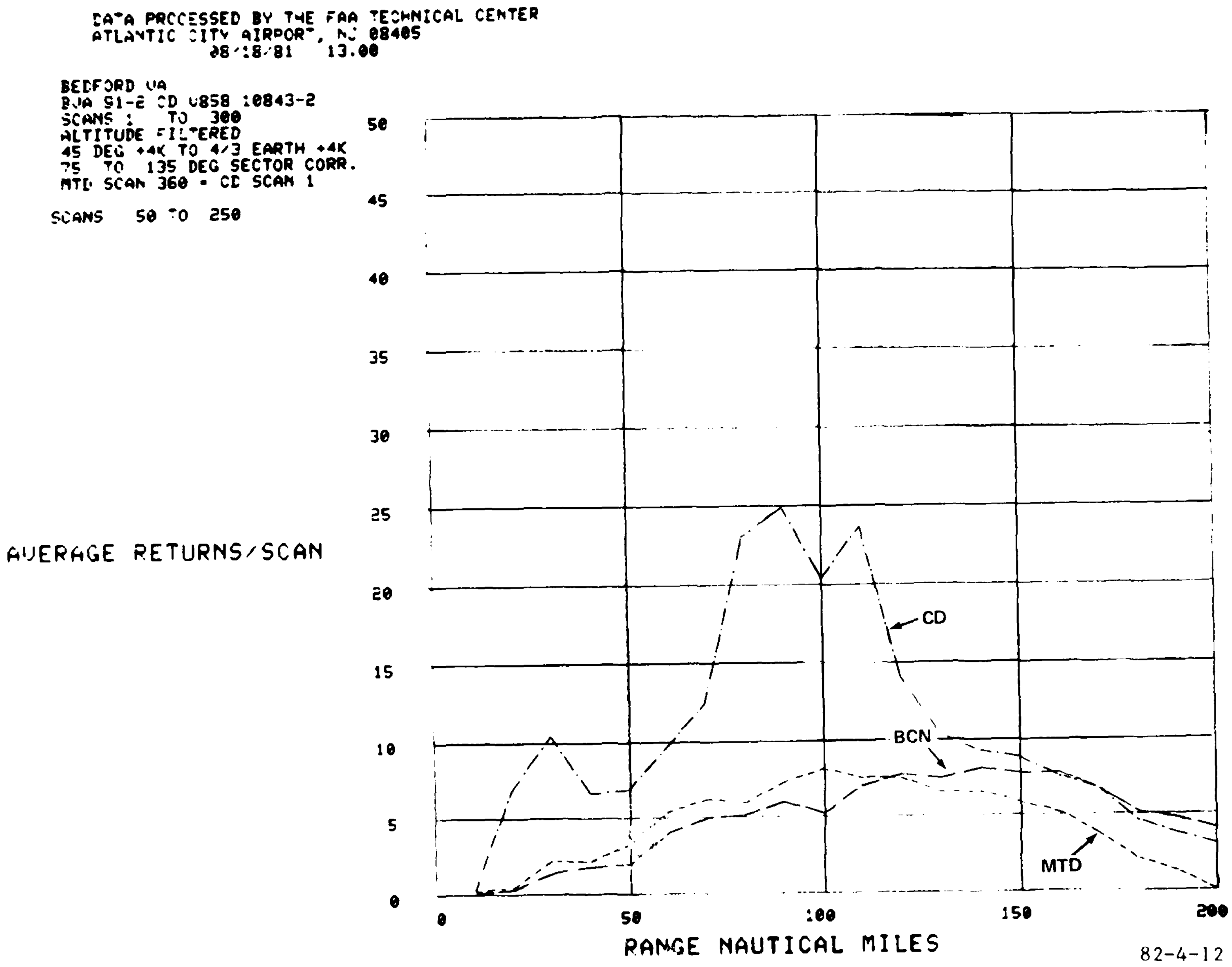


FIGURE 12. TARGET RETURNS PER SCAN, MTD II, CD, AND BEACON SYSTEMS

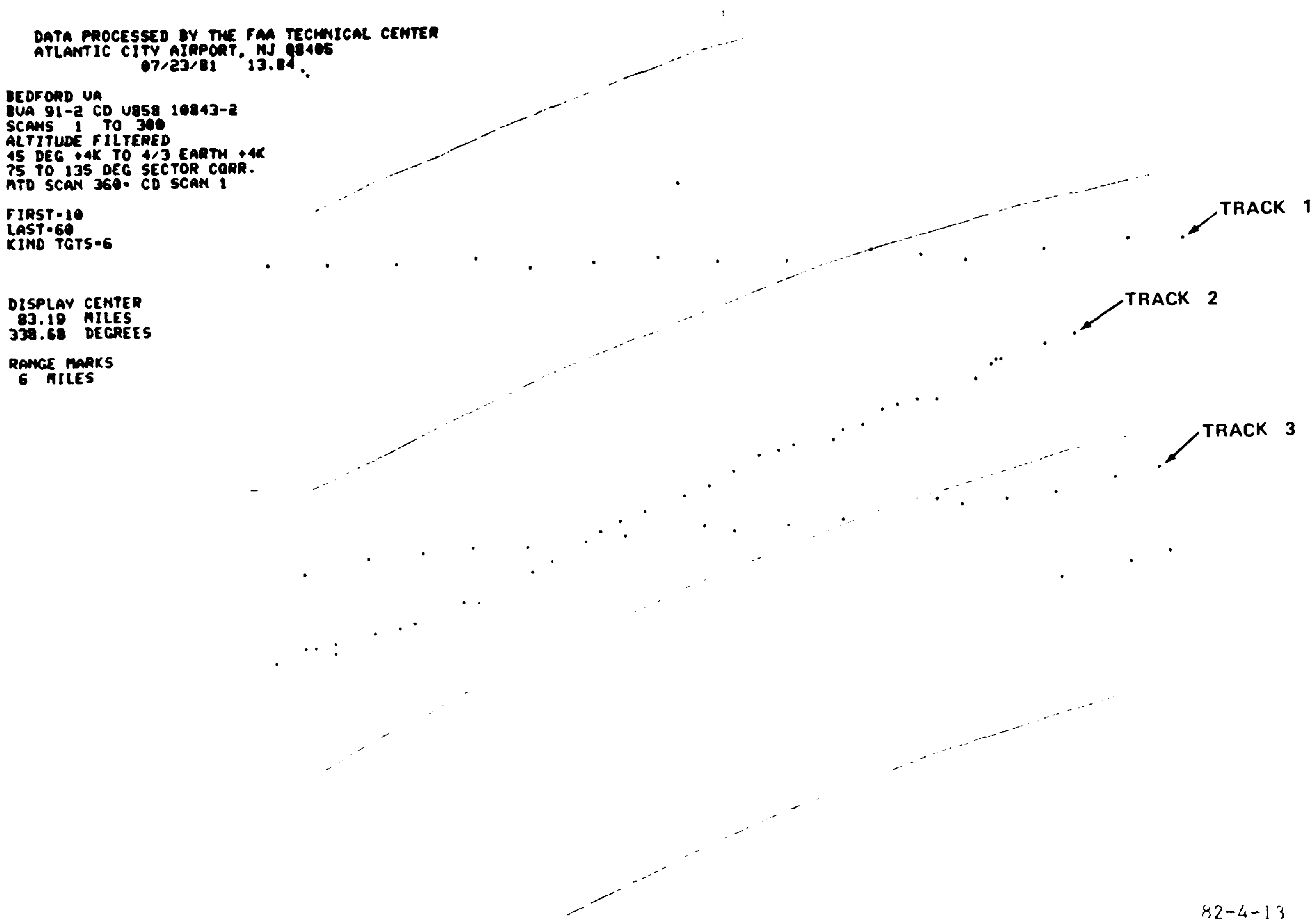


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FIGURE 13. MTD II TRACKS IN WEATHER CLUTTER

Figure 14: The same area as figure 13 with CD data only.

Figure 15: A PPI representation of the MTD II data as recorded at the site by the MTD II system, which includes coasts not included in the CD recording system, for the tracks shown in figure 8.

SYSTEM SENSITIVITY.

Test Purpose. The MTD II type processor was developed to provide improved target detection in clutter. Its target detection capability in the clear (sensitivity) should be approximately equal to that of a conventional processor such as the CD. This test was conducted to ascertain if, as expected, equal detection was provided by the MTD II and the CD equipped systems. Any significant differences between the two would indicate a system problem which needed correction. For example, early testing of the MTD II showed very poor system performance at long range as compared to the other (CD) channel. Once the causative receiver sensitivity and MTD II processor problems were isolated and corrective action taken, the two systems provided nearly equal sensitivity as discussed below.

Test Design. To ascertain if the MTD II and the CD processors provided equal sensitivity, the transmitter/receiver loop gains of the two radar channels were first measured and recorded, as discussed previously under "System Normalization." In the following section the impact of the difference in loop gains will be discussed as to its effect on relative performance. Multiscan comparative MTD II and CD target displays were developed and statistical data derived for this analysis.

Test Results. Figures 8 and 9 show the relative performance of the MTD II and the CD equipped systems.

First, the CD system can be seen to produce a large number of false alarms (targets not associated with tracks). The apparent false alarms (figure 8) produced by the MTD II system within 30 nmi are shown in figure 15, which includes track coasts to be parts of aircraft tracks. Second, in general, the two systems provided approximately the same overall detection capability for long range targets. However, in some cases (such as targets 1, 2, and 3) in figure 9, the CD system can be seen to provide better target detection. This was due to two factors. The two radar channels provided, at the time of this test, equal transmitter/receiver loop gain for the processing area within 70 nmi (CD systems minimum MTI/log normal cross over range). For ranges corresponding to the CD/log normal area, the CD equipped radar channel provided a 2.5 dB advantage in sensitivity, as mentioned previously in the "System Normalization" section, corresponding to an approximate 15 percent greater range capability for the CD equipped system. Therefore, as shown in figure 11, the CD equipped system provided 60 percent radar beacon/correlation at 190 nmi; the MTD equipped system achieved the same level of correlation at 155 nmi.

The second factor is the effect of the MTD II scan-to-scan correlator. Note that the CD presentation of the three targets (figure 9) shows degraded detection as evidenced by misses (holes) in the run length. These targets generally do not meet the initiation requirement of the MTD II scan-to-scan correlator and, therefore, were not displayed most of the time (see figure 8). A coasting function was not used during these tests. Figure 15 shows that by incorporating a coast function (three misses to drop track), an improvement in aircraft detection and display

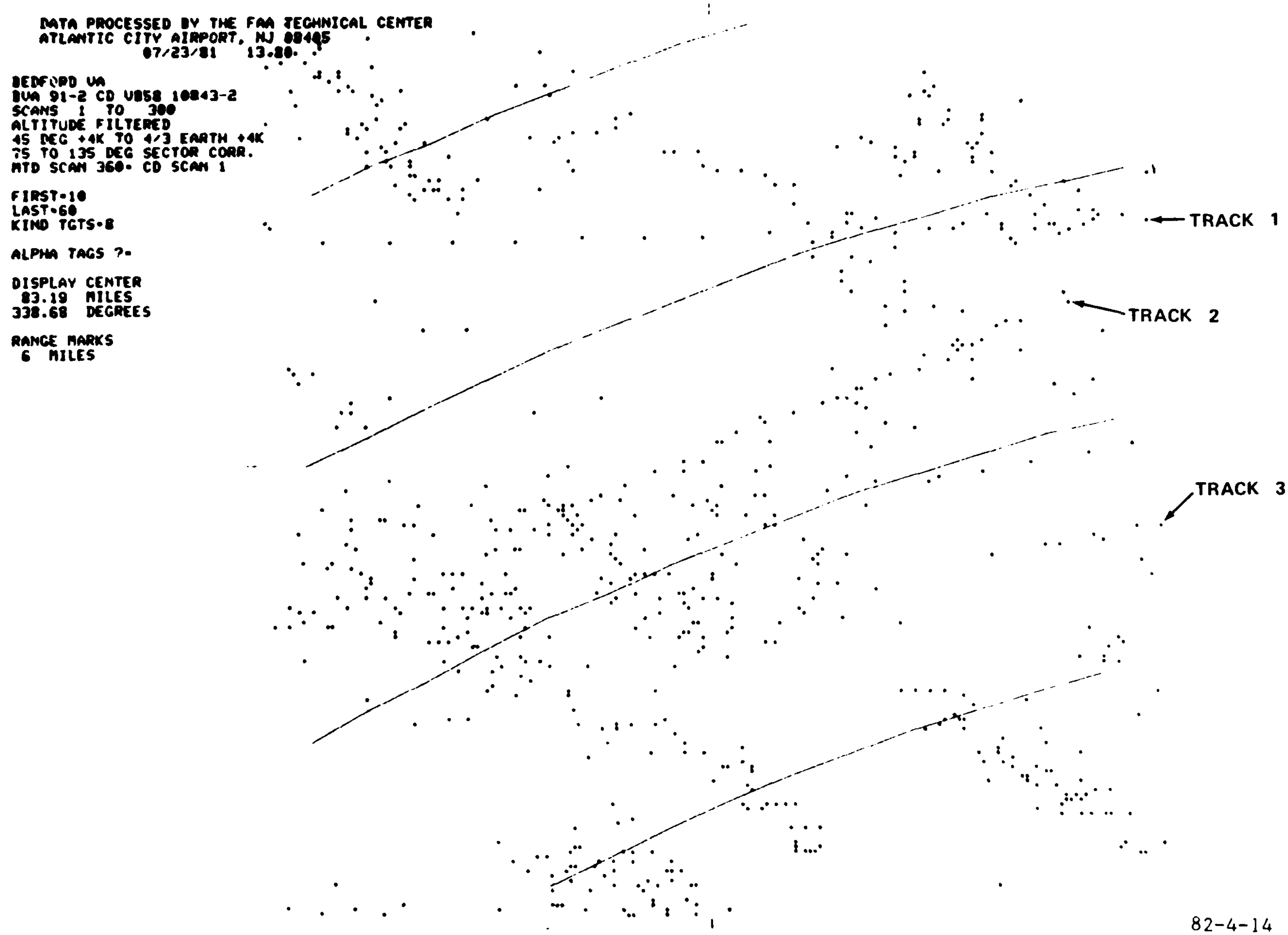

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FIGURE 14. CD TRACKS IN WEATHER CLUTTER

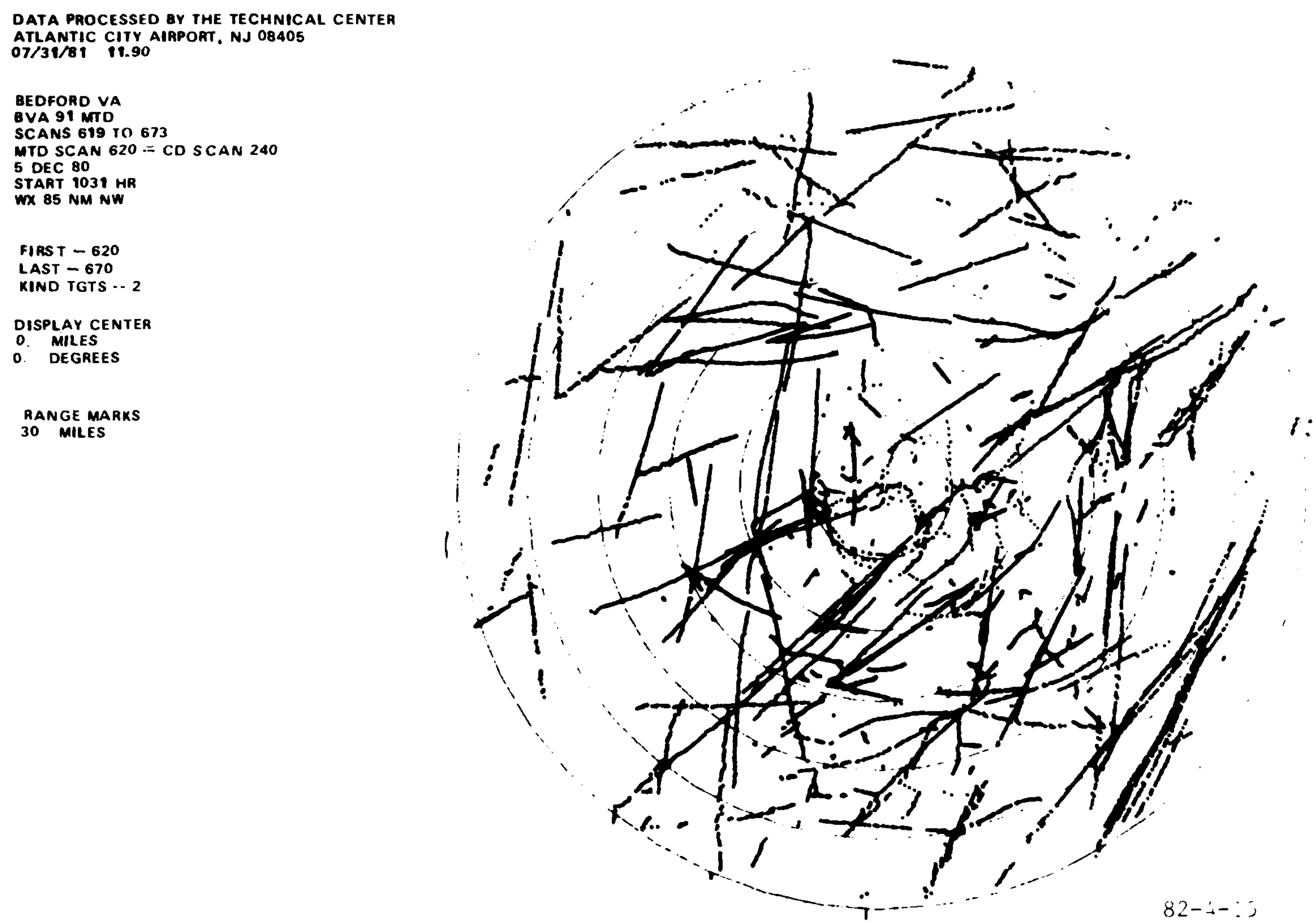

FIGURE 15. MTD II SYSTEM DISPLAY PRESENTATION WITH COASTS

is obtained. Figure 11 indicates that the comparative ability of the MTD II to acquire and sustain a track beyond 70 nmi is degraded and drops rapidly beyond 110 nmi, until at 150 nmi the MTD II is operating 20 percent below the CD system. At 50 nmi, the MTD II was 23 percent better at detecting aircraft known to be in the antenna beam, as discussed under "Subclutter Visibility." Note the range limit of the MTD II processor was 192 nmi by design. Therefore, the MTD II always goes to 0 at 200 nmi on these graphs.

This reduction in the MTD II equipped systems' detection capability beyond 70 nmi is a result of the system losses. In the discussions which follow on target detection in clutter within 70 nmi, any differences in system performance will, therefore, be attributed to processor merit.

SYSTEM SUBWEATHER VISIBILITY.

Test Purpose. Subweather visibility testing was performed to determine the relative capability of the MTD II and CD processors to detect aircraft in weather, and at the same time, not to produce false weather derived radar targets. Only a limited amount of weather occurred during the testing period.

Test Design. This test was to be performed by recording the comparative MTD II and CD derived data when weather was present, and analyzing the data to determine the target detection in weather capability and any false target generation.

Test Results. Figures 8 and 9 show the relative performance of the two systems in light weather. For the 50 scans of data shown, the locations of the weather cells are clearly discernible by the groups of false radar targets generated by the CD equipped system. The distributed false targets (not part of track) were primarily due to ground clutter. Three MTD II system targets (1, 2, and 3) of opportunity in weather are indicated on figure 13. Due to the weather effects, the targets are not discernible, or are degraded for the CD equipped system as shown in figure 14. Note the large number of weather generated false alarms from the CD equipped system.

For this test, the transmitter/receiver loop gains of the two systems were equalized for the display areas shown. Therefore, any differences seen in the relative performances of the two systems is due to the relative merit of the MTD II and the CD processors.

The target report/scan graph, figure 12, shows the CD system to have many more reports than the MTD II or beacon system at ranges corresponding to the weather cells indicated in figure 9. This disproportionate increase in CD returns and its effect on controllers' ability to detect an aircraft over weather is clearly portrayed by comparing figures 13 and figure 14.

SUBCLUTTER VISIBILITY (SCV).

Test Purpose. This test was conducted to determine the relative performance of the MTD II and CD systems in detecting aircraft targets in areas of ground clutter.

Test Design. As in the previous test, data were collected using targets of opportunity, with the two radar channels providing approximately equal transmitter/receiver loop gains in the clutter area.

Test Results. Figure 8, MTD, and figure 9, CD, are examples of comparative system SCV performance. The areas of interest (ground clutter) are at ranges of less than 70 nmi. The large number of clutter related false radar targets generated in these areas by the CD processor are seen in figures 9 and 12. As discussed in the previous section, weather cells were also present in the test areas. Note the very low false alarm rate for the MTD II system.

Nearly every target in the areas of interest show increased detection with the MTD II system. Figure 11 shows the MTD II system to be generally 10 to 30 percent better at detecting aircraft over clutter out to about 70 nmi. Figure 12 indicates that on the average in the 0 to 70 nmi range, the CD system will output significantly more targets (due to weather and ground clutter generated false alarms) than the MTD II system. The MTD II system reports up to 38 percent more returns than the filtered beacon over this range. A tabulation of beacon aircraft data (not shown) taken from this site indicates that about 6.5 percent of beacon equipped aircraft in flight were not reporting altitude and are, therefore, excluded from correlation, although they may have been "visible" to the radar. Note, for example, tracks 4, 5, and 6 in figure 8 are not seen in figure 10. It should also be stated that, while no firm data exists to indicate the actual number of nonbeacon equipped aircraft in the area during the test, it seems prudent to estimate that 5 to 10 percent of the aircraft may not have been beacon equipped.

The superior ability of the MTD II system to detect a tangential aircraft over clutter is demonstrated by observing tangential targets such as track 7 in figure 8, and the corresponding tracks in figure 9. Note that many of the CD tracks inside 70 nmi have a spotty appearance. Also, observe in figure 15 (MTD II with coasts) the solid track appearance and the few false alarms.

SUMMARY OF RESULTS

1. Comparative MTD II/CD static performance, test results were:

	MTD II	CD
False alarm rate in thermal noise	8.5×10^{-6}	1×10^{-5}
Subclutter visibility	29 dB (filters 1,2,6,7) 38 dB (filters 3,4,5)	15 dB
Improvement factor	36 dB (filters 1,2,6,7) 45 dB (filters 3,4,5)	25 dB
Signal-to-noise ratio for 50 percent target detection	7 dB	6 dB Log normal 10 dB MTI
System stability	36 dB staggered PRF 45 dB fixed PRF	------

2. Comparative MTD II/CD flight test results were:

	MTD II (%)	CD (%)
False alarm rate*		
0 to 70 nmi ground clutter zone	130	367
70 to 130 nmi weather clutter zone	112	302
Subclutter visibility**	76	55

*Radar detections (all aircraft and clutter signals) expressed as a percentage of beacon equipped altitude reporting aircraft (see figure 12).

**Percentage of correlations with beacon equipped altitude reporting aircraft in 0 to 70 nmi ground clutter zone.

3. The velocity response of the MTD II system agreed with theoretical values and with that of the MTD II terminal system tested at Burlington, Vermont.

4. The MTD II interference rejection algorithm eliminated test interference signals. No second level interference rejection capability was provided.

5. An external threshold censoring map function was implemented with the MTD II to eliminate false alarms due to ground clutter and traffic. No second level adaptive thresholding was implemented to control such false alarms.

6. The MTD II provided superior tangential target detection in clutter performance when compared to the FPS-67B MTI/CD system.

7. The MTD II system provided superior target detection to that of the FPS-67B/CD system in areas of weather clutter.

8. The MTD II system had a degraded capability for detecting targets at long ranges. This was due to the effects of the MTD II scan-to-scan correlator and the 2.5 dB sensitivity advantage (due to incomplete modification of the MTD radar channel) of the FPS-67B/CD system when using log normal video.

CONCLUSIONS

From the results, it was concluded that:

1. The moving target detector (MTD) II system provides superior performance not only in areas of high level radar clutter but in all tested areas to that of the FPS-67B common digitizer system when operated in the Bedford, Virginia, radar environment.

2. The MTD II system operation would be greatly enhanced if there were better radar set performance, second level thresholding, and processing parameters tailored to the en route radar environment.

RECOMMENDATIONS

1. It is recommended that additional work be accomplished to further enhance the moving target detector (MTD) II processing algorithms to provide better target detection and clutter signal elimination.

2. It is recommended that MTD processing be incorporated into any new en route radar system.

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3. Karp, D., and Anderson, J. R., Moving Target Detector (MTD)-II Summary Report, FAA Technical Center, FAA-RD-80-77, November 3, 1981.

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APPENDIX A

FREQUENCY AND GAIN CHARACTERISTICS

Figures A-1 and A-2 show the frequency and gain characteristics of the moving target detector (MTD) II finite impulse response (FIR) filters. These are theoretical curves provided by the contractor and were subsequently verified during the test and evaluation of the terminal MTD II at Burlington, Vermont. Note that filters 1 and 2 have nearly the same frequency response (this also applies to filters 6 and 7). This results in a loss of Doppler resolution capability (discussed in reference 2 of this report).

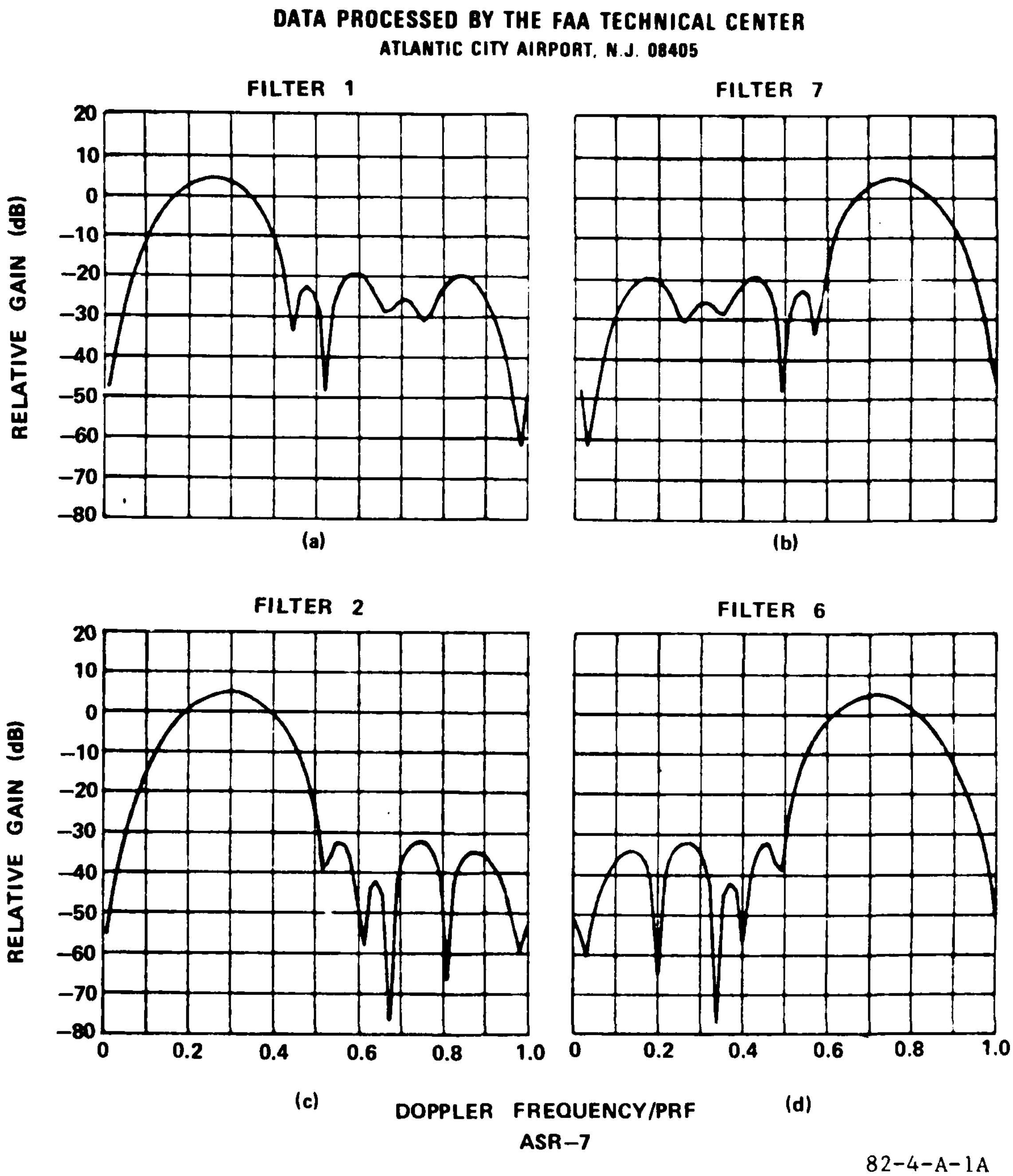

FIGURE A-1. NONZERO VELOCITY FILTER CHARACTERISTICS (SHEET 1 OF 2)

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

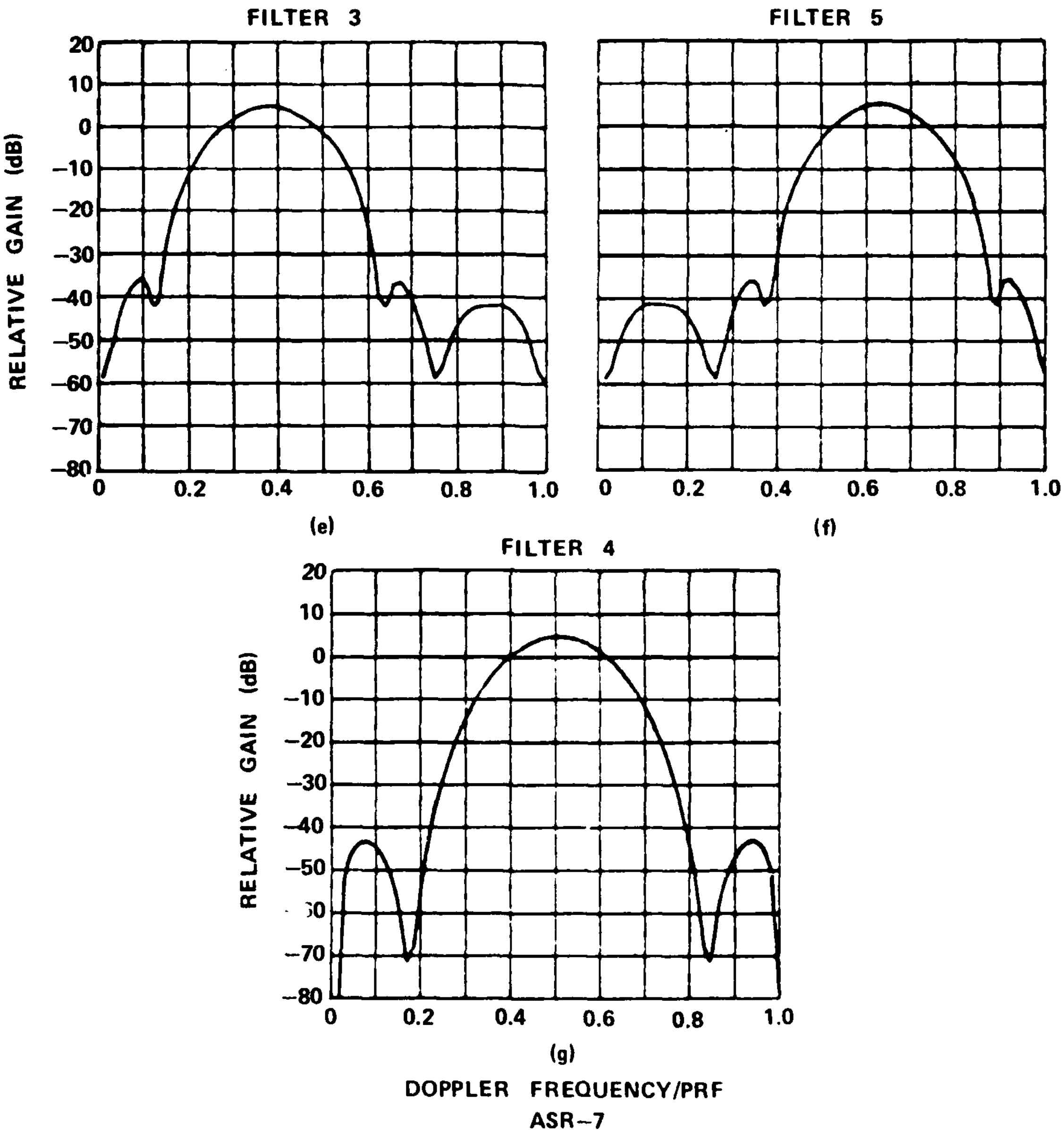

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FIGURE A-1. NONZERO VELOCITY FILTER CHARACTERISTICS (SHEET 2 OF 2)

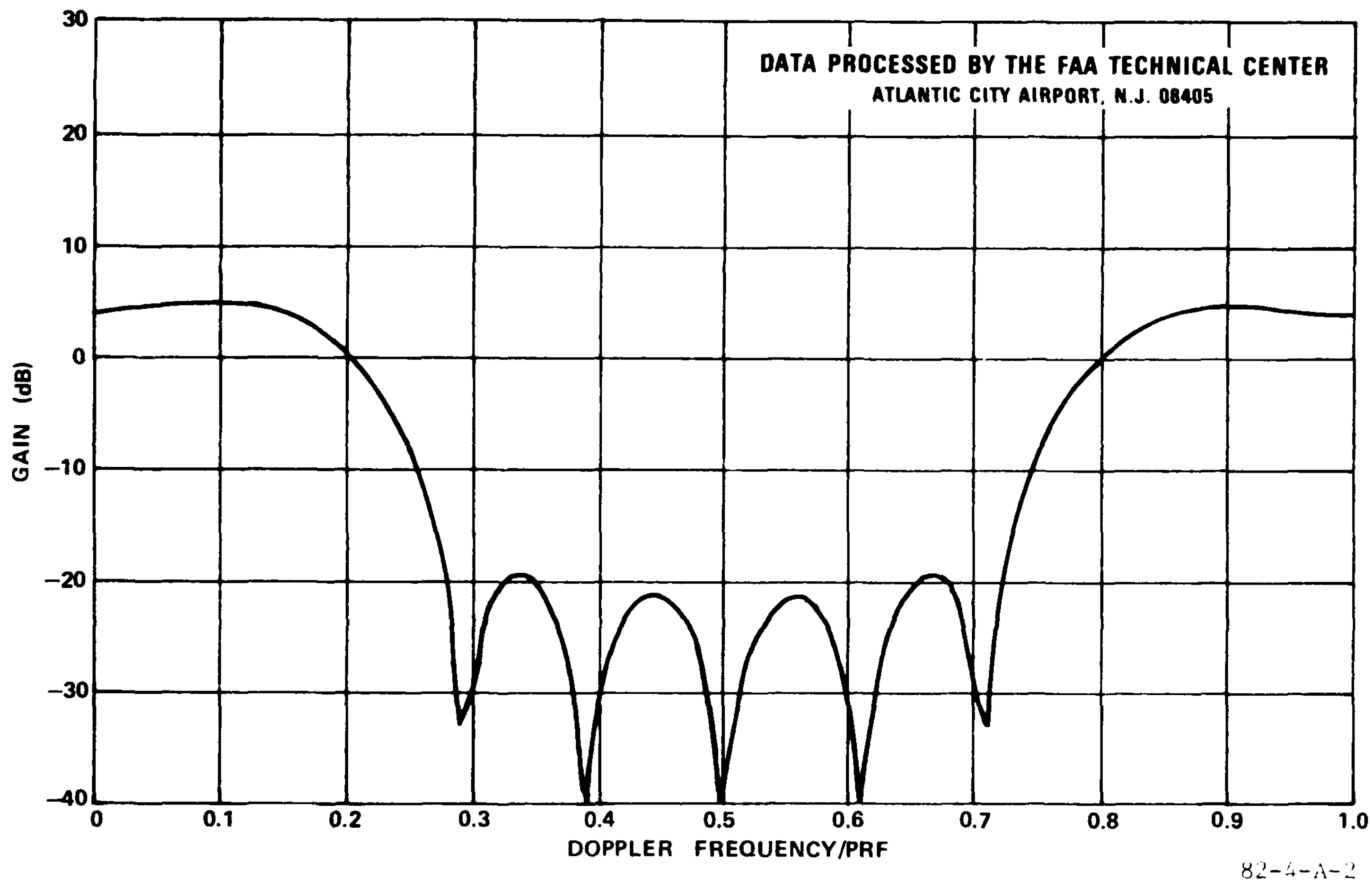

FIGURE A-2. ZERO FREQUENCY FILTER CHARACTERISTIC

APPENDIX B

DATA COLLECTION AND ANALYSIS USING THE NATIONAL AIR SPACE SYSTEM

The following is a brief description of the National Airspace System (NAS) 9020 data reduction and analysis equipment and software used during the en route moving target detector (MTD) test and evaluation.

Common digitizer (CD) messages and MTD messages (in CD format) from Bedford, Virginia, were recorded at the Technical Center on an Ampex 1800 digital recorder in CD format. The 1800 recording was then available for off-line analysis by processing the data through the data receiving equipment (DRE), the peripheral adapter module (PAM), and the 9020 computer. The various 9020 programs were then utilized to compare the data from the CD and MTD radar channels using the CD record data described below.

For most of the data collection and reduction, the CD subsystem provides the data path for reporting detectable aircraft and weather within the air route traffic control center airspace to the central computer complex. The CD subsystem is comprised of three CD adapters, one DRE (three channels), and one radar site. In off-line analysis, the 1800 recording served as the radar site. For combined CD and MTD operation, two CD subsystems were required to produce CD recordings in the following manner.

The CD data from the radar site is normally transmitted over telephone lines on three channels. In the test mode used for the MTD II test and evaluation, the CD data was transmitted on two channels with the MTD data being transmitted on the third channel. In order to correlate beacon data with MTD data, the 1800 recording was played into two DRE's simultaneously. In the first DRE, channels 1 and 2 search targets were inhibited to allow the beacon targets to mix with the MTD targets in channel 3. In DRE number 2, channels 1 and 2 were fed through, while channel 3 allowed only CD messages through. This test configuration permitted treating the CD and MTD as two separate and distinct radar sites.

Once this CD recording with the "two" radar data was obtained, various programs utilized in the NAS system were used for data analysis. These programs are listed as follows:

1. Beacon Code Sort (BCST). This program was used to read the CD record tape and to print the ranges, azimuths, and times of the first and last beacon radar returns for each beacon code. This program was used to track targets over clutter areas and at long ranges. It was also used to select targets of opportunity for data analysis.

2. Common Digitizer (COMDIG). The COMDIG program extracts selected types of data from a CD record tape and prints the data in a prescribed format. This program was used to extract beacon and radar data for percent of detection analysis.

3. Live Environment Performance Program (LEPP). This program extracts data from a CD record and computes performance parameters. For this project, beacon detection, radar detection, collimation, and distribution data were obtained for analysis.

4. Range, Azimuth, Radar Reinforced Evaluation (RARRE). The RARRE program provides the capability to retrieve, sort, and print target information pertaining to all Mode 3/A beacon equipped aircraft detected by any number of radar sites. The target information is retrieved from a CD record tape.

5. Quick Analysis of Radar Sites (QUARS). This program provides a real-time on-line monitoring and confirmation of an air route traffic control center's CD and CD subsystems interface and operational status for the NAS system. The data provided by this program are:

a. Blip-scan-ratios for beacon, moving target indicator (MTI), and log normal operations.

b. Range and azimuth splits for beacon, MTI, and log/normal.

c. Radar reinforced rate.

d. MTI, log/normal, and total collimation.

e. Code validity and reliability for beacon Modes 3/A and C.

f. Beacon ringaround.

6. Multiplot for Cal Comp Plotter. This program extracts selected beacon codes for plotting showing radar reinforced targets for selected geographical locations.

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