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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO AGARDograph 300

Flight Test Techniques Series – Volume 16

Introduction to Airborne Early Warning Radar Flight Test

(Introduction aux essais en vol des radars aéroportés d'alerte lointaine)

This AGARDograph has been sponsored by the Systems Concepts and Integration Panel (SCI) of RTO.

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edited by

J.M. Clifton
F.W. Lee

This AGARDograph has been sponsored by the Systems Concepts and Integration Panel (SCI) of RTO.

North Atlantic Treaty Organization

Research and Technology Agency

15 January 2001

TO: Recipients of AG-300 Vol. 18

FROM: Executive, Information Policy and Publications

SUBJECT: **AG-300, Vol 18, pages A-1, A-2 and A-3**

We regret that due to an oversight pages A-1, A-2 and A-3 of this publication, which list past volumes in the AG-160 and AG-300 series, were omitted. Replacement sheets to be inserted after page 69, are enclosed. Please also insert the following text in the contents on page vi:

Annex: AGARD and RTO Flight Test Instrumentation and Flight Test Techniques Series A1

We regret also that there were minor errors in both Vols 16 (on pages A-1 and A-2) and 17 (on pages A2-1 and A2-2). In both cases, you should make the following manuscript changes to the volume numbers in the left hand column:

On the first page, delete the first number '3' (against the line beginning "by F. Trenkle . . .")

On the second page, delete the numbers '4' and '5 (against the item beginning "Identification of Dynamic Systems . . .") and replace them by a single '3'.

Please pass this notice and attachments to anyone to whom you may have sent a copy of this book.

National Distribution Centres have also received electronic versions on CD-ROM. Replacement CD-ROMs, containing the corrections for all three publications, are enclosed for them.

George Hart
Information Policy & Publications

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Introduction to Airborne Early Warning Radar Flight Test

(RTO AG-300 Volume 16)

Executive Summary

During periods when military budgets and aircraft fleet sizes are shrinking, systems that serve to cost effectively increase the utility of the remaining weapons can still undergo procurement growth. The increased situational awareness and battle field management provided by Airborne Early Warning (AEW) radar is one such force multiplier. The primary role of an AEW aircraft is the long-range detection of airborne targets. As potent new airborne threats, such as low flying cruise missiles, reduce the timelines that traditional air defense systems have to react, the utility of an AEW system's long-range surveillance capabilities to recover the lost time is clear. Fundamentally, these new targets stress the principal performance capabilities of an AEW radar sensor leveling new requirements on these systems to deal with this advanced threat. These increased requirements have led to world-wide, substantive work in the development of radar upgrades to existing AEW aircraft, such as the U.S. Navy's E-2C Hawkeye and the U.S. Air Force's E-3A AWACS, as well as new systems and platforms, such as the Swedish Air Force's ERIEYE. The required increases in sensitivity, resolution, and the associated data rates that stem from these performance improvements will have profound impact on the way these systems are operated and how they perform in various environments. As these increasingly capable systems evolve, AEW radar will be expected to take on additional missions and perform other surveillance functions in the pursuit of dominant battle field awareness. Unfortunately, little or nothing has been written to document the largely unique techniques needed to perform the system level flight testing of these new AEW radars. The procedures have largely been passed from one individual to the next without the benefit of substantive documentation. The purpose of this volume is to document the theory and procedures necessary to perform the developmental flight testing of the several major categories of AEW radar.

This book is intended as an introductory document to the subject of Airborne Early Warning radar flight testing. The first chapter provides a detailed discussion of the content and utility of the book. Chapter two is a discussion of the taxonomy and theory of AEW radars. Chapter three describes the instrumentation used in AEW radar testing and provides a detailed description of one sample system. Chapters four and five examine each of the subcategories of AEW radars and focus on the basic test techniques used for each. Specific examples of test techniques are provided for sample (and fictional) systems. The book ends by making some conclusions and providing recommendations.

Introduction aux essais en vol des radars aéroportés d'alerte lointaine

(RTO AG-300 Volume 16)

Synthèse

Malgré la diminution actuelle des budgets militaires et la réduction de la taille des flottes aériennes qui en résulte, l'achat de systèmes rentables, susceptibles d'augmenter l'efficacité des systèmes d'armes existants, reste envisageable. Une meilleure connaissance de la situation des forces et une meilleure gestion du champ de bataille offertes par les radars aéroportés d'alerte lointaine (AEW), représentent un exemple de ces « multiplicateurs de force ». La fonction principale d'un avion AEW est la détection lointaine de cibles aériennes. Compte tenu des importantes menaces aériennes nouvelles, telles que les missiles de croisière à basse altitude, qui nécessitent des temps de réaction de plus en plus courts de la part des systèmes de défense aériennes classiques, l'intérêt des capacités de surveillance à longue distance d'un système AEW, qui permettent de compenser cette perte de temps, est évident. Essentiellement, ces nouvelles cibles mettent en question les principales capacités opérationnelles des capteurs radar AEW, qui devront atteindre de nouvelles performances pour pouvoir contrer cette menace sophistiquée. Ces nouveaux besoins ont entraîné des activités considérables dans le monde entier dans le domaine du développement de versions améliorées des radars équipant les avions AEW existants, tels que le E-2C Hawkeye de la Marine US et le E-3A AWACS de l'Armée de l'air US, ainsi que de nouvelles plates-formes et de nouveaux systèmes tels que le ERIEYE de l'Armée de l'air suèdoise. La sensibilité et la résolution accrues qui sont demandées, ainsi que les débits binaires nécessaires pour assurer ces améliorations de performance auront une influence très marquée sur leur exploitation et leurs performances dans différents environnements. Au fur et à mesure de l'évolution de ces systèmes de plus en plus performants, les radars AEW devront assumer d'autres missions et réaliser d'autres fonctions de surveillance dans la poursuite d'une connaissance de la situation des forces qui permettrait de dominer le champ de bataille. Malheureusement, peu ou point de littérature existe sur les techniques souvent uniques qui sont demandées pour réaliser les essais en vol des systèmes composant ces nouveaux radars AEW. D'une manière générale, les procédures ont été transmises d'une personne à une autre sans aucune documentation de base. Ce volume a pour objectif de documenter la théorie et les procédures nécessaires à la réalisation des essais de développement en vol de plusieurs grandes catégories de radars AEW.

Cet ouvrage est une introduction au sujet des essais en vol des systèmes radar aéroportés d'alerte lointaine. Le premier chapitre présente une discussion approfondie du contenu et de la finalité de l'ouvrage. Le chapitre deux examine la taxonomie et de la théorie des radars AEW. Le chapitre trois décrit les appareils de mesure utilisés pour les essais des radars AEW, avec la description détaillée d'un système échantillon. Les chapitres quatre et cinq examinent chacune des sous-catégories de radars AEW, en privilégiant les techniques de base de chaque essai. Des exemples spécifiques de techniques d'essais sont donnés pour des systèmes échantillon et des systèmes théoriques. L'ouvrage se termine par un certain nombre de conclusions et de recommandations.

Contents

Preface

During periods when military budgets and aircraft fleet sizes are shrinking, systems that serve to cost effectively increase the utility of the remaining weapons can still undergo procurement growth. The increased situational awareness and battle field management provided by Airborne Early Warning (AEW) radar is one such force multiplier. The primary role of an AEW aircraft is the long-range detection of airborne targets. As potent new airborne threats, such as low flying cruise missiles, reduce the timelines that traditional air defense systems have to react, the utility of an AEW system's long-range surveillance capabilities to recover the lost time is clear. Fundamentally, these new targets stress the principal performance capabilities of an AEW radar sensor leveling new requirements on these systems to deal with this advanced threat. These increased requirements have led to world-wide, substantive work in the development of radar upgrades to existing AEW aircraft, such as the U.S. Navy's E-2C Hawkeye and the U.S. Air Force's E-3A AWACS, as well as new systems and platforms, such as the Swedish Air Force's ERIEYE. The required increases in sensitivity, resolution, and the associated data rates that stem from these performance improvements will have profound impact on the way these systems are operated and how they perform in various environments. As these increasingly capable systems evolve, AEW radar will be expected to take on additional missions and perform other surveillance functions in the pursuit of dominant battle field awareness. Unfortunately, little or nothing has been written to document the largely unique techniques needed to perform the system level flight testing of these new AEW radars. The procedures have largely been passed from one individual to the next without the benefit of substantive documentation. The purpose of this volume is to document the theory and procedures necessary to perform the developmental flight testing of the several major categories of AEW radar.

Foreword

This book is intended as an introductory document to the subject of Airborne Early Warning (AEW) radar flight testing. The first chapter provides a detailed discussion of the content and utility of the book. Chapter two is a discussion of the taxonomy and theory of AEW radars. Chapter three describes the instrumentation used in AEW radar testing and provides a detailed description of one sample system. Chapters four and five examine each of the subcategories of AEW radars and focus on the basic test techniques used for each. Specific examples of test techniques are provided for sample (and fictional) systems. The book ends by making some conclusions and providing recommendations.

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List of Figures

List of Data Cards

Acronyms, Symbols and Abbreviations

a	acceleration
Ae	antenna effective aperture, m^2
ADC	Analog-to-Digital Converter
AEW	Airborne Early Warning
AGARD	Advisory Group for Aerospace Research and Development
AGC	Automatic Gain Control
ALT	ALTitude
AMTI	Airborne Moving Target Indicator
AWACS	Airborne Warning and Control System
BIT	Built In Test
B_n	bandwidth of the receiver
BPF	Band Pass Filter
BSR	Blip/Scan Ratio
c	speed of light, 161,875 nm/sec
CA-CFAR	Cell Averaging CFAR
CBSR	Composite Blip/Scan Ratio
CFAR	Constant False Alarm Rate
COHO	COHerent Oscillator
COMO	COherent Master Oscillator
CPI	Coherent Processing Interval
C_R	clutter loss term
CRT	Cathode Ray Tube
db	decibel
DCCS	Data Collection and Conditioning System
DEG	DEGree
DGPS	Differential GPS
DPS	Data Processing System
DR	Dead Reckoning
DRS	Data Recording System
D_{sf}	spurious free dynamic range
DU	Data Unit
DX	Data Extraction
ECM	Electronic Counter-Measures
EMI	Electro-Magnetic Interference
FAA	Federal Aviation Administration
f_c	output of COHO
f_d	target or clutter induced doppler frequency
FFT	Fast Fourier Transform
f_l	output of STALO
FL	Flight Level
f_{min}	the minimum doppler shift below which the radar cannot discern between a real moving target and clutter
F_n	noise figure of the receiver
F_o	center frequency of target returns

G	directive antenna gain
GPS	Global Positioning System
H	altitude of aircraft in feet
I	In-phase
ICS	Internal Communication System
IFF	Interrogator Friend or Foe
k	Boltzman's constant=1.38 X 10^{-23} J/deg
K	1,000
KTS	Knots
LNA	Low Noise Amplifier
LO	Local Oscillator
LSB	Least Significant Bit
MAG	MAGnetic
MDS	Minimum Discernable Signal
MOPA	Master Oscillator Power Amplifiers
MSL	Mean Sea Level
MTI	Moving Target Indicator
N	north
NATO	North Atlantic Treaty Organization
nm	nautical mile
NRB	the number of range bins for each pulse repetition interval
P_{av}	average transmit power
PCM	Pulse Code Modulation
$P_d(X)$	Probability of Detection equal to X
$P_{dc}(X)$	Composite Probability of Detection equal to X
P_{fa}	probability of false alarm
PPI	Planned Position Indicator
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
P_t	transmitted power, watts
Q	Quadrature
R	Range
R_a	the ambiguous range for each pulse
$R_c(I)$	the ith candidate unambiguous range
RCU	Remote Control Unit
RF	Radio Frequency
RFI	Radio Frequency Interference
R_h	range to radar horizon
R_o	desired range
R_{max}	radar maximum range
$R_{max\ adj}$	maximum detection range of target of interest for which detection data has not been directly measured
$R_{max\ test}$	maximum detection range of target for which radar detection data has been directly measured
$R_{max\ unamb}$	maximum unambiguous radar range
R_{min}	minimum range
RU	Recorder Unit

Sec	second
S_{min}	minimum detectable signal, watts
$(S/N)_{min}$	minimum signal to noise ratio necessary for detection
SPD	speed
STALO	STAble Local Oscillator
STAP	Space Time Adaptive Processing
STC	Sensitivity Time Control
SWT	Scan-While-Track
TACCAR	Time Averaged Clutter Coherent Airborne Radar
T_{cpi}	time between samples
T_o	temperature of the receiver in deg K
TWS	Track-While-Scan
v	velocity
W	West
α	alpha constant
β	beta constant
σ	radar cross section
$\sigma_{desired}$	radar cross section of target of interest for which detection data has not been directly measured
σ_e	effective target radar cross section
σ_{test}	radar cross section of target for which radar detection data has been directly measured
λ	wavelength
τ	transmit pulse width
θ	angle between the velocity vector and the clutter patch
η	number of pulses per dwell
$\varepsilon_i(\eta)$	integration efficiency for η pulses
τ_c	compressed pulse width

1.0. INTRODUCTION

The purpose of this document is to provide a basic introduction to the subject of developmental[1] Airborne Early Warning (AEW) radar flight testing. The taxonomy of the AEW radar is manifested in the structure of the chapters. Each category of AEW radars are discussed, providing sample test techniques for each. The discussed techniques are general enough to be directly applied to any AEW radar, regardless of the class of platform in which it is installed. Additionally, the techniques may be used for either naval AEW or land-based AEW systems. The subject is developed through demonstration. That is, a sample system representing each category is defined and sample test techniques are discussed. The intent, is that if the reader can understand the development of the sample techniques, he or she can then extrapolate and develop techniques for systems not discussed explicitly within this book. This is significant, since it is the nature of developmental flight test that new systems require continuously evolving test techniques.

In order to facilitate the unclassified demonstration of the development and application of the sample test procedures, fictitious systems were chosen and placed within equally fictitious platforms. The specific procedures and data cards, which may include altitudes, airspeeds, target separations etc., are applicable to the sample system only and appropriate parameters must be chosen for the actual system/airframe combination under test. In applying this document, basic knowledge in certain areas is assumed. The test planner should have a basic knowledge of avionics, although an electronics background is not required. A familiarity with the operation of tactical aircraft is also important. A theory section is provided as section 2.0 with specific, amplifying information included in the general section of each test. The purpose of this information is to provide the reader with the knowledge necessary to comprehend the specific example system and test procedures that follow rather than a complete treatise of the entire subject. The intent is to preclude extensive outside reading to understand the test development process. When the time comes to apply the test development knowledge presented to a real evaluation, an extensive understanding of the workings of the system under test is absolutely essential and the cursory treatment here will undoubtedly be insufficient, even if the systems are similar to the sample systems.

The layout of the individual test sections was carefully chosen with several goals in mind. Each test is fairly self-contained, exclusive of the information in the general theory section. This allows the user of the manual to extract specific sections, reference them easily and quickly and review individual tests on the occasions where they are applicable to the system under test. In addition, the titles and contents of each section have parallels to the accepted test plan and technical report structure. Finally, the layout is similar to that used in the long accepted flying qualities and performance test manuals (see reference 23 for an example).

The test development process is manifested in the structure of the sections that follow. As

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[1] Developmental testing is performed as part of the iterative design process. Data derived from developmental testing is primarily intended to measure whether the system has met its intended functional requirements, and if not, to provide data useful to the designer for improving the design. Note that this type of testing is distinctly different from operational testing. Operational testing is performed by the intended users (vice professional testers and engineers) in the intended operational environment as a final "dress rehearsal" for the system. It is important for the developmental tester to remember that when he or she has determined that the system has completed the developmental phase of testing that it must then pass operational testing. This operational requirement will necessarily influence the type of testing performed in the developmental phases of the iterative design process.

mentioned above, the procedure is begun by exploring and fully understanding the design of the system under test. This understanding provides the insight necessary to stress the system and test it to its limits and also allows the calculation of the theoretical limits of the system. General theory, applicable to each section, is included in the first part of each section. Knowing the theoretical limits allows a more efficient test to be developed.

The choice of which parameters to test is best (and only) determined by a thorough knowledge of the working of the system and its intended functionality. The process can be divided into two steps. First, the evaluator must define the required functionality of the system. The functional description should be defined in operational, vice engineering, terminology. This step requires knowledge of the intended mission of the system. Secondly, the evaluator must choose the kernel of parameters that measure the performance of the required functionality defined in the first step. This task requires thorough system knowledge. These parameters are then used as a guide for the development of the individual test procedures that are designed to measure at least one of the critical parameters. The individual test procedures listed in the chapters that follow are titled according to the parameter under test.

The first subsection of each test procedure describes the purpose of the test, which more precisely defines the parameters under test. In the general section, the basic theory outlined in section 2.0 is expounded upon as necessary to fully implement and understand the test procedure. The instrumentation requirements necessary to measure the parameters described in the purpose statement are then listed, followed by the data required to document the parameter. Next, the procedure for performing the test is described in detail followed by a discussion of the post-test analysis of the measured data required to answer the purpose statement and the recommended format for presenting the test results. The last part of each test procedure is sample data cards used to perform the test procedure and for recording the data during actual testing.

In summary, the test design process can be described as outlined below. It may be necessary to change the order in which tasks are performed as well as the relative importance of the tasks from test to test, but the list below will provide a guide for the general case.

(1) Research and understand the design specifications and operational use of the system under test. Use this knowledge to define the parameters critical to assessing the performance of the system and also as a means for calculating the theoretical boundaries of the system's performance.

(2) Precisely define the purpose of the test procedure to include the parameters to be measured during the test.

(3) Define the data necessary to calculate the parameter under test and assess the instrumentation requirements.

(4) Outline the detailed procedure necessary to perform the data collection effort.

(5) Define the analysis necessary to take the measured data and calculate or assess the parameter under test and then decide upon the proper presentation format to document the parameter.

(6) As a last effort, generate data cards that provide an outline of all information necessary to perform the data collection effort and record the results.

2.0. THEORY

All AEW radar systems fall into the class of pulse doppler radars. A pulse doppler radar is any radar capable of measuring range and the frequency shift induced on a transmitted radar signal by the motion of a target. An *airborne* pulse doppler radar system is capable of detecting and measuring this frequency shift in the presence of a much stronger frequency shifted signal, namely clutter. From a systems point of view, there are only three primary performance areas that can be specified and tested in an AEW radar system. These performance areas are sensitivity, resolution, and data rate. Sensitivity refers to the radar's ability to detect weak signals in the presence of interference. This interference can take the form of thermal noise, clutter, Electronic Counter Measures (ECM), and Radio Frequency Interference (RFI). Resolution is a measure of the radar's ability to distinguish one target from another target both spatially and temporally. Finally, data rate refers to the radar's ability to update the situational awareness of the required search volume in a timely fashion.

The rest of this section will deal with the flow down of these top-level performance requirements through the various subsystems of a generic AEW radar. Through this system engineering approach, each of the three primary performance areas will be related to specific subsystem parameters. The goal of this section is to provide the reader with insight into different technical approaches that can be employed in AEW radar system design to satisfy the above mentioned requirements. The generic AEW radar described will be the basis upon which the sample AEW radar test techniques of sections 4.0 and 5.0 are developed.

2.1. ELEMENTS OF AN AIRBORNE PULSE DOPPLER RADAR

The fundamentals of airborne pulse doppler radar are best illustrated by examining the principle subsystems that comprise this type of radar. This will be accomplished by using and expanding the simple form of the radar range equation, shown as equation 2.1 [Ref. 26: p. 15], as a guide to understanding the key performance parameters of each subsystem as it relates to system sensitivity, resolution, and data rate. Figure 2.1 illustrates the principle subsystems of a generic airborne pulse doppler radar. The functional allocation and interfaces used to develop this subsystem breakdown are detailed in the following description of each subsystem.

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}} \right]^{1/4} \qquad \textbf{(2.1)}$$

P_t = PeakTransmitted power, watts

G = Directive antenna gain

A_e = Antenna effective aperture, m^2

σ = Radar cross section, m^2

S_{min} = Minimum detectable signal, watts

2.1.1. Antenna Subsystem

The antenna subsystem's primary function is to transmit and receive the radar signals. This subsystem is comprised of the actual radiating aperture, transmit and receive manifolds, duplexers and/or circulators (to isolate the received signal from the transmitted signal), and all Radio Frequency (RF) plumbing and transmission lines leading from the transmitter subsystem and leading to the receiver subsystem. In the radar range equation, the antenna subsystem affects two related quantities, the directive gain G and the effective aperture A_e. Directive gain is a measure of the ability of an antenna to concentrate or direct energy in a

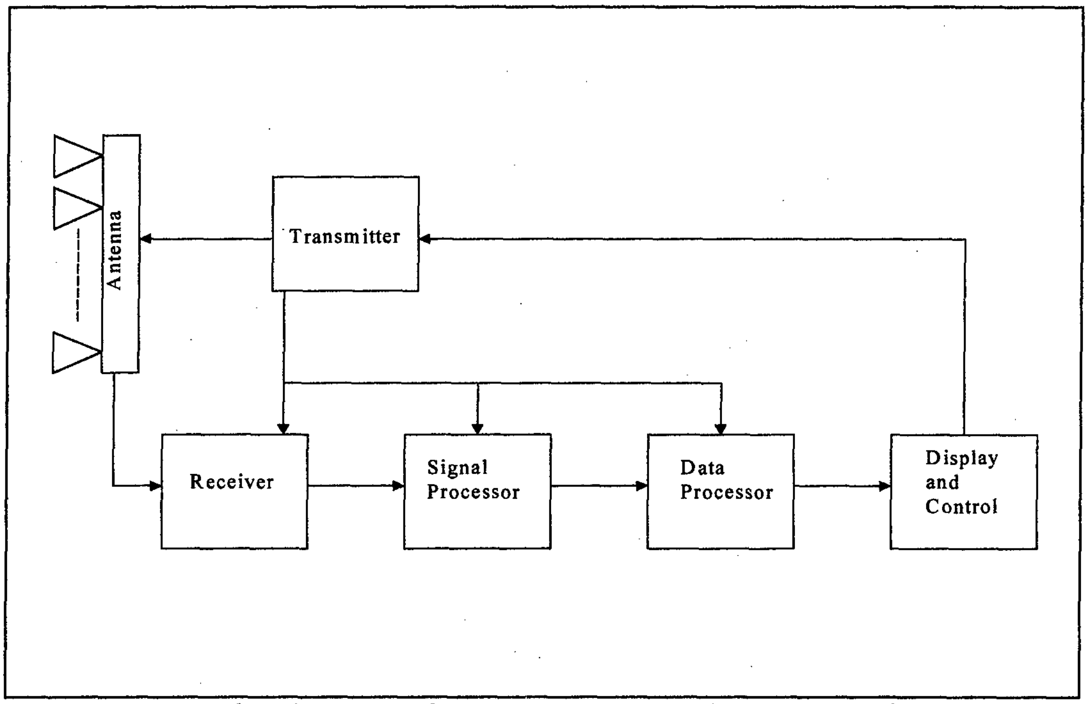


Figure 2.1: *The principle subsystems of a generic airborne pulse doppler radar.*

particular direction, i.e. the direction in which the radar is searching for a target. This measure is based primarily on the shape of the antenna's radiation pattern as illustrated in Figure 2.2. In this way, the directive gain affects both the sensitivity of the system, by setting the effective radiated power of the radar system, and the spatial resolution of the system, by establishing the azimuthal and elevation beamwidths.

The effective aperture is a measure of the effective area upon which the incident radar signal impinges. Since the same antenna is used for transmitting and receiving, clearly, the effective aperture and the directive gain of the antenna must be related. In fact, the directive gain can be expressed in terms of the effective area as shown in equation 2.2.

$$G = \frac{4\pi A_e}{\lambda^2} \qquad (2.2)$$

G = Directive antenna gain

A_e = Antenna Effective Aperature, m^2

λ = Wavelength

Two other parameters that have an impact on system sensitivity involve the antenna's polarization and sidelobe radiation levels. The selection of polarization is typically a tradeoff between what is most desirable for all weather performance, circular polarization, and what is easiest to achieve, linear polarization. Of the two linear polarizations, horizontal polarization is the preferred choice for low frequency AEW radar applications since in most cases the target signal is enhanced by the multipath bounce, especially for low flying targets. In this way, polarization does play a small role in enhancing system sensitivity, however, since the enhancement is only good for specific targets and ranges, it is typically discounted in the evaluation of overall system sensitivity and consequently will not be incorporated into our expansion of the radar range.equation.

The sidelobe radiation levels impact on overall system performance. In terms of their impact on system sensitivity, sidelobe levels can increase a system's susceptibility to sidelobe jamming and, in some systems, they can have a profound

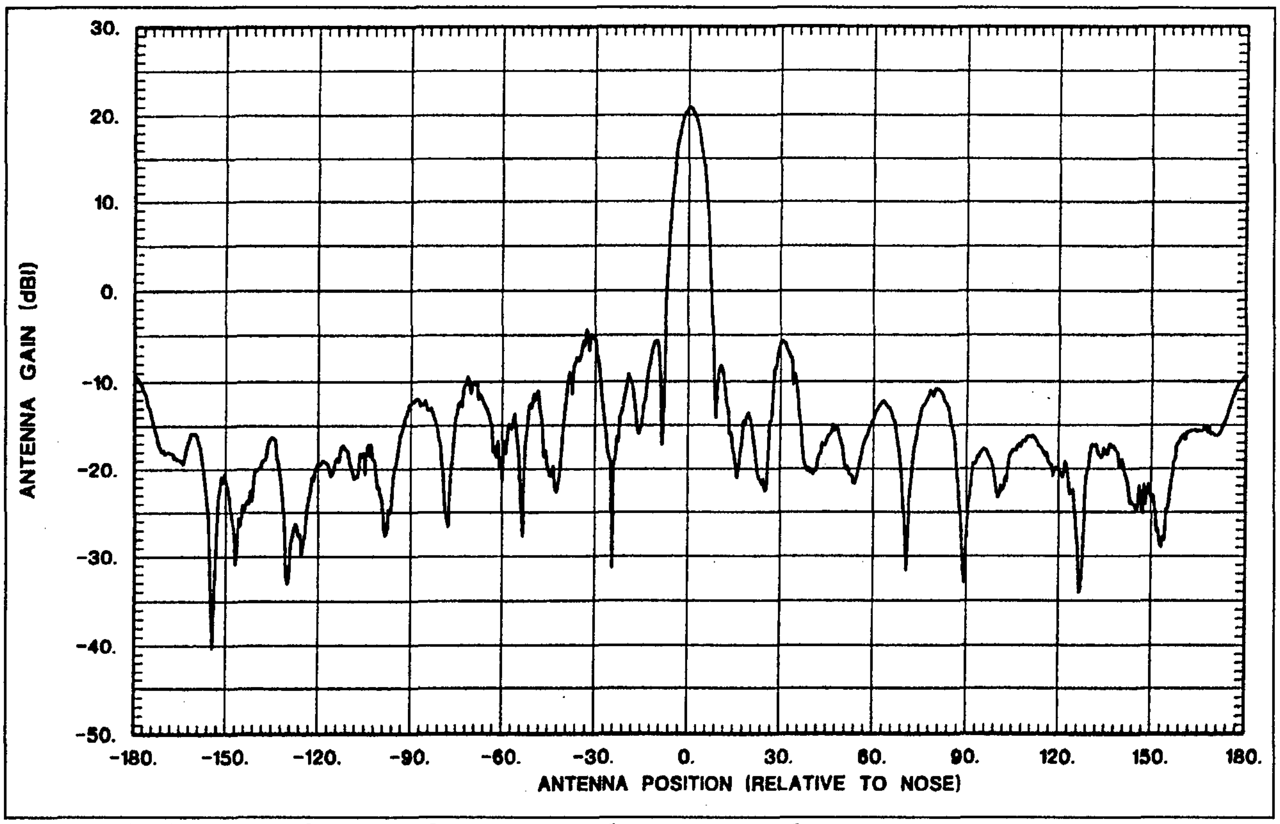


Figure 2.2: *Generic Airborne Early Warning radar antenna radiation pattern.*

impact on subclutter visibility. However, several different design options exist for the signal processing subsystem that can mitigate both of these effects. In terms of resolution, high sidelobe levels can cause sidelobe returns to appear as false targets. Once again, this impact can be corrected downstream in the data processing subsystem. Clearly, low sidelobe levels are a desirable feature of any radar antenna since the larger the sidelobes, the larger the requirements on the signal and data processing subsystems. Unfortunately, lower sidelobe levels come at the expense of spatial resolution, therefore a balance must be reached in terms of the additional processing requirements levied by higher sidelobes to achieve a specified angular resolution.

2.1.2. Transmitter Subsystem

The transmitter subsystem's primary function is to both generate and amplify the waveforms that are to be directed at the targets. With virtually no exceptions, all airborne pulse doppler radar systems employ transmitters which can be classified as Master Oscillator Power Amplifiers (MOPA). The key to a MOPA transmitter is it's ability to amplify a signal while preserving the signal's initial phase and modulation characteristics. Because of this, the power P_t in the radar range equation need only refer to the peak transmit power of the MOPA transmitter. Of more interest to the radar system designer is the average power of the transmitter, P_{av}, which is related to the peak power by equation 2.3.

$$P_t = \frac{P_{av}}{\tau PRF} \qquad \textbf{(2.3)}$$

PRF = Pule Repetiton Frequency

τ = Transmit pulse width

P_{av} = Average Power

P_t = Peak power

Also included in this subsystem is the signal and transmit waveform generation, key to which is the Coherent Master Oscillator (COMO). The COMO is used to set the overall system timing including the phase reference of the modulated transmit waveform, the timing of range gates, and the Pulse Repetition Frequency (PRF). In this way, all signals can be related back to a single phase reference. Although coherent operation is not a specific requirement of airborne pulse doppler radars, all modern AEW radars employ coherent operation to improve the effectiveness of the downstream signal processing. Consequently, the value of coherent operation and it's impact on system sensitivity and resolution will be assessed in the signal processing subsystem. Also, instantaneous and tunable bandwidth, both key factors in the design of the transmitter subsystem, will be assessed next when the receiver subsystem is covered. It is assumed that the receiver will be designed to match these performance parameters.

2.1.3. Receiver Subsystem

The primary function of the receiver subsystem is to acquire and convert the signals received by the antenna and to provide this data to the signal processing subsystem, usually in a digital format, without corrupting the basic nature of the signals. For coherent radar systems this is accomplished using a synchronous receiver as shown in Figure 2.3. In this type of receiver, there are two key performance parameters that will impact the system performance measures. Of foremost concern to the radar system designer is the noise figure of the receiver. The noise figure can be thought of as a measure of the degradation or increase in the minimum detectable signal as that signal passes through the receiver. From this perspective S_{min} can be expanded using equation 2.4. In this expression, the noise figure can be viewed as "adding" more thermal noise to the Minimum Detectable Signal (MDS). Clearly, increasing the MDS has a profound impact on the system by making it less sensitive, thus reducing it's capability to detect weak targets at long ranges.

$$S_{min} = KT_oB_nF_n\left(\frac{S}{N}\right)_{min} \qquad \textbf{(2.4)}$$

S_{min} = Minimum detectable signal

K = Boltzman's constant = 1.38×10^{-23} J/deg

T_o = Temperature of the receiver in deg K

B_n = Bandwidth of the receiver

F_n = Noise figure of the receiver

$\left(\frac{S}{N}\right)_{min}$ = Minimum signal to noise ratio necessary for detection

Another key performance metric of the synchronous receiver is it's dynamic range. For radar applications, the dynamic range of most interest is the spurious free dynamic range of the receiver. Typically measured as the difference between a full scale input and the peak spurious response as shown in Figure 2.4, the spurious free dynamic range is a measure of the linearity of the receiver. This is important in AEW radar applications since typically all targets are detected in the presence of a much larger return, namely clutter. If the expected clutter level will drive the receiver into a nonlinear region, the designer is forced to implement a Sensitivity Time Control (STC) correction in the receiver design. The STC circuit is designed to geometrically decrease the attenuation of all incoming signals as a

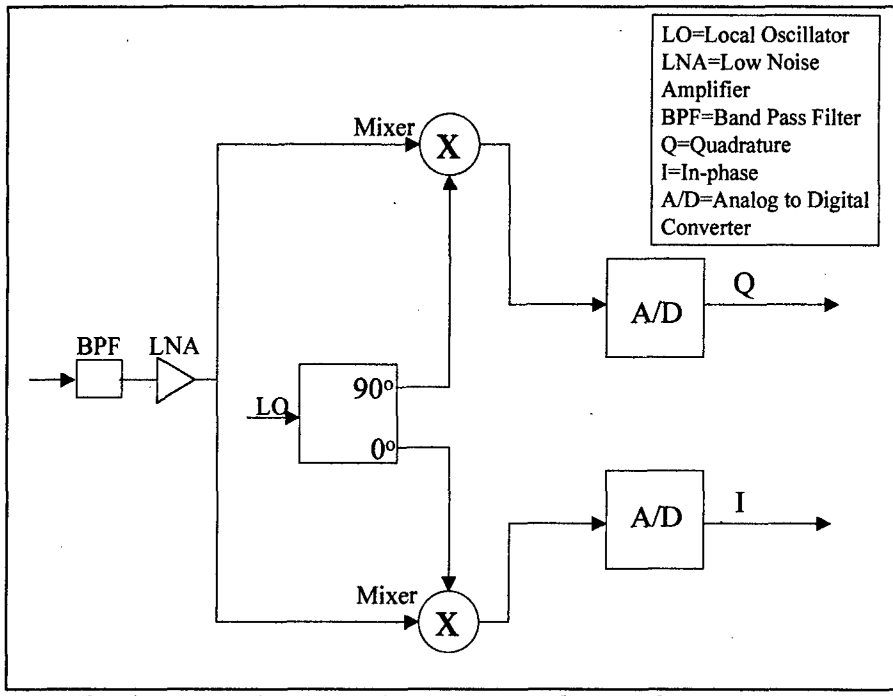


Figure 2.3: *Typical coherent Airborne Early Warning radar synchronous receiver architecture.*

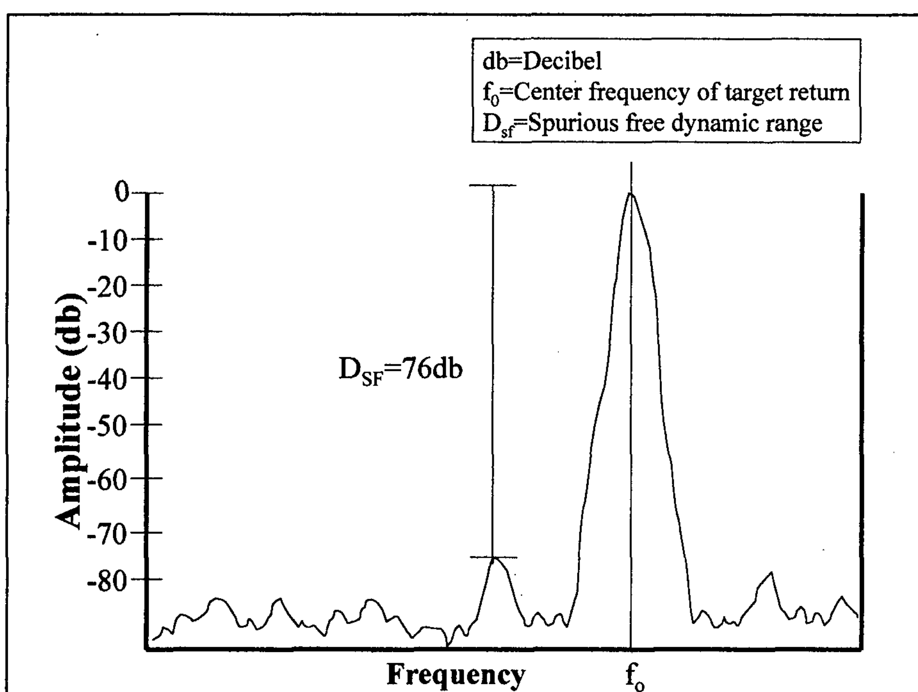


Figure 2.4: *Spurious free dynamic range shown as the difference between the amplitude of the full scale input and the peak, or largest, spurious response.*

function of range as shown in Figure 2.5. The net effect of an STC circuit is to limit the sensitivity of a radar system.

For the purposes of this generic AEW radar system, the receiver subsystem is assumed to house the Analog to Digital Converters (ADC). In modern radar systems, the ADC is responsible for quantizing the analog signal into a digital representation for the purpose of allowing the rest of the radar system to be implemented in discrete digital logic. If properly designed, the ADC is not a limiting factor in any of the performance measures of the system. To ensure this, the radar system designer must take great care to set the overall analog gain of the receiver such that the Least Significant Bit (LSB) of the ADC is toggling from one to zero at the thermal noise floor of the system.

2.1.4. Signal Processing Subsystem

The signal processing subsystem is perhaps the most complex subsystem of the entire radar. The primary function of the signal processing subsystem is to take the converted signals from the receiver and change them into target detections. The signal processing subsystem can be thought of mathematically as a transfer function that transforms the sampled output of the receiver from the synchronous signal domain into the discrete, asynchronous data domain. An illustration of the different stages of a typical signal processor can be seen in Figure 2.6. The primary goal of the signal processing stages prior to the threshold detector stage is to maximize the signal to noise ratio upon which the detector logic will function. To better understand this process and the impact it can have on sensitivity, resolution, and the data rate of the AEW radar system, it is instructive to examine the spatial and temporal characteristics of clutter, the

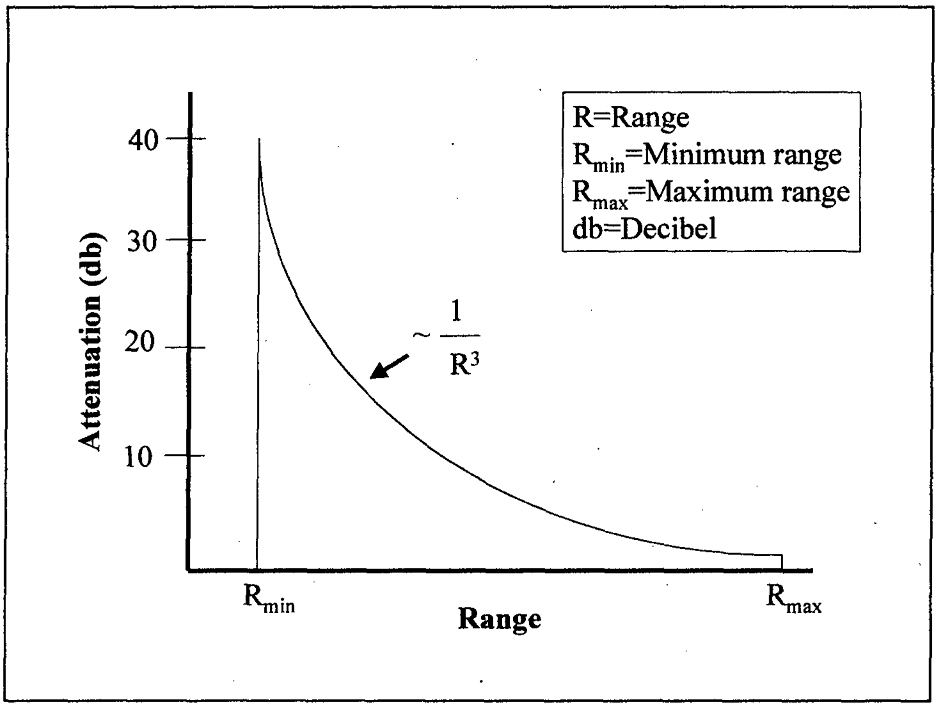


Figure 2.5: *Sensitivity time control attenuation curve used to prevent saturation of the receiver dynamic limits at shorter radar ranges.*

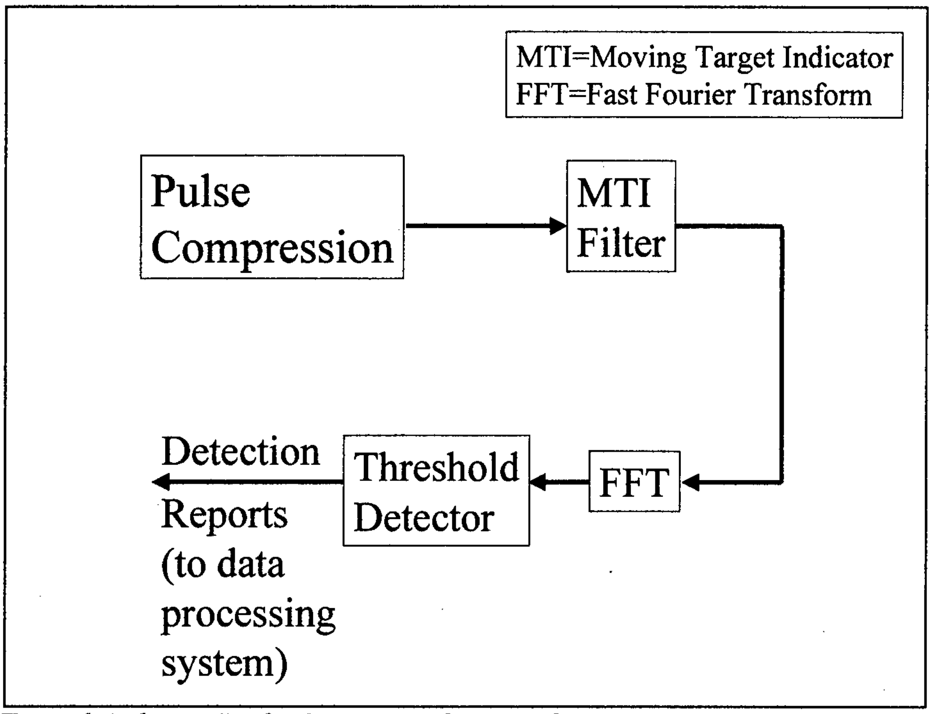


Figure 2.6: *Typical Airborne Early Warning radar signal processor.*

primary signal with which the target must contend.

2.1.4.1. Airborne Clutter Spectra

The effects of the platform motion of an airborne radar on clutter is quite profound. The returns from seemingly stationary objects, with respect to the ground, are in constant motion with respect to the platform. The apparent velocity of the objects is directly proportional to the component of the velocity of the radar in the direction of the object. The doppler frequency of a patch of clutter can be expressed according to equation 2.5, as illustrated by Figure 2.7. If the PRF of the radar system is high enough, then all

$$f_d = \frac{2V_a}{\lambda}\cos\theta \qquad \textbf{(2.5)}$$

V_a = Aircraft velocity

θ = Angle between the velocity vector and the clutter patch

λ = Transmitter wavelegth

f_d = Doppler frequency

the clutter patches are localized as viewed in Figure 2.8, leaving a clutter free region for target detection. In this case, we refer to the clutter as being unambiguous. On the other hand, if the clutter is ambiguous, i.e., the PRF is so low that the sidelobe clutter folds and completely fills in and overlaps the entire doppler domain as shown in Figure 2.9, more sophisticated means are required to detect the target. Representing the problem of clutter residue in the radar range equation is best accomplished by adding a clutter loss term (greater than unity) to the denominator of the radar range equation, yielding equation 2.6. In this way we see that the effect of clutter residue is to increase the noise term, that when reduced to unity, leaves the original thermal noise equation. The following three signal processing techniques are all attempts to increase the signal to noise ratio by either increasing transmitted signal strength, reducing the clutter residue, or both.

$$S_{\min} = kT_o B_n F_n \left(\frac{S}{N}\right)_{\min} C_R \qquad \textbf{(2.6)}$$

K = Boltzman's constant = 1.38×10^{-23} J/deg

T_o = Temperature of the receiver in deg K

B_n = Bandwidth of the receiver

F_n = Noise figure of the receiver

$\left(\frac{S}{N}\right)_{\min}$ = Minimum signal to noise ratio necessary for detection

C_R = Clutter loss term

$S_{\min}$ = Minimum detectable signal

2.1.4.2. Pulse Compression

Pulse compression is a technique that allows an AEW radar to utilize long pulses to achieve large duty factors and consequently higher average powers without giving up the inherent range resolution of a short pulse radar. The methodology of pulse compression has not changed dramatically from the basic concept described in R. H. Dicke's patent of 1945 and are adequately covered in several texts on radar systems. The pulse compression ratio is a measure of the degree to which pulse compression can be employed. Digital techniques have allowed pulse compression ratios to exceed 1000 to 1. All the parameters for pulse compression signal processing are present in the radar range equation. The purpose of pointing the technique out here is to enforce the notion that, although long pulses for sensitivity appear to be at odds with resolution, signal processing techniques exist for overcoming this apparent obstacle and that the radar range equation embodies both sensitivity and range resolution through the pulse compression ratio, sometimes referred to as the time-bandwidth product.

2.1.4.3. Airborne Moving Target Indication (AMTI) and Doppler Filtering

AMTI and doppler filtering are naturally handled together since both can be thought of as temporal filters designed to increase signal gain relative to clutter. An AMTI filter accomplishes this by making use of the coherence in the radar signal on a pulse to pulse basis. This is best illustrated by considering a synchronous detector, such as Figure 2.10, followed by a digital delay canceler shown in Figure 2.11. The synchronous detector modulates the transmitted signal with a copy of both the COHerent Oscillator (COHO) a signal derived from the COMO, and the STAble Local Oscillator (STALO), a signal designed to translate the COHO up to the designed center frequency of the radar. In this way the down converted signal will include a doppler shift signal on a pulse to pulse basis if the signal is from a moving target or the signal will be constant on a pulse to pulse basis if the shift is solely due to the motion of the platform. Viewing the frequency transfer function of this delay line canceler in Figure 2.12, the nature of this filter is clear. As the frequency shift induced by the target's motion approaches PRF/2, referred to as *optimum* doppler, the signal is amplified in the AMTI filter. On the other hand, signals which exhibit no doppler shift are attenuated by 30dB or more depending on the stability of the STALO, COHO, and the transmitter. One type of clutter cancellation system that uses this technique is known as Time Averaged Clutter Coherent Airborne Radar (TACCAR). In contrast to an AMTI filter, where a single filter is tuned to reject signals with no doppler, doppler filtering uses a bank of filters in order to individually increase the gain of a discrete number of doppler frequencies. Once again, using the digital synchronous detector as a front end, the doppler filter buffers all range data for a number of pulses in what is known as a Coherent Processing Interval (CPI). A CPI is typically an integer power of two. For low PRF systems, CPI's of 16 or 32 are typical. For high

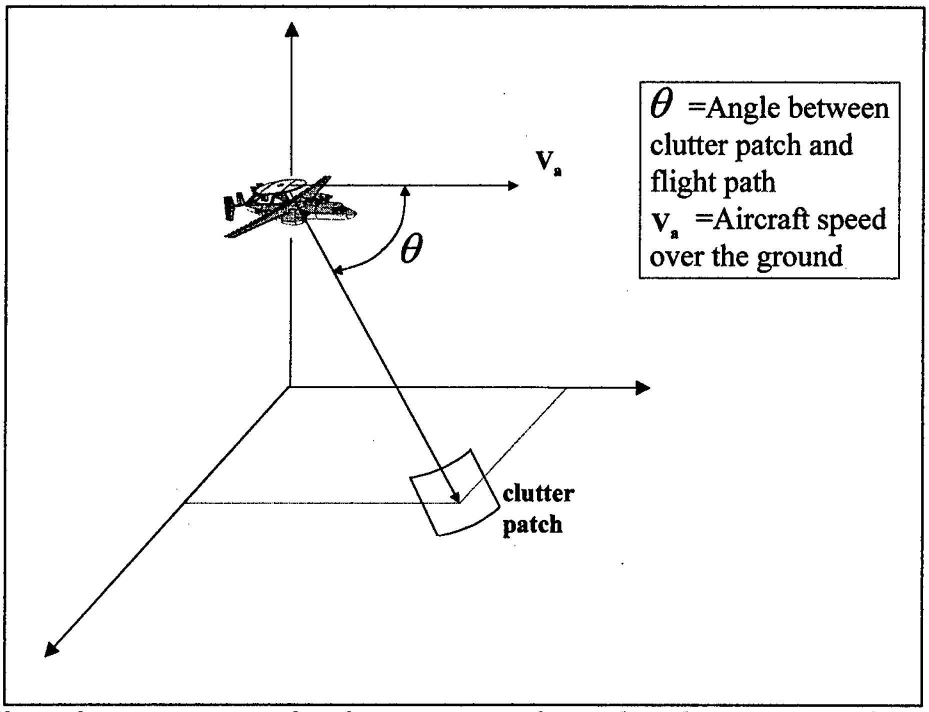


Figure 2.7: *Clutter has an apparent doppler component due to the relative motion of the radar carrying aircraft over the ground. The nature of the clutter is defined by the angle between the aircraft velocity vector and the clutter patch, and the groundspeed of the aircraft.*

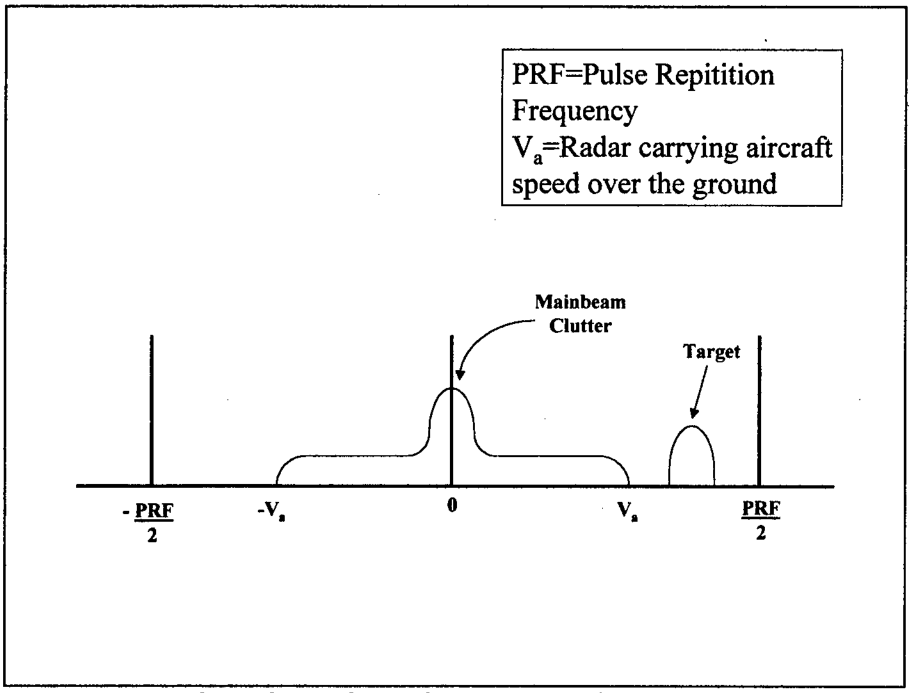


Figure 2.8: *Clutter spectrum of a radar with a pulse repetition frequency high enough, such that the clutter is unambiguous at the radial component of the radar platform groundspeed along the clutter patch angle.*

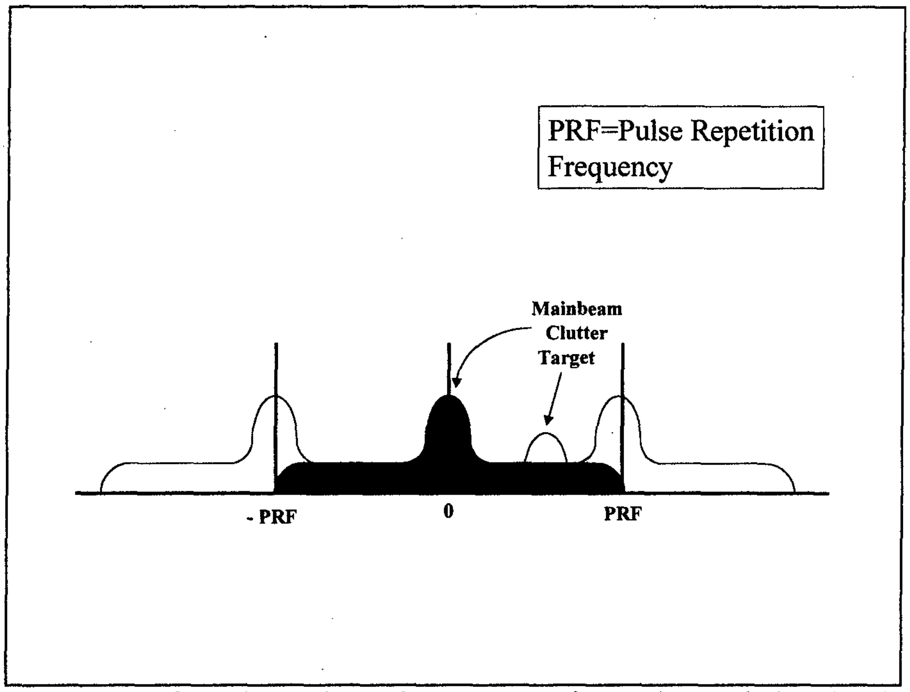


Figure 2.9: *Clutter spectrum of a radar with a pulse repetition frequency, such that the clutter is ambiguous at the radial component of the radar platform groundspeed along the clutter patch angle.*

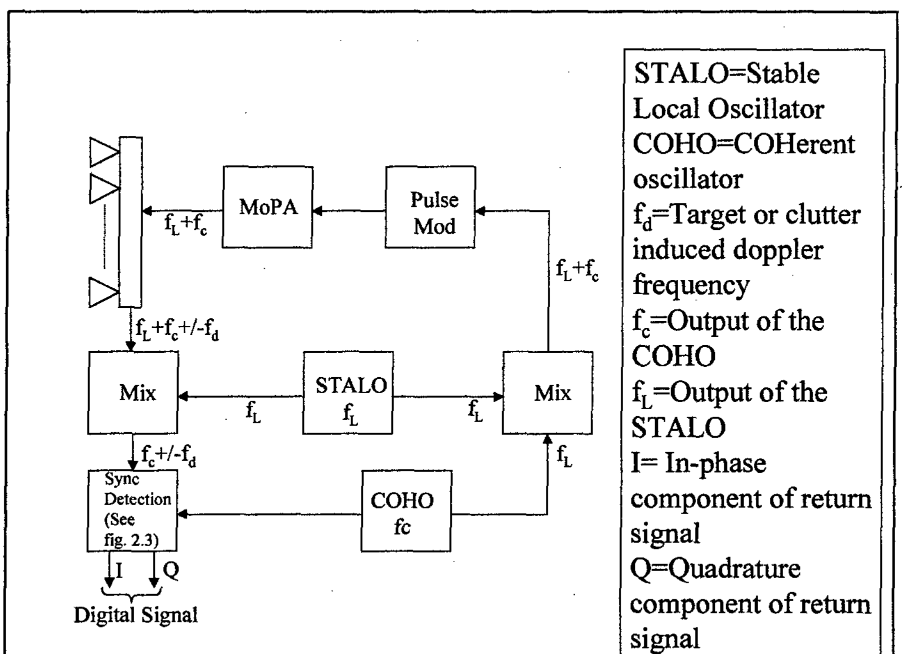


Figure 2.10: *A synchronous detector, used to perform airborne moving target indicator radar return signal processing.*

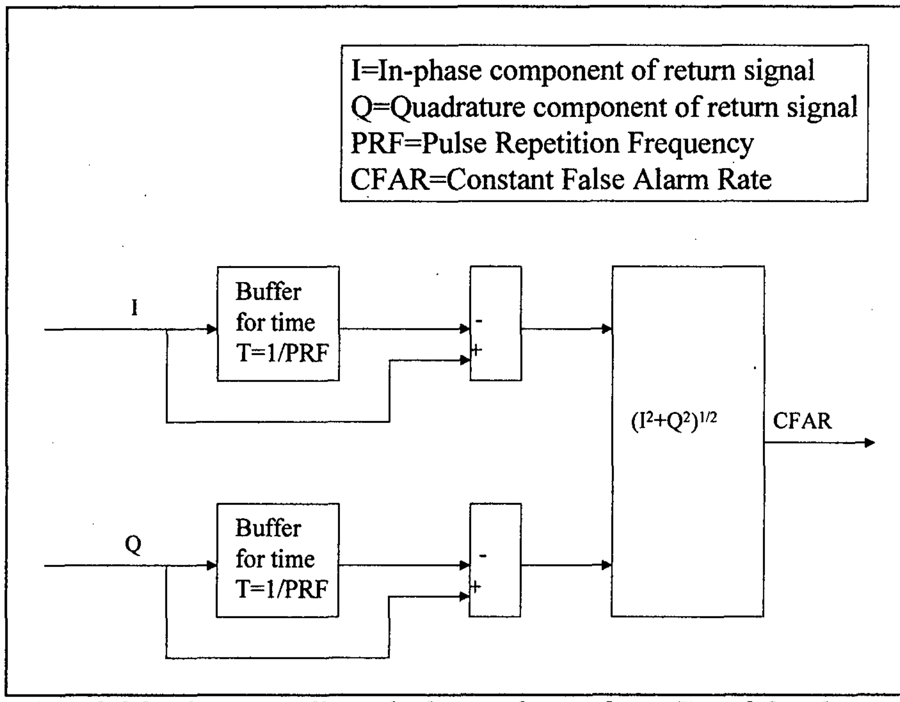


Figure 2.11: *A digital delay line canceller, which uses the In-phase (I) and Quadrature (Q) output of a synchronous detector to cancel out the effects of stationary clutter and to highlight the presence of targets with motion over the ground.*

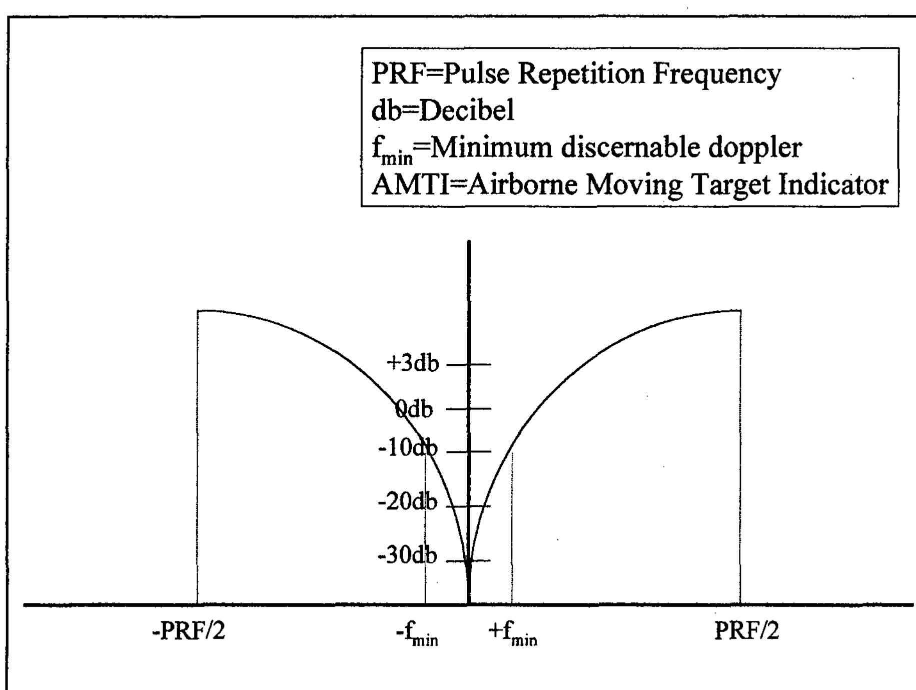


Figure 2.12: *The transfer function of the Airborne Moving Target Indicator(AMTI) filter, showing the maximum output when the doppler shift of the target approaches half of the Pulse Repetition Frequency (PRF) and a zero output when the doppler shift approaches zero. f_{min} is the minimum doppler shift at which the radar can discriminate between real moving targets and the clutter return signal.*

PRF designs, a CPI may be longer than 256 pulses. This collection of range and pulse data is best thought of as a matrix where the first column of the matrix represents all of the pulse sample for a particular range cell with column two being all the pulse data for the next range cell, and so on. The doppler filter bank is applied by taking the Fast Fourier Transform (FFT) along the columns of the matrix, such that, now the first column contains the complete doppler frequency spectrum (with a discrete number of doppler frequency bands equal to the number of pulses in the CPI) for the first range cell, an so on for all range cells. Since clutter is assumed to fall in the zero doppler filter, the down stream detector need only search for targets in those doppler frequency bands where there is a non-zero frequency response.

In practice, it is not unusual to see an AMTI filter followed by a doppler filter. This is for two reasons. First, since a doppler filter has frequency sidelobes which will allow clutter to "leak" in from the zero doppler, or clutter filter, an upstream AMTI filter can go a long way in attenuating this signal prior to any doppler filtering being performed. Second, since it is desirable for the down stream data processing to know the relative radial rate of the target for tracking and reporting, the particular doppler filter that a target is detected in is an instantaneous measure of this vital information.

The topic of radar signal processing is a rapidly evolving field. Other clutter cancellation techniques such Space-Time Adaptive Processing (STAP) can be employed to better improve the detectability of a target. However, for the purposes of this text, all such techniques will be summarized using equation 2.7. By thinking of the filtering occurring over the CPI as an integration, this addition to the radar range equation is inherently treated as signal to noise enhancement with an efficiency factor (less than one for imperfect integration) being the distinguishing factor between all such clutter cancellation methods. Therefore, these methods can be viewed as increasing the sensitivity of radar system and the resolution (in terms of doppler resolution) and establishing the data rate of the signal processing system. This last point is very subtle. It is with this expansion of the radar range equation that the concept of a coherent processing interval is introduced. This has a profound effect on the overall data rate of the system. From now on, the sensitivity of the system will be characterized for a given period of time and for a number of doppler bands and a number of range cells for a particular search angle. Thus, the date rate of the signal processing system is given by equation 2.8. If the data rate is multiplied by the number of beam positions required to fill the search volume, then one obtains the total scan to scan data volume. For wide area surveillance systems, it is not unusual for this data volume to exceed 100 million data cells capable of holding target detections.

$$\sigma_e = \sigma \cdot \eta \cdot \varepsilon_i(\eta) \qquad \textbf{(2.7)}$$

η = Number of pulses per dwell

$\varepsilon_i(\eta)$ = Integration efficiency for η pulses

σ = Target radar cross section

σ_e = Effective target radar cross section

$$\text{Data Rate} = \frac{PRI \cdot \eta}{\tau_c} \qquad \textbf{(2.8)}$$

PRI = Pulse Repetition Interval

τ_c = Compressed pulse width

η = Number of pulses per dwell

2.1.4.4. Constant False Alarm Rate Detectors

Constant False Alarm Rate (CFAR) detection is the key processing step in the implementation of an automatic detection and tracking AEW radar system. It is at this point in the system that the very nature of the data is changed. The CFAR function serves as the transition point where the data is converted from the signal or measurement domain to the data or report domain. All of the major performance areas are effected by this conversion. The sensitivity of the system is fundamentally established by the threshold setting of the CFAR detector. This is best illustrated by examining the Cell Averaging CFAR (CA-CFAR) system of Figure 2.13. The CA-CFAR is one of the simplest CFARs to employ since it approximates the average of the range cells before and after the test cell by merely summing a number of samples and then sets the threshold to the greater of these two sums. This averaging yields a threshold that has the statistical property that if a target signal is surrounded by temporally "white" noise, then the probability of the sum of the noise samples exceeding the level of the target, i.e., the probability of false alarm, is constant. Another property of this particular CFAR is that the impact on sensitivity due to the inherent loss in such a detector decreases as more samples are averaged. A typical result of such a CFAR system can be seen in Figure 2.14 for a target signal in noise. Here we plot the probability of detection, i.e., the probability that a target signal will not have lower signal strength than the surrounding noise as a function of signal to noise for various probabilities of false alarm out of the CFAR detector. A typical design point for radar systems on this curve is to design the power aperture product and signal processing gain of the system to achieve a desired range, R_o, for a probability of detection P_d=.5 and a probability of false alarm $P_{fa}=10^{-6}$.

The impact of the CFAR is not only felt on the sensitivity performance area, it also impacts both the resolution of the system and establishes the data processing system input data rate. The resolution of the system is affected by the CFAR by establishing test cells and guard cells which fundamentally limit the available range resolution of the system. Typically, the resolution of the system is limited to 50% of the available range resolution by the CFAR process. This will keep range extended targets and range straddling targets from consuming detector bandwidth and valuable downstream resources. The input data rate is established by the amount of detections that the CFAR allows through.

2.1.5. Data Processing Subsystem

The primary function of the data processing subsystem is to convert the raw target report output from the signal processing subsystem into a semblance of order for the purpose of displaying useful information to the operator. This involves determining which of the target reports belong to new, existing, or false tracks. The tracking process can also be thought of as a filtering process. Through this process, the metric estimates provided by the signal processing subsystem are smoothed and refined, providing a more robust measure of the primary target parameters such as range, range rate (velocity), bearing, and elevation. The data processing required is a function of the type of waveform the system is using. The data processing requirements of a low PRF system differ dramatically from those of a high PRF system. The next few subsections deal with the

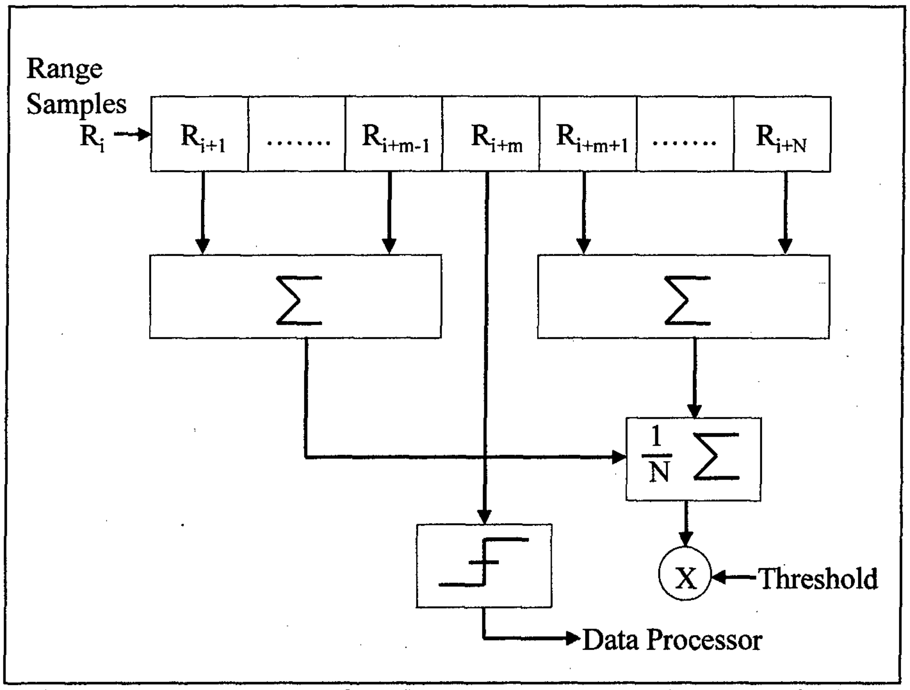


Figure 2.13: *Cell Averaging Constant False Alarm Rate (CA-CFAR) system which approximates the average of the range cells before and after the test cell by summing samples and then setting the threshold to the greater of these two sums.*

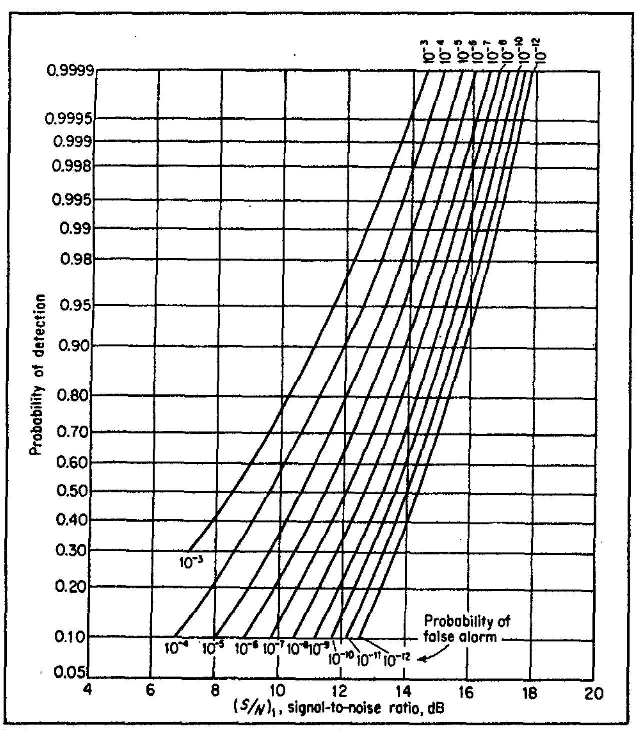


Figure 2.14: *Probability of detection as a function of the signal to noise ratio [Ref. 26: p.28].*

three different waveforms. The unique data processing requirements of each are described.

2.1.5.1. Low PRF

The term low PRF typically refers to a waveform that is unambiguous in terms of the instrumented range of a radar system, i.e. , the round trip time delay of a target return at the maximum range of the radar is less than or equal to the minimum pulse repetition interval of the waveform as described in equation 2.9. Low PRF waveforms have many advantages for wide area surveillance applications. First and foremost, low PRF returns provide the most accurate range measurement possible. Also, since range rates for most airborne targets are rather slow relative to a coherent processing interval, correlation on a CPI to CPI basis is greatly simplified, increasing the efficiency of non-coherent integration, which is typically the first stage of a data processing subsystem. This, coupled with a simple monopulse bearing estimate, tremendously simplifies the initial data processing requirements for two dimensional plotting of the data, typically the first step in attempting to form tracks.

$$R_{\text{max unamb}} = \frac{(c)(PRI_{\min})}{2} \qquad \textbf{(2.9)}$$

$$PRI_{\min} = \frac{2R_{\text{max unamb}}}{c}$$

$$R_{\text{max unamb}} = \text{Maximum unambiguous range}$$

$$c = \text{speed of light}, 161{,}875\,\frac{nm}{\text{sec}}$$

$$PRI_{\min} = \text{Minimum Pulse Repetition Interval}$$

$$PRI_{\min} = \frac{1}{\text{PRF}_{\max}}$$

$$PRF_{\max} = \text{Maximum Pulse Repetition Frequency}$$

The primary consequence of using a low PRF waveform is that the target's Doppler shift is ambiguous. This presents a problem to the data processing subsystem when it is required to separate low speed clutter contacts, typically induced by ground moving objects such as cars or trucks, from airborne targets. This can be accomplished by utilizing a set of PRFs, each satisfying equation 2.9 and chosen in such a way that high speed airborne targets yield different apparent doppler shifts on a CPI to CPI basis. Groups of contacts which don't exhibit this behavior are marked as low speed contacts and separated from the high speed contacts. The data processing subsystem utilizes the unambiguous range measurement to associate detections from CPI to CPI and a knowledge of the PRFs to "unwrap" the phase shift to determine the actual doppler shift. This technique does have one major drawback. Low PRF waveforms, by their very nature, have very short coherent processing intervals. In terms of the number of pulses integrated, a typical system may have as few as 16 pulses in a CPI. In this instance, the technique described often yields a very poor doppler shift estimate which is further degraded by adding the errors from a different CPI to infer the actual doppler shift. To overcome this problem, it is not unusual for the data processing subsystem to instead rely on a direct calculation of the range rate by measuring the change in range estimates over an interval of time, such as the target revisit rate.

2.1.5.2. High PRF

On the other end of the spectrum from low PRF, a high PRF waveform provides for unambiguous detection of the actual target Doppler frequency at the expense of highly ambiguous range information. The benefits of a high PRF system are what make this type of waveform very attractive. First, it is possible to achieve very high average power with appreciably lower peak power than that typically associated with a low PRF waveform. This is due to the fact that, although high PRF systems typically operate with time bandwidth products equal to that of low PRF systems, the higher duty factors associated with using long expanded pulse widths relative to the pulse repetition interval can yield as much as a ten fold reduction in required peak power for the same average radiated power. Another clear benefit of a high PRF waveform is that with no ambiguous doppler frequencies, there exist no doppler blind zones due to folded main beam clutter. Also, there is a great deal of clutter free spectrum available for target detection.

All of these advantages, however, come at a substantial price when considering the data processing requirements of a high PRF waveform. The highly ambiguous range measurement is by far the most formidable obstacle that the data processor must overcome. One very clever solution to this problem is to use a technique known as the Chinese Remainder Theorem. The theorem is based on the fact that the ambiguous measurement of the range represents the remainder of the actual range divided by the number of range cells in the PRI. The unambiguous range must be one of the ranges generated from equation 2.10. Therefore, the ambiguous range measurement changes in direct relation to the number of times the range is folded by the specific selection of the PRF. If PRF's are judiciously chosen, preferably PRF's where the number of range bins in each share no small prime factors, an algorithm can be deployed to generate the set of potential unambiguous ranges which satisfy the equality of equation 2.11. Typically, PRF's are chosen such that the second range is beyond the detection limit of the system, thus the first range is almost always the correct solution. This technique has the added benefit of helping to overcome the inherent range eclipsing that happens when signals returning form the first pulse arrive at the receiver when the radar is transmitting.

$$R_c(i) = R_a + i(NRB) \qquad \textbf{(2.10)}$$

$i = 0, 1, 2, \ldots.$

$R_c(i)$ = The ith candidate unambiguous range

R_a = The ambiguous range for each pulse repetition interval

NRB = The number of range bins for each pulse repetition interval

$$R_c(i) = R_{a1} + i(NRB_1) = R_c(j) = R_{a2} + j(NRB_2) \qquad \textbf{(2.11)}$$

$R_c(i)$ = The ith candidate unambiguous range

R_{a1} = The ambiguous range for Pulse Repetition Interval (PRI) number 1

NRB_1 = The number of range bins for PRI 1

2.1.5.3. Medium PRF

Medium PRF is probably the worst choice of waveform that can be made for the wide area surveillance job that the AEW radar is required to do. The medium PRF waveform is by definition ambiguous in both range and Doppler. This presents a major problem for the data processor. Without a single unambiguous measurement in either temporal domain, the signal processor must use angle only measurements to associate multiple target detections for the purpose of resolving the ambiguities. For AEW detection volumes, which in some cases can include over 10 million cubic miles, the number of ambiguous reports could easily exceed 100,000. Since multiple different associations are not only possible, but likely, the data processor will easily become saturated with different and potentially conflicting hypotheses that need to be tested. This, coupled with having to run both range and doppler ambiguity resolving algorithms, imply that the medium PRF data processing requirements are best suited for radar applications where the number of possible targets are extremely limited, such as airborne interceptor radars.

2.1.5.4. Tracking Techniques

The foremost purpose of tracking is to provide an improvement of the estimates of target position and velocity over that afforded by a single radar measurement. The basic principle behind tracking is to combine multiple radar measurements to smooth out the inherent measurement noise present in the individual position and velocity measurements and to predict the position and velocity at the next sampling interval. In this way, tracking techniques can be viewed as a combination of two basic types of algorithms operating in a feedback loop. The first algorithm is responsible for deciding which measurements are derived from the same target over some defined period of time. The second algorithm is a form of predictive filtering which attempts to predict where the next target report will be at the next update. This position forms the basis for the tracking gate which will be used to select the next report that will be associated by the first algorithm. In viewing the process this way, there exist two basic processes that are occurring in the tracking system. These are the processes of track initiation and track maintenance.

Track initiation is by far the most demanding of the two processes. Fundamentally, the track initiation process is the optimum assignment problem which has been proven to be NP complete. Therefore, only sub-optimal approaches to this algorithm are practical for a real-time tracking system. A complete coverage of different association algorithms is beyond the scope of this section. For the purpose of illustration, let us consider the simplest approach. Referred to as the nearest neighbor algorithm, this technique simply takes and associates target reports based on the criterion of minimum geometric distance between any pair of reports. The next step in the process is to use these two associated measurements to form a smoothed prediction of the target's future position to facilitate the process of track maintenance.

A common approach to providing smoothed measurements and predicting the future position and velocity of the next target report is to implement an α-β tracker. The α-β equations, 2.12 and 2.13 provide for the smoothing of the velocity measurement. Similar α-β equations can be constructed for positional measurements as well. In this way α and β can be considered as relevance or forgetting factors. For α=0 and β=0, the current measurement is ignored, where as, for α=1 and β=1, the latest estimate is taken to be the current measurement without any smoothing. These then are used to predict the future velocity using equations 2.14 and 2.15. After the prediction is formed, track maintenance is provided by selecting the report using the above mentioned association method. That is, the report closest to the *predicted* position derived from the α-β tracker.

$$\hat{v}_m = \hat{v}_{pm} + \alpha(v_m - \hat{v}_{pm}) \qquad \textbf{(2.12)}$$

$\hat{v}_m$ = Smothed velocity estimate for sample m

$\hat{v}_{pm}$ = Predicted velocity for sample m

v_m = Measured velocity for sample m

α = Apha constant

$$\hat{a}_m = \hat{a}_{pm} + \beta\frac{(v_m - \hat{v}_{pm})}{T_{cpi}} \qquad \textbf{(2.13)}$$

$\hat{v}_{pm}$ = Predicted velocity for sample m

v_m = Measured velocity for sample m

β = Beta constant

$\hat{a}_m$ = Smoothed estimate of acceleration for sample m

$\hat{a}_{pm}$ = Predicted estimate of acceleration for sample m

T_{cpi} = Time between samples

$$\hat{v}_{p(m+1)} = \hat{v}_m + \hat{a}_m T_{cpi} \quad \textbf{(2.14)}$$

$\hat{v}_{p(m+1)}$ = Predicted velocity for sample $m+1$

$\hat{v}_m$ = Smoothed velocity estimate for sample m

$\hat{a}_m$ = Smoothed estimate of acceleration for sample m

T_{cpi} = Time between samples

$$\hat{a}_m = \hat{a}_m + \beta \frac{(v_m - \hat{v}_m)}{T_{cpi}} \quad \textbf{(2.15)}$$

$\hat{v}_{pm}$ = Predicted velocity for sample m

v_m = Measured velocity for sample m

$\hat{a}_m$ = Smoothed estimate of acceleration for sample m

$\hat{a}_{pm}$ = Predicted estimate of acceleration for sample m

T_{cpi} = Time between samples

β = Beta constant

2.1.6. Display Subsystem

The nature of the AEW mission dictates that the AEW radar information be presented to the operator in a format that contributes to good battle-space orientation. For this reason, virtually all AEW systems use the Plan Position Indicator (PPI) type display. This format is also called the P-Scope. The PPI is "an intensity-modulated circular display on which echo signals produced from reflecting objects are shown in a plan position with range and azimuth angle displayed in polar (rho-theta) coordinates, forming a map-like display." [Ref. 26: p. 355]

This format allows the operator to relate radar data directly to the physical world. The rho-theta system is typically displayed with true or magnetic north at the top of the display. This contributes to the map-like utility of the display. Often, geographic and aeronautical features are overlaid on the same display. The map-like qualities of the PPI are often not adequate to convey some alpha-numeric based information, and so the PPI often allows for simultaneous display of overlaid text and numbers and/or a supplemental display is provided. Figure 2.15 shows a typical AEW radar display.

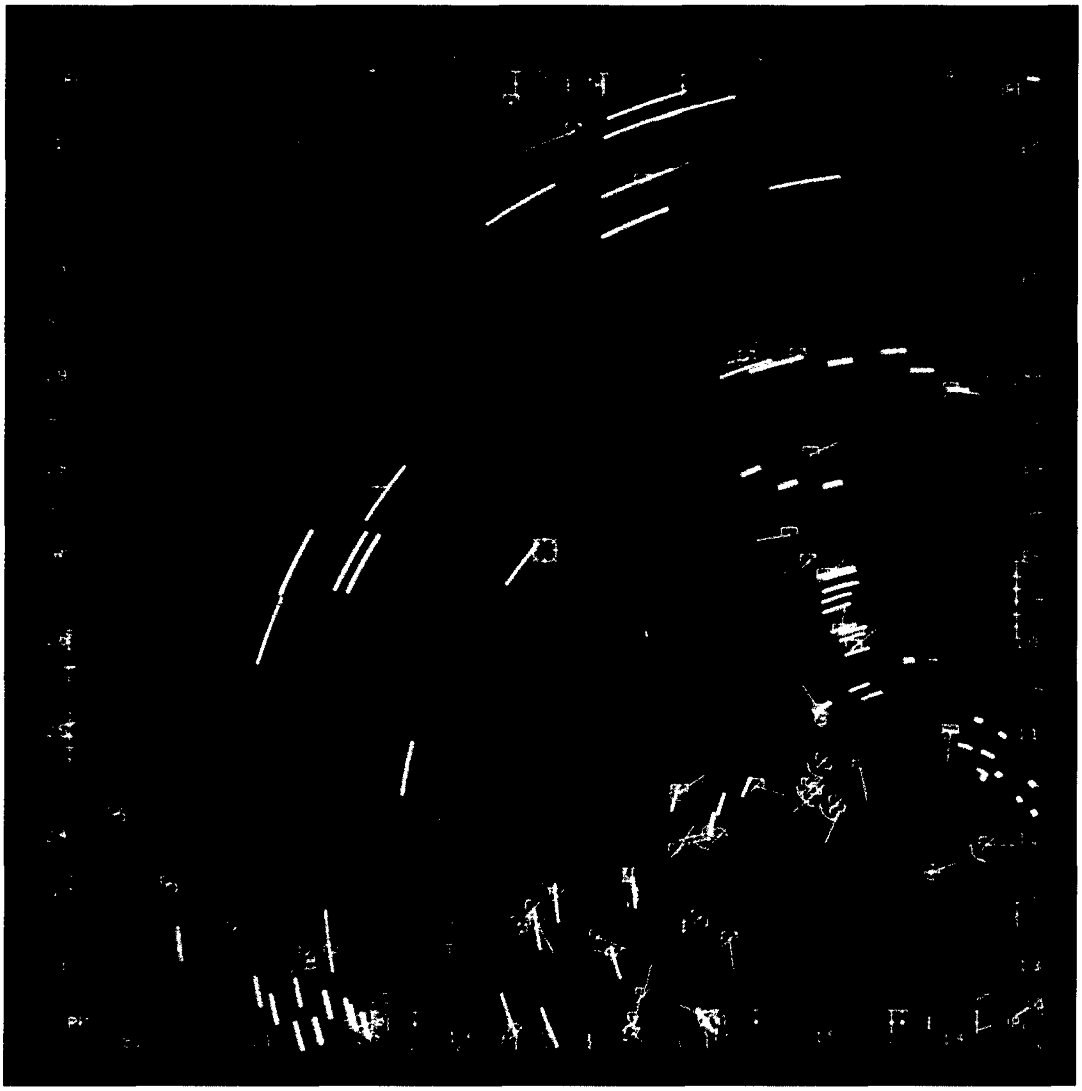


Figure 2.15: *Typical Airborne Early Warning radar display showing radar detection data, radar tracks, map overlays and supplemental alpha-numeric data.*

3.0. INSTRUMENTATION[2]

AEW radar testing can be inherently expensive. Targets must fly very long profiles and must reflect the characteristics of mission relatable targets. This usually implies high performance aircraft and a high cost per flight hour. The cost of flying the AEW radar platform is thus compounded by the expense of flying targets. Given the expense of flying the test scenarios, it is often a prudent decision to invest heavily into instrumentation to allow a maximum of data to be collected during each target run.

Data requirements can be derived based upon two very different philosophies, driven by cost and flexibility. In the first case, the objectives of the test are developed and the instrumentation suite designed specifically to measure these parameters. This has the benefit of lower cost and minimum instrumentation impact but it allows for little flexibility. If unanticipated problems are noted during the development, additional instrumentation may have to be installed after the fact, hindering the test effort. In the second case, maximum data is collected whenever possible, mitigating the possibility that the test program may have to be delayed at a later date to upgrade the instrumentation suite, but requiring more up-front investment. The correct solution is usually somewhere in between and must be determined for each test program based upon the issues listed below:

- ✓cost of the instrumentation components
- ✓cost of the instrumentation installation
- ✓cost of data reduction algorithms and equipment
- ✓technical risk of the program
- ✓time criticality of test completion
- ✓cost of the lost opportunity of the test assets

A typical developmental instrumentation suite is described below. However, it must be noted that digital recording technology is rapidly progressing and the system described below will no doubt be dated at the time of this publishing. Despite this, it may be used as an object lesson for selecting instrumentation parameters and an architecture. The suite described corresponds to the needs for testing of the sample AEW radar system described in the Track-While-Scan, low PRF test techniques section.

The sample instrumentation suite includes four distinct sub-systems. The first sub-system is the global data collection system, collecting certain data points over the entire radar search volume. The data collected is limited for each track or detection and includes information which has been partially processed and filtered so that the smaller amount of data can be collected for the entire search volume within the bandwidth restrictions of the recorder.

The second subsystem records data on a limited portion of the search volume. Data very close to pure measurement data can be collected within the bandwidth of the recorder because the number of detections and tracks are limited.

The third subsystem is a display video and audio recording system for video taping the display as the operator sees it and simultaneously what the operator hears in his or her head set. The fourth and final subsystem is a 35 mm still camera for recording discrete display events.

The global radar data recording system components are categorized in three distinct groups. The first group makes up the Data Recording System (DRS). This system can be

[2] The sample instrumentation system is based upon a suite in use for testing of E-2C radar upgrades at the time of the writing of this document. Further information can be obtained by contacting the authors.

described as a generic data recorder with the flexibility to accept data of many different formats and types. It is designed to be flexible and used on many disparate data collection jobs including both radar and non-radar data. The second group makes up the Data Collection and Conditioning System (DCCS). These components tap into the radar system and route it to the DRS. The sample DRS was designed to accept most data with little or no conditioning, anticipating the data flow within the radar under test. The third group consists of the equipment necessary to transfer the collected data to a data reduction computer and then the algorithms necessary to filter and reduce the data to an interpretable format.

Some parameters require significant measurement and acquisition assets. For instance, it may be necessary to measure and record a parameter that exists only as a varying pressure value. This parameter would require a transducer measurement, possibly an analog to digital conversion, appropriate sampling, conversion to one of the data formats recorded by the DRS and routing to one of the DRS input channels for subsequent multiplexing onto the recording medium. Other parameters require much less complex instrumentation. As an example, the bus used to transfer radar measurements and radar calculations between radar sub-systems may be of a standard, commercial format, allowing direct porting to the DRS. If the radar is built with data taps already installed, the only requirement is to pass wiring between the appropriate connectors. The cost of instrumentation in a developmental system should be considered in the preliminary design of an AEW radar system. This can allow these taps to be included in the over-all radar design.

Figure 3.1 depicts the sample DRS. The DRS is made up of three electronics boxes. They include the Recorder Unit (RU), the Data Unit (DU) and the Remote Control Unit (RCU). The heart of the RU is a Mammoth recorder head with a 20 gbyte uncompressed data capacity, a 3mbyte/sec sustained data transfer rate and a 7 mbyte/sec burst data transfer rate. RU internal data transfer and control is via a VME backplane. The RCU provides instrumentation status displays to the operator as well as instrumentation system controls. The DU provides physical connections and conditioning for up to 60 total data channels. The possible formats include the following commercial standardized formats:

- ✓Pulse Code Modulation (PCM)
- ✓MIL-STD-1553
- ✓Ethernet
- ✓Parallel Digital
- ✓IRIG-B Time
- ✓RS-232/RS-422 Serial

In addition, the following formats are unique to the sample system for which this instrumentation is designed and are options for recording:

✓Built-In-Test (BIT) Serial. This is a format used to pass radar BIT reports to the host aircraft's mission computer.

✓Radar Common Bus. This is a unique format used in the sample system for passing radar reports from the radar pre-processor to the multi-scan processor. The pre-processor performs the calculations necessary to develop scan-by-scan, CPI integrated reports and pass them to the multi-scan processor. The multi-scan processor associates the scan-by-scan detection data, correlates the data, and then uses the data within the tracking filter.

✓Analog Synchro. An analog signal representing the antenna pointing angle with respect to the fuselage reference line. The analog-to-digital conversion necessary for recording the data occurs within the DU.

✓Analog Voice. Specifically designed to accept, digitize and record the analog signal from the aircraft internal

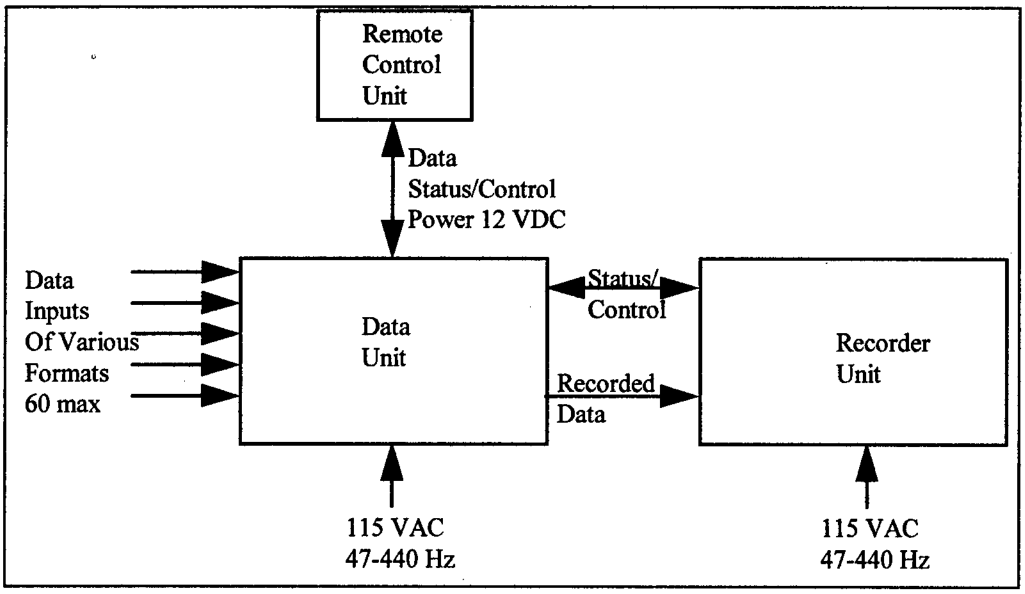


Figure 3.1: *Sample data recording system showing the three main sub-systems and the inputs/outputs.*

communications system.

✓Radar/Interrogator Friend or Foe (IFF) Video. Records the same signal which is sent to the display to provide the AEW radar processed video and corresponding IFF processed videos.

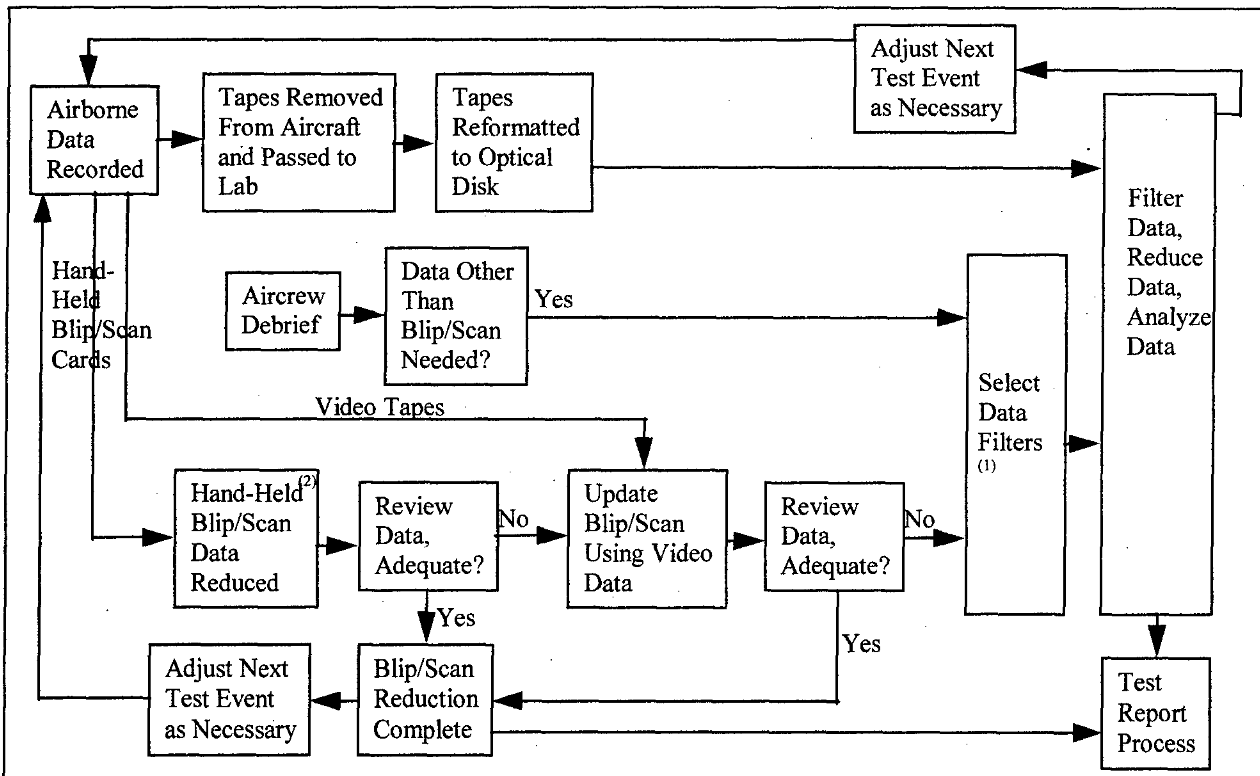
As mentioned above, the DCCS consists of the hardware and software necessary to accept the various radar parameters, convert them into a format compatible with the DRS formats described above, and to route the data stream to the DRS. The radar parameters which exist in a format which the DRS can record directly are listed below:

✓IRIG-B time, which is used to time stamp all recorded data. Data on separate mediums can later be merged and compared using the time stamp.
✓ICS voice.
✓Processed video for both the radar and IFF systems.
✓Test bed pitch, roll, heading and position.
✓Radar target report files.
✓Radar track files at each track update.
✓Radar trigger which marks the beginning of each radar pulse.

In addition, the following parameters require manipulation to allow DRS recording:

✓Radar cooling air pressure and temperature. Pressure transducers and thermocouples provide analog signals which are then passed to specialized analog-to-digital converters and formatted as PCM inputs to the DRS.
✓Waveguide pressure is similarly conditioned and recorded.

The DRS recorder medium is 8 mm exabyte mylar tapes. The tapes are removed from the aircraft after a flight test. Figure 3.2 shows the process by which the data is formatted, filtered and converted to a format appropriate for engineering analysis.



(1) Data filters allow for selected data to be pulled from the full set for further processing. As an example, a spatial filter may be placed over the known (and moving) location of a target to look for likely radar reports corresponding to that target.

(2) Hand-Held data will be discussed in the Track-While-Scan, Low Pulse Repetition Frequency, Maximum Detection Range test procedure section.

Figure 3.2: *Data processing, reduction and analysis process for the Data Processing System (DPS).*

The second type of digital data recording system records measurement data in a geographic area less than the full search volume. The two types of data recorded are In-Phase and Quadrature (I&Q) measurements which are retrieved by directly tapping the digitized antenna sum and difference channel signals and doppler information simultaneously captured by recording the output of each doppler filter. Both sets of data are collected for each range bin and each PRI. This level of data allows validation and development of the algorithms used to determine the presence of and evaluate the accuracy of detection reports. Dynamic radar parameters such as clutter levels and Automatic Gain Control (AGC) are also recorded.

The geographic region being recorded is defined in a bearing and range format, centered on a target of interest, which may be moving over the earth. The radar platform is also translating relative to the target. As a result, the recording system uses a dedicated processing board to continuously update the angular limits relative to the aircraft fuselage and the radar range bin numbers for which the data are collected. The data are placed in a buffer memory unit while the radar sweeps the angular extent of the recorded zone. During the time when the beam is not sweeping the zone, the data are ported to the recorder. Time stamping of the data based upon the common IRIG-B time code generator allows correlation with the other data recording systems. The recording medium is similar to the Exabyte recorder head used in the previously described recorder. The data are reduced similarly to the process described in Figure 3.2.

The sample instrumentation suite also includes a video recording system to directly record one of the operator displays as well as any voice which is passed over the same Internal Communications System (ICS) headset used by the operator at that station. The sample recorder uses no camera but rather records the same inputs provided to drive the display, manipulated slightly to a format compatible to a SVHS format. IRIG-B time is also added to allow correlation with data recorded on other mediums. A commercial SVHS recorder head is then used to record the display and play back is via any commercial SVHS video cassette machine. The ICS signal is manipulated slightly to make it compatible with a SVHS soundtrack and recording is done on the same SVHS recorder concurrent with video recording.

Flight reports often require display pictures to clearly illustrate and document events. The sample instrumentation also has a 35 mm still camera mounted over one of the displays to capture instantaneous events. IRIG-B time is displayed and simultaneously photographed on a special display below the mission display. These still photos are easily converted to a printable, half-tone format. Additionally, some specialized data are more easily recorded via this medium.

As a final note, it is significant that the sample system includes no real-time, telemetered AEW radar data and no corresponding real-time processed data. This is typical due to the huge bandwidths necessary to collect AEW radar data and the real-life bandwidth limits of telemetry systems. Figure 3.3 provides an overall view of the entire sample instrumentation system.

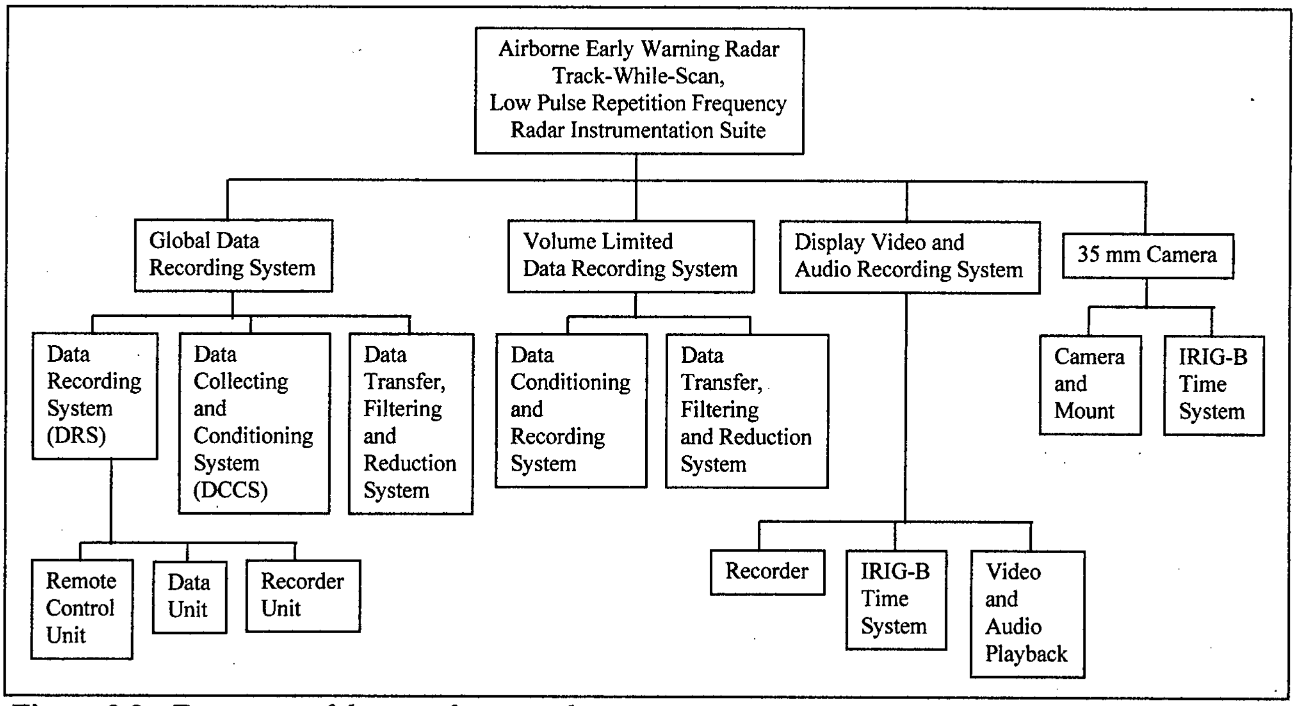


Figure 3.3: *Taxonomy of the complete sample instrumentation system.*

4.0. TRACK-WHILE-SCAN RADAR TEST TECHNIQUES

4.1. TRACK-WHILE-SCAN LOW PULSE REPETITION FREQUENCY RADAR TEST TECHNIQUES

4.1.1. Scan Rate

4.1.1.1. Purpose

The purpose of this test is to measure the scan rate of the Track-While-Scan (TWS) radar and to assess the effects that the rate has upon the utility of the radar to perform the AEW mission.

4.1.1.2. General

TWS radars may have either a mechanically steerable beam or a combined mechanically steerable antenna with limited beam steering. Electronically steerable antennas usually use a complex algorithm to optimize the search of the entire field of regard for new targets while at the same time updating known track positions.[3] These algorithms, and the resultant placement of the radar beam, are best tested indirectly, by analyzing the resultant quality of the radar detection and tracking capabilities. These tests will be described later during a discussion of the Scan-While-Track (SWT) radars. A more direct measurement can be made of the scan rate for many mechanically steerable antennas.

Mechanically steerable antennas can be further sub-categorized into three groups. In the first, the antenna scans at a constant rate, relative to the aircraft fuselage.[4] This simple scheme allows for the use of an uncomplicated antenna drive mechanism; however, it also implies that the ground-stabilized antenna beam scan rate varies as the aircraft turns. In the second, the antenna scans at a constant rate, relative to an inertially fixed reference, such as true north.[5] In the third, the antenna is mechanically rotated in a varying fashion for reasons similar to the electronically steered beam described above. Due to the inertial properties of a large AEW antenna, this technique is realistically limited to slowing the antenna over certain azimuths to allow for increased detection opportunities in known threat directions. It is also possible to simultaneously combine the electronically steerable technique with the mechanically steerable technique. This has the advantage of simplifying antenna construction while allowing a limited amount of dwell as the antenna scans past known azimuths of interest.

The scan rate test can be performed essentially identically for all three cases described in the paragraph above; however, it must be recognized that distinct parameters are measured in all three cases. In the case of the fuselage referenced system, the average rate at which the antenna rotates with respect to the fuselage is measured. This implies that the instantaneous rate at which the beam sweeps across the ground may vary. In the case of the inertially/geographically stabilized system, the rate at which the antenna rotates with respect to north is measured. This implies that the instantaneous rate at which the beam rotates relative to the airframe may vary. For the system where the scan rate is modulated to increase detection opportunities in a defined sector, the rate at which a single point, not in the sector being highlighted, is revisited is measured. Here the instantaneous scan rate may vary over the entire volume.

For purposes of illustration, the sample system, used for developing the test technique described below, has an antenna which rotates at a constant rate relative to true north. The antenna rotation rate is controlled digitally via the internal radar data bus. Aircraft true heading and ground track is accepted from the aircraft navigation data bus.

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[3] The ERIEYE system is of this type.

[4] The E-2B system uses this scheme.

[5] The E-2C Group II system uses a similar antenna scanning scheme.

An analog signal representing the antenna angle with respect to the fuselage reference line is accepted from the rotodome, converted to a digital format and placed on the radar bus. The signals are then compared and a feedback signal provided to the rotodome hydraulic control valve to provide the correct hydraulic drive pressure to drive the dome at the required rate irrespective of the aircraft turn rate. The sample system also has a mechanical back-up mode. During this mode of operation, the antenna drive hydraulic controller is set to a pre-determined pressure, which in turn, drives the antenna to rotate at a constant rate with respect to the aircraft fuselage.

4.1.1.3. Instrumentation

The instrumentation requirements include a digital recorder, tied to the display bus, a stop watch and data cards. A digital recorder tied to the radar and the navigation bus is optional.

4.1.1.4. Data Required

The time for the antenna to make ten scans is recorded. Optionally, IRIG-B time, the true heading and aircraft ground track is recorded from the aircraft navigation bus and the antenna angle with respect to the fuselage reference line and antenna controller feedback signal are recorded from the radar bus.

4.1.1.5. Procedure

Record the hand-held and the digital data during the entire range of mission altitudes and airspeeds for which the radar is designed to be used. For the sample system, the designed mission altitudes varies between 15,000 and 35,000 feet Mean Sea Level (MSL). The sample aircraft flies its mission profile via a constant angle of attack and so the airspeed varies as the mission progresses and fuel is burned. The altitude and airspeed interval (in this case time interval = weight interval) depends upon the system under test. For the sample system, 5,000 feet and 30 minutes are used. The test is repeated during straight and level flight and during mission turns. Finally, the test is performed with the antenna controlled via the degraded mode.

4.1.1.6. Data Analysis and Presentation

The time necessary for the antenna to make ten scans is divided into 3600 to obtain the scan rate in °/sec. For the geographically referenced mode, the value should be the same whether in a turn or flying straight-and-level. The display should also be examined for inconsistencies in the scan rate. If none are noted, it may be possible to avoid further data reduction. In cases where the rate varies in a fashion not expected, the optional data is analyzed to isolate the cause. The data reduction required will depend upon the symptoms noted.

As an example, this test was actually performed on a real AEW radar. The test indicated that the antenna slowed at a certain point with respect to the aircraft fuselage. The navigation system was previously tested and the output was not suspect. The antenna pointing angle measurement was also verified via a ground test. The recorded inputs were passed through a model of the antenna rate control logic and the correct antenna control signals were generated by the feedback logic. This implied that either the control algorithm was faulty or there was a mechanical problem with the dome rotation system. Further examination showed that the dome had a mechanical problem which increased friction at the same point that the dome slowed.

When the degraded mode of operation is selected, the data is examined the same way when the aircraft is flying straight and level. When in a turn, the antenna rotation rate must be corrected for the turn rate of the aircraft. As an example, for a left, 2° per second turn rate and an antenna that rotates counter-clockwise, the turn rate must be subtracted from the data to obtain the fuselage referenced rotation rate of the antenna.

4.1.1.7. Data Cards

Sample data cards are provided as data card 4.1.

Scan Rate Data Card

[While in the geographically stabilized mode and at mission profile at the listed altitudes, and at the listed time intervals after takeoff, record the amount of time necessary for the antenna beam to make 10 scans. Repeat while performing standard rate (2°/sec) flat turns. Repeat again for the fuselage referenced mode.]

TIME	ALTITUDE	Geo Stab Mode-Straight Heading	Geo Stab Mode-Mission Turn	Fuselage Ref Mode-Straight Heading	Fuselage Ref Mode-Mission Turn
Climbout	15 K				
	20 K				
	25 K				
	30 K				
	35 K				
+ 30 min	15 K				
	20 K				
	25 K				
	30 K				
	35 K				
+60	15 K				
	20 K				
	25 K				
	30 K				
	35 K				
+90	15 K				
	20 K				
	25 K				
	30 K				
	35 K				
+120	15 K				
	20 K				
	25 K				
	30 K				
	35 K				
Descent	15 K				
	20 K				
	25 K				
	30K				
	35 K				

Data Card 4.1: *Track-While-Scan Low Pulse Repetition Frequency Scan Rate*

4.1.2. Maximum Detection Range

4.1.2.1. Purpose

The purpose of this test is to measure the maximum detection range of the Track While Scan (TWS), Low PRF AEW radar.

4.1.2.2. General

The maximum detection range is one of the most quoted operating parameters of an early warning radar. This is because the primary purpose of the system is to maximize the reaction time to a threat. Unfortunately, it is also one of the most misquoted parameters, since it may be defined in many ways. The exact definition must often be tailored for the system and mission scenario under discussion. As an example, AEW radars must detect targets in an environment that includes ground clutter out to the limit of that clutter (radar horizon). The maximum range at which the clutter exists is also known as the clutter line. Some very long range AEW radars also detect elevated targets beyond the radar horizon, in a region that is effectively free of ground clutter. Depending upon the magnitude and treatment of the clutter, the probability of detecting a target can be greater in the clear region than for some band of ranges in the clutter. It is thus possible for a scenario to exist where an inbound target can have some initial detections at large ranges and then to be invisible for a long period as the target closes. Depending upon the relative amount of time the target is in this clear region, where detection is likely and the time the target is masked by the clutter, defining the maximum detection range at that range which the target first becomes visible in the clear may have no tactical significance and may not be an appropriate metric of the radar's utility. As a method of illustration, one set of industry standard definitions are presented in this document. Care should be taken to understand the limitations of these definitions and to tailor them as necessary for the system under test.

The most fundamental definition used to measure the maximum range performance of the sample system is the Blip/Scan Ratio (BSR). As the sample radar scans the search volume, it sends out radar pulses at the PRF. Each pulse is an opportunity for the radar to send out and then receive RF energy on a single target. Since the beam has finite width, there are a known number of detection opportunities defined by the beam angular width, scan rate and the PRF[6]. Detection must imply that not only does the radar receive energy reflected from the target, but the received signal must be recognizable as a target. In very old radars, the individual pulse to pulse hits on a target appeared as very small spots on a phosphor based display. A spurious hit or false alarm looked like one very small dot on the display. The phosphor allowed the dot to have some amount of longevity. On a real target, within the usable detection envelope, the display would show one of these small dots for each PRI. The combination of the dots became an arc of radar video, recognizable as a real target. The operator was essentially visually integrating the individual returns into a confirmed target detection. Most modern systems still provide similar displays; however, the phosphor display is usually replaced with a Cathode Ray Tube or flat panel and the effects of the phosphor is replaced with an algorithm which visually mimics the decay of the brightness of the hits with time. As this tutorial implies, detection requires an integrated series of hits over a single scan.

Most modern systems provide a more mathematically rigorous version of the visual integration described in the previous paragraph and the system itself determines whether a series of hits reflect a true target. In the case of the

[6] The beamwidth is typically defined at the point where the in-beam power drops by 3 db. This implies that the number of hit opportunities on a target varies also with range since at closer ranges, detections will occur outside the "edges" of the beam and at longer ranges detections will only occur at the center of the beam where the power on the target is highest.

sample system, the operator may still view the real radar returns, albeit on a flat panel, digitally controlled display. For the sample system, this type of video is called real video. The system also integrates the pulse-to-pulse returns in real time and determines the locations of the valid targets. The presence of a target is displayed as a slash of video, similar in shape to what the operator would see if viewing the real video. This second type of video is; however, sufficiently distinct in appearance from the real video so that the operator may select both simultaneously. Each slash of this second type of video also represents a report sent to the mission computer where it is used over multiple scans to establish and update tracks. For the sample system, this type of video is called synthetic video.

A blip is a positive, integrated detection embodied as either a recognizable slash of real or synthetic video. A scan implies the passage of the beam as it scans the search volume and thus represents the possibility of a target detection. Blip/Scan is thus the quotient of the number of integrated detections divided by the number of detection opportunities. For the sample system, either type of video may be observed and recorded as Blip/Scan data. The Blip/Scan value must be associated with a range to be of value and so it is typical to define bins of radial ranges, where this ratio is calculated. Typically, the range where the Blip/Scan ratio reaches a value of 0.5 is of interest. This is a somewhat arbitrary value but has become an industry standard. This value is also known as the Probability of Detection of 0.5 range, P_d=0.5 or P_d(.5). The simplest way to perform the calculation is to divide the search volume into discrete range bins of equal length. The bin is identified by the average of its start and end range. As an example, a radar with a 500nm range could use a bin width of 10nm with a total of 50 bins. If a target remains within the range limits of the 400nm to 410nm bin for enough time to allow the radar beam to sweep its position 20 times and a recognizable piece of video is presented 10 total times, the Blip/Scan ratio for this bin is 0.5 and the P_d(.5)=405nm.

Care must be taken to select a bin which is wide enough so that enough detection opportunities are provided to make the definition statistically significant. A typical guideline is to ensure the bin is wide enough to allow for at least a dozen detection opportunities. This requirement can be at odds with the desire to come up with a P_d(.5) value with more granularity than the width of the bins. This can be provided by using a sliding window for the calculations which is shifted at any desired range interval. The same calculation is performed within the translated window of ranges and stopped when the P_d(.5) point is reached. This technique is much more computationally intensive and is often not essential. For the sample system, the fixed bin method will be used. Blip/Scan Ratio (BSR) then is the number of detections divided the number of detection opportunities within each of the fixed bins. An independent calculation is used for the two types of video described above.

The physical interpretation of the BSR and particularly the P_d(.5) range is dependent upon the envisioned use of the system. In a typical scenario, the AEW radar is used to provide warning of a target inbound to a high value unit. A threat axis is approximately known and the AEW unit is placed along the threat axis. The target thus approaches the AEW radar radially and the P_d(.5) point is the range at which the operator has a 50% chance of seeing a slash of video representing the target. In the case of the synthetic video, it is also the point where the system has a 50% probability of declaring the presence of a valid target.

As mentioned above, it is quite possible for the BSR to be higher for longer ranges than some intermediate range. This can be visualized qraphically quite readily by plotting the BSR for each bin as a bar graph with range along the abscissa and BSR along the ordinate. Figure 4.1 is a sample BSR plot. Several statistics are often calculated to provide a numerical interpretation of the consistency of the BSR throughout the search volume. One example is the percentage of bins for which the BSR is greater than 0.5 for all bins less than the range where the $P_d(.5)$ criterion is first met.

The data from several flights can be combined on a single plot. The data runs are first categorized in groups appropriate for combination. Usually this implies that the same type of target is used (similar radar cross section), the same geometry (for example maneuvering or straight-line inbound to the test aircraft), the same category of clutter environment is present (usually over-water, over-land or near-land), and the same EMI environment (casual or intentional jamming). The detection opportunities are summed directly within each range bin for all the flights, the hits are summed directly within the same range bins and the quotient plotted as the Composite Blip/Scan Ratio (CBSR). This plot provides a more statistically significant visualization of the performance of the system as a function of target range. The Composite $P_d(.5)$, or $P_{dc}(.5)$, also increases in statistical significance as subsequent data is collected. A further measure of statistical rigor can be gained by calculating the variance of the $P_{dc}(.5)$ and the BSR in each range bin as data runs are added and the collection of data can be discontinued when the variance is less than a desired value. A failure to converge may indicate a problem in data collection, or a short-coming in the radar, such as an inability to detect consistently at the range bins corresponding to the clutter line. Figure 4.2 is a sample CBSR plot.

VIDEO TYPE: Synthetic

		TEST A/C		TARGET A/C	
DATE:	1 Jan 97	MODEL:	E-9C	MODEL:	LEAR 36
FLIGHT:	486	BUNO:	179000	BUNO:	150000
RUN:	#1	ALTITUDE:	24,000 ft MSL	ALTITUDE:	28,000 ft MSL
TERRAIN:	Near-land	GND SPEED:	205 KTS	GND SPEED:	320 KTS
PROFILE:	44				

RANGE BINS	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250
BLIPS	6	13	17	16	18	26	24	16	7	6	10	24	29	12	11	13	4	6	13	13	9	5	3
SCANS	8	16	20	16	20	28	29	20	20	20	26	40	40	20	20	21	21	21	21	22	24	23	30
B/S RATIO	.75	.81	.85	1	.90	.92	.82	.80	.35	.30	.69	.60	.72	.60	.55	.61	.19	.28	.61	.59	.37	.21	.10

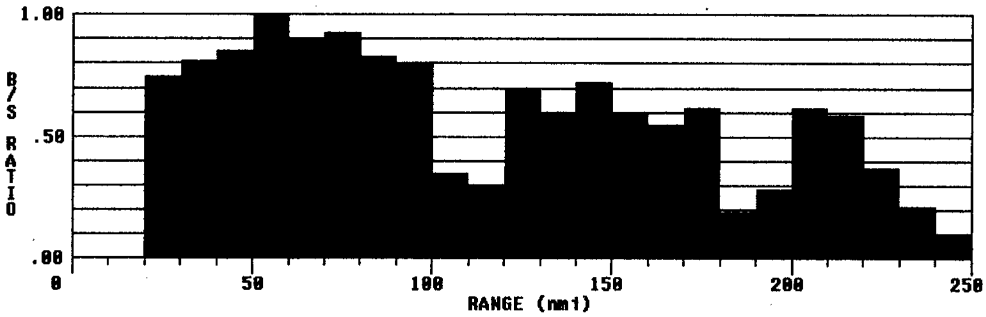

Figure 4.1: *Sample Blip-Scan (B/S) ratio plot for target flying a radial inbound track in near-land environment with the land-sea interface at 110 nm and the clutter line at 190 nm.*

VIDEO TYPE: Synthetic

		TEST A/C		TARGET A/C	
DATE:	1 Jan 97	MODEL:	E-9C	MODEL:	LEAR 36
FLIGHTS:	486, 487	BUNO:	179000	BUNO:	150000
RUNS:	#1, #3	ALTITUDE:	24,000 ft MSL	ALTITUDE:	28,000 ft MSL
TERRAIN:	Near-land	GND SPEED:	205 KTS	GND SPEED:	320 KTS
PROFILE:	44				

RANGE BINS	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250
BLIPS	11	25	35	31	35	50	45	32	13	11	37	49	57	23	21	24	12	11	24	23	18	11	7
SCANS	16	32	40	32	40	56	58	40	40	40	52	80	80	40	40	42	42	42	42	44	48	46	60
B/S RATIO	.60	.70	.87	.96	.87	.89	.77	.80	.32	.27	.71	.61	.71	.57	.52	.57	.28	.26	.57	.52	.37	.23	.11

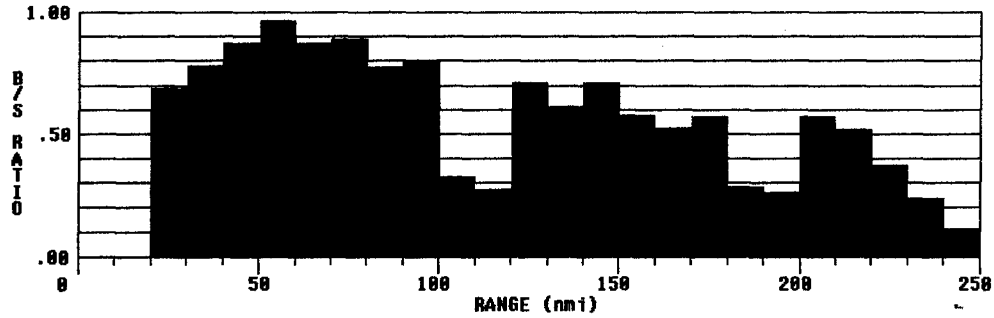

Figure 4.2: *Sample composite Blip-Scan (B/S) ratio plot for two target runs where the targets are flying a radial inbound track in a near-land environment with the land-sea interface at 110 nm and the clutter line at 190 nm.*

Truth data can be very hard to derive for very long-range AEW systems. The ranges between the radar and the target can be on the order of several hundred miles and it is often impractical to develop space positioning ranges with sufficient volume to perform all required tests for all the required environments. On-board truth data is often the answer. In many AEW systems, the aircraft also carries an Interrogator-Friend-or-Foe (IFF) for use as an aide in identifying cooperating targets. Commercial versions are used on almost all aircraft that fly commercial airways. Because it is a cooperative system, the accuracy is often better than the AEW radar. In this case, the IFF system is first tested to verify its accuracy. If the combined IFF and radar data is used in a tracking solution, it is also necessary to develop a test function which precludes a selected track from being updated with the IFF data. The IFF track position updates then become the truth data for the radar tests. This method has the added benefit of providing real-time feedback of the target location and so it is less likely that the tester will waste valuable test time by collecting data for the wrong target.

In some cases, IFF is not available or greater accuracy is needed. Recently, the advent of the Differential Global Positioning System (DGPS) has provided a solution. Highly accurate DGPS position updates and time of measurement are simultaneously recorded on board both the AEW radar test aircraft and the target and later correlated based upon the time. The drawback of this method is that the operator is not given real-time feedback as to the actual position of the target.

In some cases, long-range tracking sites exist with sufficient dimensions to perform at least some testing. Typically, beacons are installed on the test aircraft and targets and each are simultaneously tracked by the ground site. The data is usually recorded for post-flight merging with time-stamped radar data and also displayed in real-time at the ground site. The ground site operator can then provide feedback to the airborne tester as to the target's actual location, providing some of the advantage of the IFF based truth data.

Clutter and Electro-Magnetic Interference (EMI)[7] can greatly affect the detection range test. Because they are of so much importance to the radar's effective range and to the utility of the radar, most modern AEW systems provide the operator with a measure of both for real-time use during the mission. In the case of the sample system, a measurement is made of the total signal entering the receiver for a certain time slot following the transmission of each pulse. The timing is chosen such that the sample does not include any of the radar signal returned from clutter sources. EMI sources within the clutter region are still measured since they are not synchronized to the radar PRF and appear at all radar ranges. The measurement is referenced to the level of the system internal noise which is measured during the transmission of the radar signal, when the receiver is isolated from the antenna. Since the return signal caused by long-range air targets is so small, the effect is a real-time measurement of the amount of EMI entering the radar receiver. In the sample system, the EMI measurement is displayed real-time by tracing a plot, concentrically around the center of the PPI display. The range of the plot from the center of the display in nm displays a corresponding number of db above the reference signal. Figure 4.3 shows the appearance of this display.

It is the nature of casual EMI that it is very hard to control or to artificially produce. The sources are often very numerous and distributed, low-power emitters. Occasionally, some high-power emitters are also in the background; however, they tend to be less numerous and their effects are similar to intentional jamming, which will not be discussed in this document. Even though casual, background EMI is not under the control of the tester, it may be somewhat predictable. For example, if a low EMI level is desired, it may be possible to perform the test in a remote location or a location where the direct line-of-sight to cultural features like cities are masked by the horizon, mountains, etc. Casual EMI often reduces during weekends or at late night to early morning hours, even in the vicinity of cultural features. If possible, the level of the EMI in mission relatable scenarios should be determined before testing is begun. The scenario locations and time of test should then be chosen to provide maximum detection range data at levels well below this value (to isolate the variable) and again at values at least slightly above the expected operational need, to determine whether the radar can meet the specification in the presence of a realistic environment. If time and money allows, it may be of value to test in the most stringent scenario available to the tester, to provide data in both extremes. If the radar meets the specified requirement at the lowest EMI level, but not in a mission relatable environment, the radar may require redesign to increase its performance in the presence of EMI.

The sample system does not have a measurement of the clutter level. The effects of clutter must thus be inferred by placing the radar in mission relatable clutter environments and measuring the effects in each. Usually, the required radar range is defined in terms of specific clutter environments. A typical set of scenarios would include one where the entire search volume is over water (over-water scenario), one where the entire volume is over land (over-land scenario), and a third where the target crosses the shore

[7] In this case, EMI is defined to include all the cultural and natural interference sources which exist in the test area that are not specifically generated to affect the AEW radar under test.

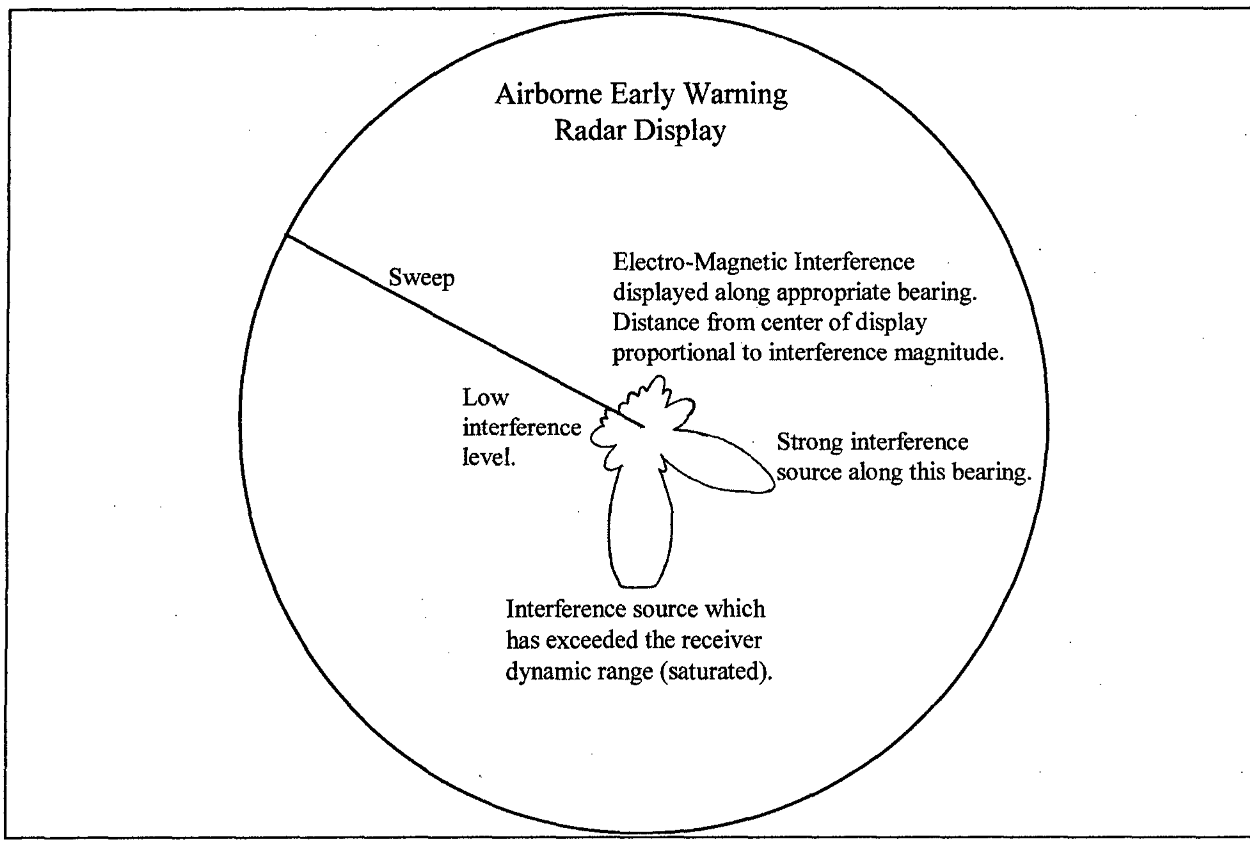

Figure 4.3: *Radar display depicting a method for graphically displaying the levels of electro-magnetic interference for the entire search volume.*

inbound to the test aircraft (near-land scenario). Whether the test aircraft is over land or water during the near-land scenario must be based upon the expected operational usage. Since the clutter scenario will change as the profile is moved from one location to another, it is important to maintain the same profiles as the radar's development progresses to allow for a direct comparison of the data from one test run to the next.

As explained in the theory section, low PRF, long-range radars are inherently ambiguous in doppler. The effect is that targets can fly at correspondingly ambiguous speeds and the radar will detect the same doppler shift. As an example, the PRF of a radar may be such that radial ground-speeds of 200 kts, 400 kts, 600 kts, etc. all have the same apparent doppler shift.

Another limitation is that a filter must be placed to eliminate clutter in the region of the low doppler shift. Since doppler is ambiguous, the filtered area is also ambiguous and the effect is that targets are not visible when flying at multiples of radial velocity, corresponding to the placement of the low doppler shift filter. Extending the example above, if a filter is selected corresponding to the doppler shift equivalent to 10 kts, the radar will not detect targets flying with a closing or opening radial velocity of 0 to 5 kts, 195 to 205 kts, 395 to 405 kts, 595 to 605 kts, etc. Most modern systems mitigate this effect by staggering the PRF at each interpulse period or over each scan. In the sample system, the PRF is staggered each scan using three different PRFs. The changing of the PRF is manifested as a change in the maximum sweep length on the display. This may also limit the maximum range of the radar for targets of a sufficient cross section for the sweeps where the higher PRF is used. Thus, for a target of sufficient radar cross section where it is detectable by the radar at the maximum sweep length of the lowest PRF, the BSR will be no better than 0.33 while at ranges beyond the sweep of the middle PRF, and no better than 0.66 at ranges beyond the sweep of the highest PRF. Similarly, if a target is flown at any of the three blind radial ground speeds, it will have no better than a BSR of 0.66.

4.1.2.3. Instrumentation

Hand-held Blip/Scan cards are required. Video recording of the radar display and digital recording of the radar target reports in the vicinity of the target is desired. Real time recording of the electromagnetic environment encountered during the test is desired. In the case of the sample system, the operator's display of the EMI environment has been sufficiently verified during ground test to allow the mission display to be used as the EMI data source and recording is done via video recording of the display.

4.1.2.4. Data Required

Several redundant forms of data are recorded for the sample system. Manual blip-scan is recorded for both real and synthetic video for each target. As mentioned previously, the sample system automatically determines if a valid radar return has been received and uses this to establish a track. The target reports are displayed as synthetic video. Even in modern systems, the real video is often still used. The real video may be present when synthetic video is absent if the system misses a detection or is not functioning. Additionally, the real and synthetic videos are often used for low-scan-rate systems when the target is maneuvering since the track course and speed will necessarily lag the updates manifested by the videos. Finally, observation of the real and synthetic videos allows several efficient checks of radar performance to be performed. The ability of the system to declare targets in the presence of actual radar detection video can be inferred by comparing the synthetic and real video presence and the accuracy of the synthetic video reports can be inferred by comparing the location of the two videos. It should be noted that the automatic system may be more sensitive in a modern radar system than the real video allows. This may mean that synthetic video may be present without real video. This must be recognized in the data reduction.

EMI is recorded via the mission display. Video is also recorded from the mission display as each Blip/Scan call is made. Voice is recorded for all Blip/Scan calls as well as any radio calls used to control the targets. Target reports from the radar pre-processor, which declares a target report and initiates the synthetic video, is digitally recorded. For the sample system, recording is provided by sending data extraction from the mission computer to a special signal conditioner and recorder head. The radar configuration must be fully documented.

4.1.2.5. Procedure

A separate verification of the sample IFF system accuracy and the validity of the EMI measurements is made prior to beginning the AEW radar testing. This test will not be documented here but usually requires use of precise onboard instrumentation or an instrumented range to validate IFF accuracy. This test is usually easier to coordinate than the radar tests because the geometry and environmental requirements are typically much easier to satisfy. The EMI measurement system validation is usually performed in an anechoic chamber with calibrated signals.

Scenario planning is paramount in a successful AEW data collection. Most AEW scenarios require extremely long-range target runs in a straight, uninterrupted line. Very few areas of reserved airspace exist of sufficient size to allow this testing and so it is necessary to share the airspace with other users including commercial aircraft. Another complicating factor is that the scenarios almost certainly must cross the airspace of more than one controlling agency. For example, a long-range scenario designed to test detection in a near-land scenario just south of Norfolk, Virginia (a frequently used profile) requires that the targets transit through airspace controlled by two different Federal Aviation Administration (FAA) centers with at least two controllers and cross into a Warning Area controlled by the military, all while the test aircraft follows Oceanic Rules while flying 70 nm off the coast. In addition, all the aircraft must coordinate all the normal take-off and transit times to allow all the players to be on station at the necessary instant to start the test. The necessity to perform the tests over various geographic and cultural features to exercise a range of clutter environments and to test in various casual EMI densities makes conflict a certainty.

The only method for minimizing airspace conflicts is to exhaustively coordinate the flights well before the events. A coordination conference can help to disclose any problems while in the planning stage. Once a scenario is devised and proves to work, it should be distributed formally, allowing it to be re-used with less effort. The re-use of the scenarios is often consistent with the necessity for statistically significant data collection and allows the development of a historical perspective and a performance baseline to compare system improvements. Given the cost of multiple target AEW tests, it is often cost-effective to place liaison personnel at the airspace controller organizations during the first flights of new or difficult profiles. Figures 4.4, 4.5, and 4.6 are sample scenarios which have seen frequent use.

At the start of each target run, the targets are vectored to a start point beyond the theoretical maximum range of the system. In the absence of previous testing data or confident estimates of this range, the maximum range at which the target may be displayed may be used. In the case of the sample system, the IFF system track is used to provide control of the targets and no outside assets are required to place the targets at an appropriate start point. In cases where this is not possible, significant coordination is required for the targets, or an outside controlling unit is used. A single operator is assigned to control the targets and to be the sole person to communicate with them via the control frequency. This is done to ensure that the test does not distract the operator from the duties necessary to provide safe target control and monitoring. This usually includes using the system as much as possible to provide traffic information. Most AEW radar target tracks require the use of so much airspace that it is not feasible to perform the test in Restricted Areas and traffic avoidance is critical. As a second precaution, the targets are assigned discrete altitudes (usually 1000 feet separation is enough) to minimize the risk of mid-air collision.

The targets are placed in a line-of-bearing inbound to the test aircraft and flown directly to the test aircraft. The distance between the aircraft must be sufficient to ensure that they are distinct as targets but not so far apart as to complicate the data collection for the operators. Five to ten nautical miles between targets is usually sufficient. If the targets are too far apart, the operator will not be able to observe the radar video on all the targets simultaneously, requiring multiple Blip/Scan observers. The targets are turned outbound prior to reaching the test aircraft. The minimum range may coincide with the minimum usable displayable range or some other mission significant range. Most AEW systems are tactically positioned to avoid coming within missile range of enemy aircraft and so 20 to 40 nm is usually a suitable turn range.

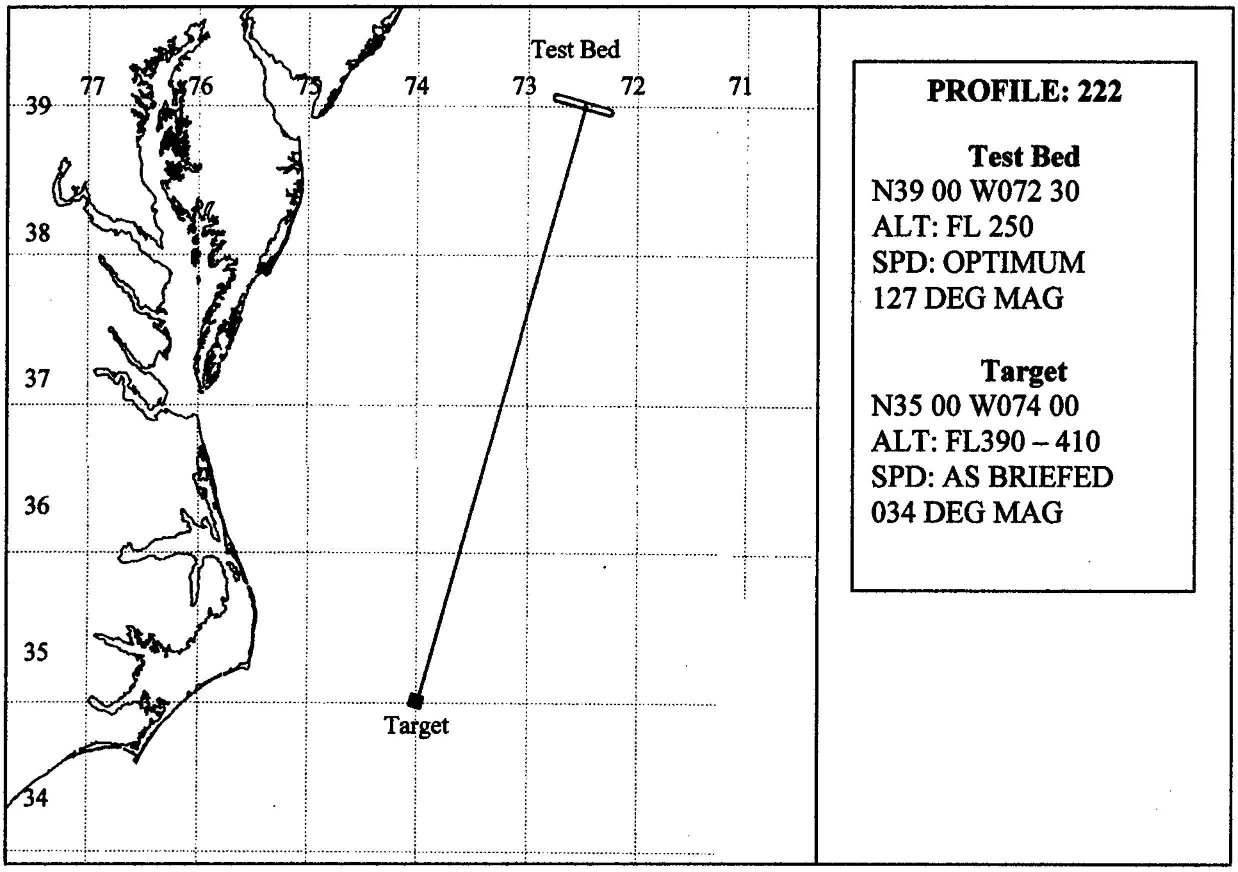

Figure 4.4: Over-water maximum detection range test scenario.

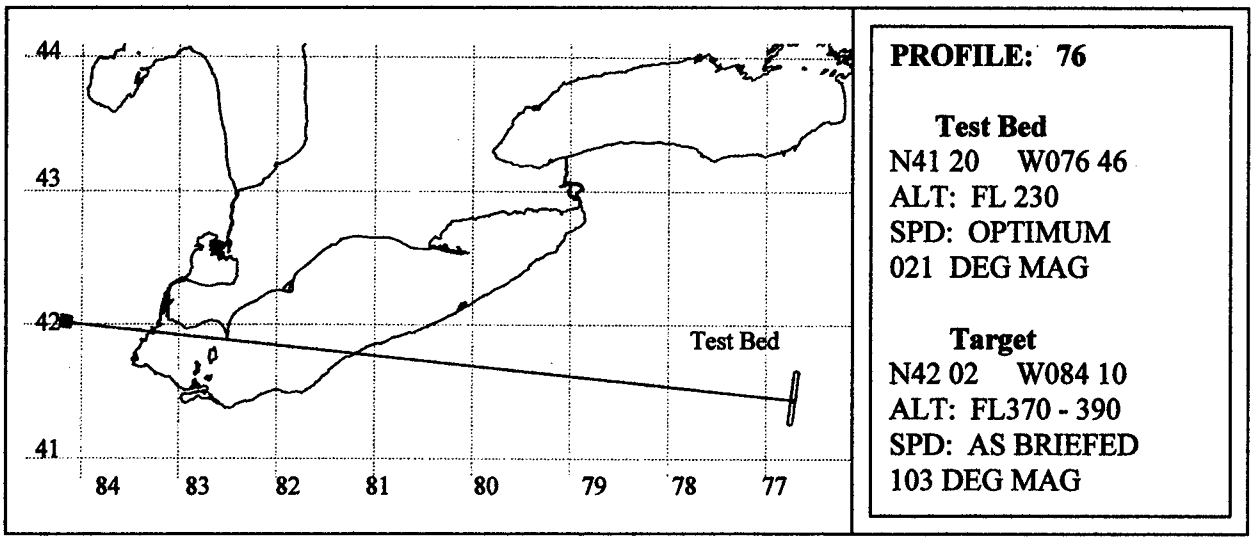

Figure 4.5: Over-land maximum detection range test scenario.

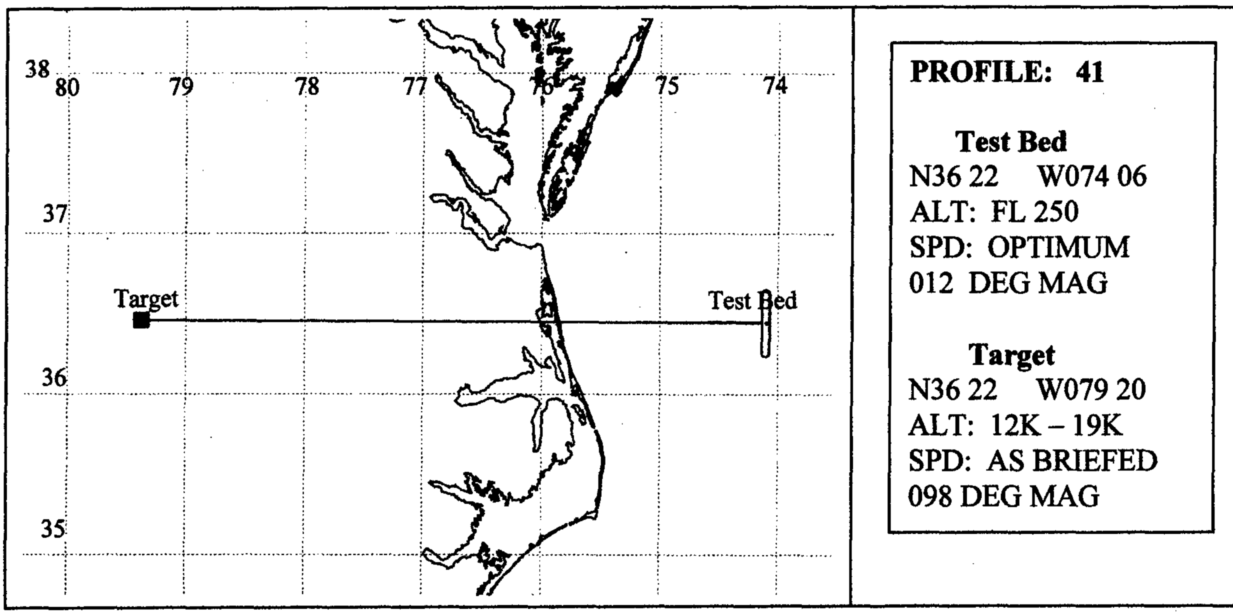

Figure 4.6: *Near-land maximum detection range test scenario.*

In any case, the targets should be turned such that they do not come any closer than 10 nm from the test aircraft to avoid any possibility of mid-air collision. Altitude separation is not essential if this minimum range is applied.

Prior to beginning each data run, the instrumentation must be turned on, recording all target reports and selected data extraction points. Usually, many data points of many types may be extracted. The number of data types extracted can affect system loading since mission computer time is required to filter the data and must be limited in number. Finally, the recorder itself is turned on and any confidence tests performed. For the case of the sample system, the data recorder provides a confidence light which illuminates when valid data is being recorded and verified via periodic built-in-tests. The sample system also has a video recorder which collects display video as it is sent to the display head, thus no camera is required. The recorder also collects any internal or radio communications heard at the test crewstation. This recorder is turned on prior to the target turning inbound for the data collection run.

Prior to the first run, the clutter environment and the EMI environment must be documented. As outlined above, the sample system displays the measured EMI environment as an irregular line enclosing the origin of the sweep, with the range to each point on the line indicting the magnitude of the EMI at that bearing. This ring is recorded on the video recorder. If the system under test uses various techniques to cancel the effects of EMI, the check should be repeated with these features selected in all possible combinations and the appropriate mission-relatable mode selected. If a significant EMI source is located along the test bearing, it may be necessary to move the profile by translating it so that the bearing is off the location of the source or rotate the bearing to gain the same affect. The testing of the system in the presence of large casual EMI can be inferred by the system performance of the system during jamming. These test techniques will not be discussed in this document.

As described earlier, the sample system does not have the capability to display a measurement of the clutter levels as it varies over the surface of the search volume. The thorough testing of clutter is inferred by performing the test over the various types of terrain and cultural features over which the system will be used. This allows repeatability from test to test by using the same profile except for the case of over-water testing since the clutter level will vary with the instantaneous sea state. The sea clutter level can be partially documented by selecting the real video and recording the range out to which the clutter is displayed as a circle of video at the target bearing and also recording the sea state as provided by the local meteorological office. The technique for determining where the clutter end range is measured depends upon the system under test and should be documented prior to the first flight and reused for each following test.

Manual Blip/Scan recording is usually performed using at least two persons. The first person monitors the display and declares whether video is present as the sweep passes the target's position. In the sample system, the actual target location is known because a test function allows the system to establish an IFF track at the target location without corrupting the radar reports. In essence, the system treats the reports as if IFF were not installed on the target aircraft and the system was tracking a radar-only non-cooperative track. The person monitoring the video declares a "miss" or a "hit" for each type of video, for each target. In a system with a scan rate of around six scans per minute, experience has shown that a maximum of three targets, and two videos per target, can be monitored by a proficient tester. As the hits and misses are called, the second person records a "1" or a "0" for each target for each scan. In the sample system, the sweep passes the target each 10 seconds and so elapsed time can be inferred by counting the number of scans. At the start of each run, and periodically during the run, the actual instrumentation time is also recorded as a note associated with the line of Blip/Scan. Target bearing and range are also recorded periodically. The non-Blip/Scan data can be recorded independently for the various targets to facilitate recording in the time between the scans. The order in which the data is called for each target, the order in which the targets are called and a numbered assignment for each target (usually leading to trailing in range is used) is agreed upon during the preflight brief. As an example, three scans of data for three targets may sound as follows: "Hit Hit, Hit Hit, Hit Miss, target one 275 for 125. Hit, Hit, Hit Miss, Hit Hit, target two 276 for 131, time 122608. Hit Hit, Hit Hit, Hit Hit, target three 275 for 138." In this case, two misses were taken in synthetic video, the target positions were recorded in magnetic degrees and the range in nautical miles and the time was recorded in hours-minutes-seconds. The recorder placed a 1 or a 0 in each box associated with each target on the line for that scan of data and used the note section on the data card to record the other data. Short-hand may be used but must be standardized and briefed before the flight. Figure 4.7 describes one style of Blip/Scan short-hand.

Following each data run, the targets are turned outbound to the initial point, and the data recorder, data extraction system, and video recorder are turned off. The test is repeated as flight time allows.

Data must be collected for each type of clutter environment. This usually includes the over-water, over-land and near-land scenarios described earlier. In order to isolate the effect, the target groundspeed should be selected to

BLIP/SCAN SHORT-HAND

Event	Annotation
Target Number (TGT 1, TGT 2...)	① ② ③
Target (No.), Bearing	① 270/192
Target (No.), Course and Speed	① 090/250 C/S
Target Altitude	① 15.5K
Target Heading	② H095
Target Acquisition	② AQ
Target Check Track	① ✓
Target Drop Track	② ⬇
Test-Aircraft Start Turn (Left, Right)	↶ ↷
Test-Aircraft Stop Turn	⊗
Videos	
Real Video	RV
Synthetic Video	SV
Target Calls	
Hit	1
Miss	0
No Call	-
Merge	M

Note: Record time every 10th scan. Use XX:XX:XX on the hour and then just minutes and seconds XX:XX until the next hour.

Figure 4.7: *A sample of blip/scan short-hand applicable to the sample track-while-scan, low pulse repetition frequency Airborne Early Warning radar system including notation necessary for both Blip/Scan data collection and tracking data collection.*

preclude the blind doppler effects described earlier for the majority of the data runs; however, once a baseline of data is established, the test must be repeated specifically flying the target at a blind speed. The test should also be repeated in the presence of a minimum of casual EMI and in the presence of EMI at least as high as the predicted operational environment.

4.1.2.6. Data Analysis and Presentation

The sample system is designed to allow the operator to perform manual detection using the real or synthetic videos and for the system to perform detection of targets for later use by the tracking algorithm. For this reason, two sets of BSR and CBSR plots are needed. In the first, a valid detection on a target is provided whenever the operator has declared a hit (1 on the data card) in either real or synthetic video. The scan number and periodic time updates from the data cards are combined with the known groundspeed of the target and the periodic range updates, to determine the radial range bin for each line of data. A simple computer program or virtually any commercial spread sheet can be used to reduce the data into the BSR format. If a commercial spreadsheet is used, most have the capability of plotting the data in the BSR format previously presented. The $P_d(.5)$ point is annotated. Any bins with ranges less than the bin for which $P_d(.5)$ was first noted are examined for possible causes. As an example, the clutter line will lie approximately at the radar horizon defined by equation 4.1 and sometimes causes an intermittent drop in target detection levels. A drop may also occur at the land-sea interface for near-land scenarios. The impact of $P_d(.5)$ must be related to the reaction times provided for mission significant targets and target speeds. The impact of the drops in detection and their duration can be related to the possibility of missing intercepts while directing fighters or missiles to the target. Remember that the data are applicable to a target of a defined radar cross section and must be mission related in terms of that size of target, or the data must be adjusted analytically to estimate the performance using targets of other cross section. Equation 4.2 may be used to adjust the maximum detection range measured for a test target to reflect a second target of different radar cross section. This equation may be used as long as the two cross sections are not too different.

$$R_h = 1.23\sqrt{H} \qquad \textbf{(4.1)}$$

R_h = Range to radar horizon
H = Altitude of the aircraft in feet

$$R_{\max\,adj} = R_{\max\,test}\left(\frac{\sigma_{desired}}{\sigma_{test}}\right)^{1/4} \qquad \textbf{(4.2)}$$

$R_{\max\,adj}$ = Max detection range of target of interest for which detection data has not been directly measured

$R_{\max\,test}$ = Max detection range of target for which radar detection data has been directly measured

$\sigma_{desired}$ = Radar cross section of target of interest for which detection data has not been directly measured

σ_{test} = Radar cross section of target for which radar detection data has been directly measured

In situations where the detection of the target occurs at ranges beyond the unambiguous range of the highest of the three PRFs used in the sample system, consideration must be made of the effects upon the data. The easiest procedure is to recognize that the opportunities for detection are reduced to one in three sweeps for range bins between the maximum low PRF range and the maximum middle PRF range and to divide the BSR at these long range bins by 0.333 to allow direct comparison to the shorter range bins. Similarly, the range bins between the maximum range of the highest PRF and the maximum range of the middle PRF are divided by 0.666.

The EMI traces must be examined to determine the approximate level of EMI. The levels can be approximated by reviewing the video taped recordings of the EMI level and estimating the average level of EMI for 360° around the aircraft and the average level along the target bearing. In more sophisticated data collection efforts, the EMI data can be digitally recorded or a separate EMI data collection system is installed. In these cases it is possible to perform more statistically rigorous quantification of the EMI level. The sea clutter range should be annotated on the plot and if consistent differences are noted in $P_d(.5)$, or the BSR decreases consistently at this range, it may be necessary to develop categories of over-water data for different sea clutter levels.

The BSR data from each data run are combined in CBSR plots for all runs with similar test conditions. The CBSR will reflect consistent artifacts in the detection level, such as a more statistically rigorous $P_d(.5)$, consistent loss of detection at the clutter line (remember that this range will vary with aircraft altitude above the terrain, and possibly with sea state), consistent loss of detection at the land sea interface (for data collected at a consistent range to the shore line), and consistent loss of detection in the presence of higher levels of casual EMI.
Until this point, the only data used was the manually recorded data on the Blip/Scan cards. If the data show that the system meets the specified requirement, it is often sufficient to

stop the analysis using only this data. If the system missed the specification values or more rigor is needed, the next step is to review the video tapes to determine if the operator missed any Blip/Scan calls. The video may also be used to fill in if the operator has made "no calls". The data reduction can be discontinued at this level using the same criterion used to determine if examination of the video tapes is necessary. If the data still show that the radar does not meet the specification or if further rigor is necessary, then the digital data may be examined to determine if the radar declared a target correlating with the IFF derived position. Note that it is possible that the data may not have been processed appropriately by the radar and display system and the radar detections may not have been available to the operator. Comparison of the radar digital data and the display video tapes should highlight this problem.

4.1.2.7. Data Cards

Sample data cards are provided as card 4.2. Card 4.2 shows the first page of the blip-scan data cards. Subsequent pages would continue the number scheme until enough rows are provided to ensure that the target run can be completed without a break in the numbering sequence.

BLIP/SCAN CARDS

Date:_________ Flight Number:_________ Profile:________

Aircrew Assignments:

Target Data:

Target No.	**Type**	**Call Sign**	**IFF Code**
1			
2			
3			
4			

Target groundspeed ____________________

Radar Configuration:

Data Extraction Points:____

Data Card 4.2: *Track-While-Scan, Low Pulse Repetition Frequency Maximum Detection Range*

BLIP/SCAN CARDS

Page 1

Scan	T1	T2	T3	T4	Brng/Rng	Events
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						
34						

Flight Number:____________ Run Number:____________

Data Card 4.2: *Track-While-Scan, Low Pulse Repetition Frequency Maximum Detection Range (Continued)*

4.1.3. Straight-Line Tracking

The purpose of this test is to measure the performance of the straight-line tracker of the Track While Scan (TWS), Low PRF AEW radar and to assess the effects of the tracker upon the AEW mission.

4.1.3.1. General

Many, if not most, AEW mission scenarios involve the detection of a threat inbound to a defended point. For this reason, the ability of the radar system to track straight-line, inbound targets is paramount. Any tracking is inherently complicated in a TWS system since the radar does not continuously update the target position. Tracking requires three distinct steps to occur: detection, association and track vector updating. The process and testing of detection was described in the previous section. Once detection has occurred, the radar must determine whether this new data is associated with previous detections. In the simplest scenario, the system can associate two detections, and based upon the two positions and time difference between them, Dead Reckon (DR) a track course and speed. The radar system can then predict the location of the next detection and use radar detections located close to this projected point to further update the track. Realistically, the process is more complicated, requiring more detections to build confidence in the validity of the track as a valid representation of a target, but the concept is similar.

In the sample system, the radar collects new detections and first attempts to link them to established tracks, if it cannot, it looks for second detections from previous sweeps that could possibly be from the same target. If one is found, a track position is projected forward based upon a DR of the track position. If a third detection is found on the subsequent sweep within a defined window placed over the DR position, a track is posted representing the target. The procedure is adjusted at ranges between the maximum range of the highest PRF and the maximum range of the lowest PRF to account for the absence of opportunities for detection. A symbol is placed on the operator's display at the location of the radar detection (superimposed upon the radar video). The symbol has an alphanumeric readout of target course and speed and a small vector projecting from it representing its course and speed. The track is given a unique number assignment which can also be read on the radar display. If a miss of detection occurs on the third opportunity, a second DR is performed. Two subsequent detections are then required to confirm that a track exists before a track is displayed. In the sample system, the actual course and speed calculations are not performed as a point-to-point calculation, but a unity plant Kalman filter is used. Subsequent detections allow the window, which is projected forward, to shrink, since confidence in the actual course and speed of the target grows. This helps to prevent the use of spurious detections on established tracks. When misses are taken on subsequent scans, the window continues to project and grows in size, until six misses occur, and then the track drops. The track symbol on the radar display is modified to reflect that misses are occurring (coasting Kalman) after three consecutive misses. The effect of a target which is maneuvering will be discussed in a later section.

4.1.3.2. Instrumentation

Hand held blip/scan cards are required. Video recording of the radar display and digital recording of the radar track states is required.

4.1.3.3. Data Required

This test is performed in conjunction with a detection test. In addition, the operator records when a track is established on the targets, when the track modifier is posted, indicating the track is taking misses, when a drop track occurs, and the displayed course and groundspeed. The operator also uses Data Extraction (DX) to collect the track states including radar measurement parameters, Kalman filter derived course and groundspeed, and the DR position.

4.1.3.4. Procedure

While collecting blip-scan data as described in the maximum detection range test procedure, additional DX points are selected to allow collection of the tracking DX data described above. In addition, the operator looks for when the radar posts target symbology indicating that a track has been established on the targets. The operator calls "track acquisition" with the track number and associated target number when a target is posted with a track symbol on the display, calls a "check track" with the target number when the target symbol displays the modifier indicating that the track has taken misses, and calls a "drop track" with the target number when enough misses occur to cause the track to be dropped from the display. The recorder makes annotations on the data cards as shown in Figure 4.7.

4.1.3.5. Data Analysis and Presentation

The test is performed in conjunction with a detection test for two reasons. First, the tests are completely compatible and allow for an efficient use of the flight time. Second, tracking cannot occur without detection, and so the detection data must be available to determine if a track is missing because the detection level does not support tracking or if the tracker itself is failing.

It is possible for a short-lived track to establish and drop at artificially extended ranges due to intermittent hits at long ranges. For this reason, a choice must be made as to where to begin measuring the performance of the tracker. For the purposes of the sample system, the detection range performance is measured and specified in terms of $P_d(.5)$ and so the performance of the tracker will be measured starting at the same range. The total time for which a track is present for the target aircraft is divided by the time it takes the aircraft to travel from the $P_d(.5)$ point to the range at which the test is discontinued, less any time during which the detection levels did not support tracking. In the case of the sample system, the requirement is to maintain tracking whenever the probability of detection is greater than or equal to 0.25, and within the $P_d(.5)$ point. As examples, if a track is established at or before $P_d(.5)$ and does not drop before the target discontinues the data run, the track life is 1.0. If the track drops for 10% of the time but those times correlate with ranges where detection is such that the BSR is less than 0.2, then the track life is still 1.0.

As with detection data, a composite track life can also be calculated. The data from the runs are combined for profiles which are similar. The same criterion may be used to combine data as were used for the detection data. The combined data will help to eliminate the effects of intermittent performance and give a more statistically significant indication of system performance.

As with the detection data, if the manually derived data show that the system has missed the specified requirement or more rigor is required, the video and the DX data may be examined to determine if the operator missed the existence of a track. As long as the video recorder shows that the display of a track was available, the data may be amended to include the missed data.

The heading and groundspeed must be compared with the known truth data provided by the target aircraft. The requirements depend upon the intended mission of the system; however, accuracies of 25 KTS and 10° are not unusual requirements.

The track life (composite track life if available) should be related to the necessity of the operator to provide manual track dead-reckoning of attacking aircraft or missiles in a high target density environment. The accuracy of the course and groundspeed values should be related to the probability of missed intercepts while the operator provides control of intercepting aircraft or targeting data to surface-to-air missiles.

4.1.3.6. Data Cards

Sample data cards were provided in the Maximum Detection Range section as card 4.2.

4.1.4. Crossing Tracks

The purpose of this test is to measure the performance of the tracker of the Track While Scan (TWS), low PRF AEW radar in a crossing track situation and to assess the affects of its performance upon the AEW mission.

4.1.4.1. General

As described in previous sections, after targets are initially detected and tracks started which represent them, targets must subsequently be detected, then correlated to the existing track and then the state vector of the existing track updated using the new information. A window is projected forward to the predicted position of the target. A detection within this window is used to update the track. If more than one detection occurs within the window, the correct one must be selected for use. Typically this includes comparing any doppler information available to the predicted doppler value for the track and comparison of any other tracks with overlapping windows to find the best mapping of available updates to existing tracks. This situation is particularly stressed when the targets have similar doppler values. The scenario is significant in situations where effort is expended to positively identify a target and then the symbol is swapped to a crossing track, effectively misidentifying the new target. Figure 4.8 is a scenario used frequently to test for this phenomenon. This scenario exemplifies the geometry necessary for the problem to occur.

4.1.4.2. Instrumentation

The instrumentation for this test is the same as described for the maximum detection range test procedure.

4.1.4.3. Data Required

The data required for this test are the same as described for the maximum detection range test and the straight-line tracking test. Additionally, note must be made of whether the tracks swap as the targets cross positions.

4.1.4.4. Procedure

Develop a profile similar to that shown in Figure 4.8 after performing enough maximum detection range and straight-line tracking test procedures to be confident that the crossing point will be well within the range where tracks are established on both targets. The range should; however, be long enough to be tactically significant. Start the DX and collect the EMI data as described in the maximum detection range test. Maximum detection range and straight-line tracking data are compatible with this test and should be collected concurrently. The targets must remain separated by at least 500 feet of altitude. Care must be taken to ensure that both targets start at the initial point at the exact same time. As the targets track inbound, adjust the speed of each target to cause them to make the crossing point at the same time. Note whether the track number of each track remains consistent after crossing using the event section of the data cards included in the maximum detection range test description. Continue to collect maximum detection range and straight-line tracking data until the profile minimum range is reached, turning the targets outbound. Repeat the test as flight time allows.

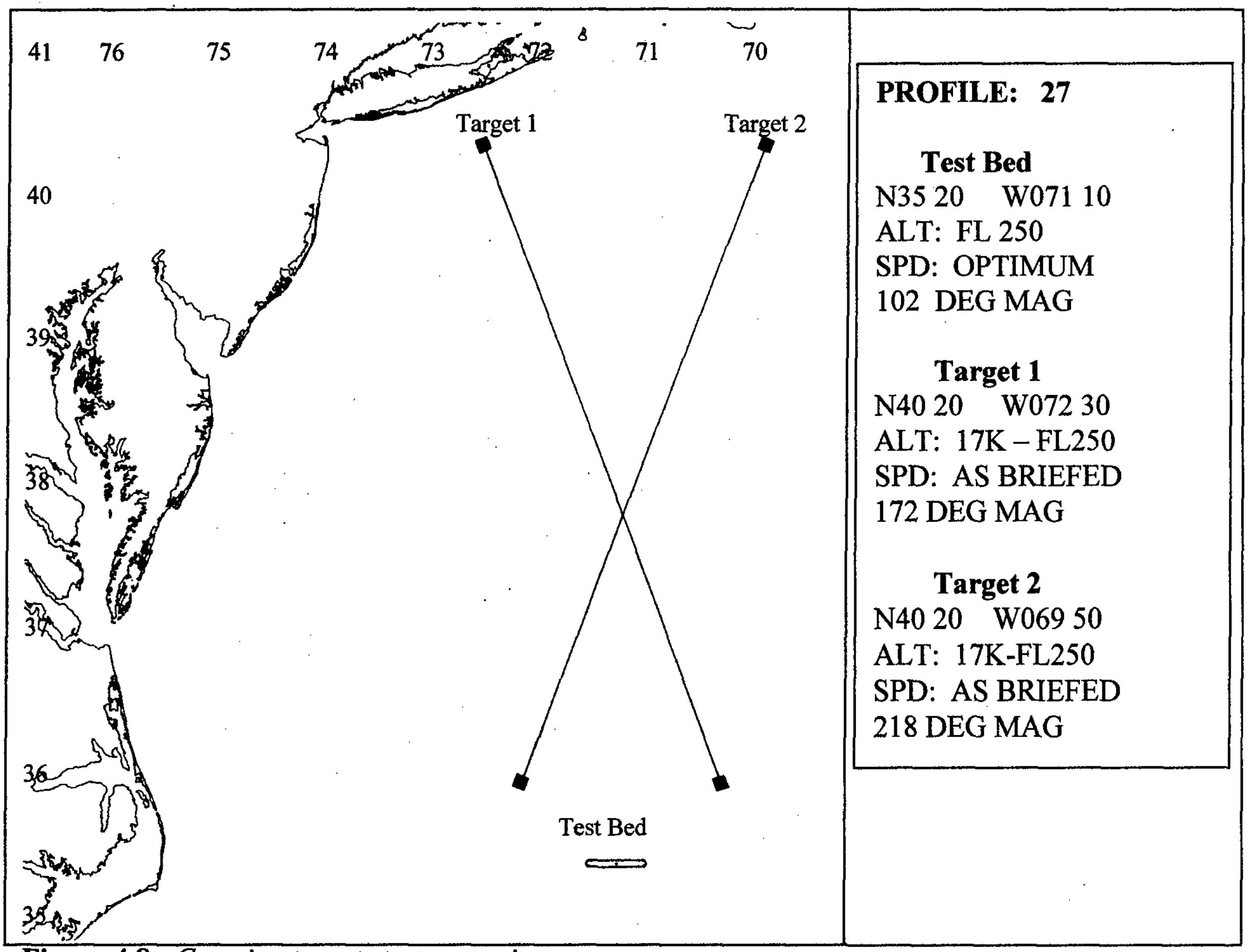

Figure 4.8: *Crossing targets test scenario.*

4.1.4.5. Data Analysis and Presentation

If the tracks do not swap, reduce the data as described in the maximum detection range and straight-line tracking sections. If a swap occurs, the DX may be examined to determine the cause and to precisely define the geometry and detection report parameters.

4.1.4.6. Data Cards

Sample data cards were provided in the Maximum Detection Range section as card 4.2.

4.1.5. Maneuvering Target Tracking

4.1.5.1. Purpose

The purpose of this test is to assess the performance of the TWS, low PRF AEW radar maneuvering target tracker and its effects upon the radar's mission performance.

4.1.5.2. General

Most AEW radars are not optimized to provide automatic tracking of targets during high acceleration combat maneuvers. This is particularly true in the case of TWS radars, since the update rate tends to be too slow to support such tracking. Accounting for this element of realism, it is usually still considered a requirement for the radar to track targets which may be performing limited maneuvering along a general course or performing standard racetrack loitering maneuvers. Figure 4.9 depicts a profile which has been used to highlight the capability of the TWS AEW radar to track targets performing these limited maneuvers.

As mentioned in the straight-line tracking section, most modern trackers use a Kalman or other filter to provide an estimation of the target's course and speed. It is the nature of such trackers that they may become desensitized to changes in the target's parameters after prolonged periods of straight and level flight. The usual method for accounting for this weakness is to provide a method for discerning that a maneuver has happened and then to reset the filter using the new position and parameters. In essence, the filter is re-started using newly estimated parameters, post-maneuver.

In the sample system, when the tracker notes that it has no valid target detections within the projected target window, it projects a larger window, shaped to allow inclusion of detections for targets performing moderate maneuvering. Since the window is larger, there may be more than one detection within the window. The algorithm then allows for a calculation of a statistical quality for each detection, based upon the closest fit of position and doppler information. The quality is also adjusted based upon the use of the same detection for other non-maneuvering as well as maneuvering tracks to help prevent the swapping of tracks in close proximity. After several misses within the standard, projected gate, the track is placed at the location of the new track and the filter gains are reset to reflect the characteristics of a new track file, while more detection information is collected on the new course and speed.

During the resetting and track placement process that occurs post-maneuver, the operator will see that the track symbol may not correlate closely to the correct, or any, track video. This period is then followed by a jumping of the symbol from one location to another. This is often disconcerting to the operator. The amount of time necessary to perform the maneuvering track update and the quality of the initial groundtrack and groundspeed information is the major determinant of operator perception. While the exact procedures used vary from system to system, the sample radar tracker is representative of the types of tradeoffs used in TWS maneuvering tracker design.

4.1.5.3. Instrumentation

The instrumentation for this test is the same as described for the maximum detection range test procedure.

4.1.5.4. Data Required

While collecting Blip/Scan data, the operator should add, as event annotations, when the pilot of the target begins and ends each of the test turns as well as when the track jumps to the post-maneuver location. The evaluator should also make event annotations of the target course and speed at least every other sweep until the track stabilizes on the new course. All the other straight-line tracking events should also be noted. Note qualitative comments concerning the utility of the maneuvering tracker for providing the operator with situational awareness as the target maneuvers. Comments should be made concerning the utility of the track location information, course and speed. Collect all the video and digital data outlined in the straight-line tracking section.

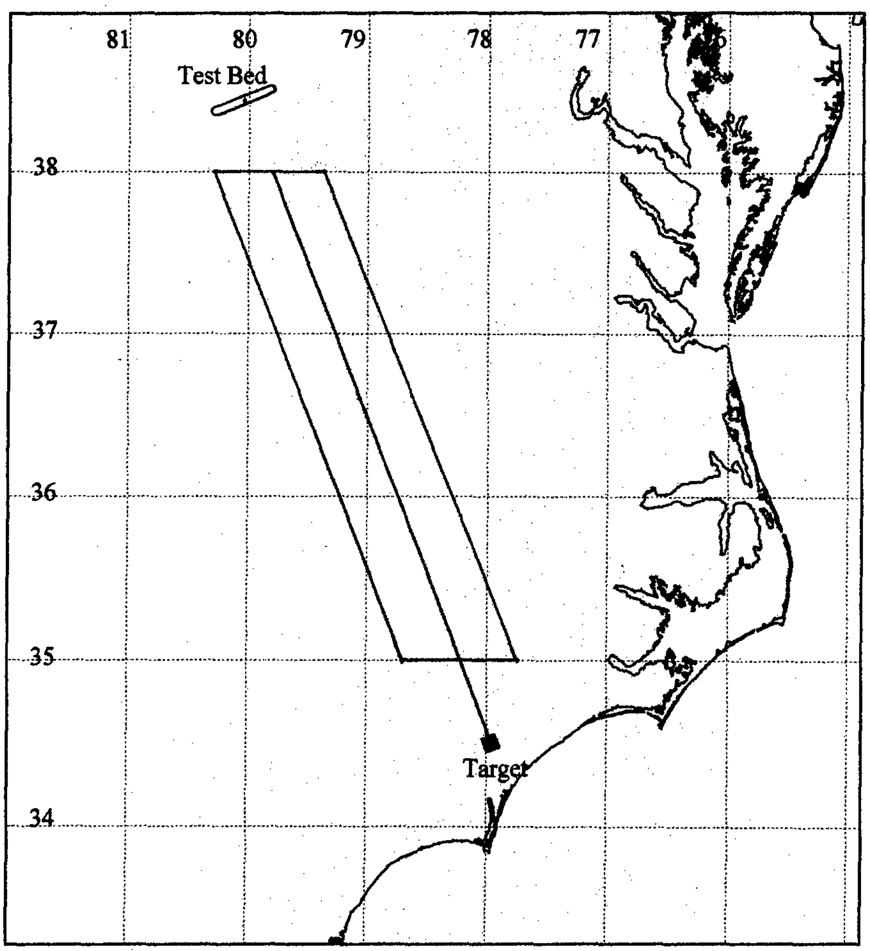

Figure 4.9: *Maneuvering target test scenario.*

4.1.5.5. Procedure

Provide control of the targets and collect the data as outlined in the straight-line tracking section. Have the target make a radio call at the beginning and end of each maneuver to facilitate annotation of the data cards and tapes. Collect the data as listed above. Care should be taken during the collection of the qualitative comments so that the evaluator does not become involved in the collection of the Blip/Scan to the detriment of observing the general performance of the tracker during the maneuvers. Consideration should be given to using a different evaluator to make the qualitative assessment concurrent with the Blip/Scan data collection.

4.1.5.6. Data Analysis and Presentation

Begin the data analysis by noting the qualitative comments of the operators. If the comments are very positive, it may be possible to preclude in-depth analysis of the maneuvering tracking data. If performance is in doubt, or a more in-depth analysis is required, note should first be made of the percentage of maneuver opportunities during which the track did not make the appropriate jump to the new track location. The amount of time necessary for the jump is dependent upon the tracker rules in use. The amount of time for the tracker to provide heading and groundspeed accuracies equivalent to the straight-line tracker should not be significantly different than the performance of the straight-line tracker at track initiation. Rigorous evaluation of the post-maneuver heading, groundspeed and track location errors will probably require reduction of the digital data. One possible analysis is to filter out all the course, speed and bearing/range data after each successful leap for a number of scans. The number of scans is governed by the amount of time necessary for the track to stabilize upon the correct parameters, commensurate with straight-line tracking accuracies. Observation of the data may allow for a general number of scans to be selected that ensure that most of the variations are complete while using a single number of scans for each turn. The mean errors at each post-maneuver scan are then calculated for the total of all the maneuvers knowing the documented (preflight planned) groundspeed and groundtracks. If a statistical confidence is necessary, a variance may also be calculated. Comparison may then be made of the data to the requirements, or statistical rigor may be added to the operator's qualitative comments.

4.1.5.7. Data Cards

Sample data cards were provided in the maximum detection range section as card 4.2.

4.1.6. False Alarm Rate

4.1.6.1. Purpose

The purpose of this test is to qualitatively and partially quantitatively assess the detection false alarm rate and its effects upon the radar's mission performance.

4.1.6.2. General

AEW radars generally search very large volumes. In order to perform a rigorous false alarm rate investigation, it is necessary to have detailed knowledge of the actual targets within the search volume under investigation. Unfortunately, few test areas, large enough to contain the entire search volume of an AEW radar exist where access to this type of information is available. One method for partially testing the global false alarm rate is to perform the evaluation over a smaller, representative area that does not include the entire search volume. The largest area is used for which the truth data can be obtained.

Even with the technique described above, There are several limitations. First, areas must be available which represent the correct operational environment, particularly the clutter and EMI levels. Second, the truth data may be hard to document, even over controlled ranges, particularly in the over-land scenarios. Most AEW radars make the distinction between the classes of targets (land vehicle, aircraft, ship) at least partially using doppler information. This implies that even a properly operating radar, functioning as designed, may declare that an air target is present when a high-speed land vehicle is present (for example a truck on a road). This is not considered a false alarm in most systems. The test is complicated because there are very few areas large enough for flight testing that also restrict all land traffic. Similar, but even more severe problems, can occur with AEW radars designed to also detect ships and land surface vehicles. For the purposes of the current discussions, only the air target false alarm rate will be covered.

The type of data required and the exact definition of a false alarm can complicate the test and can drive the test design beyond most test budgets. The test designer must fully understand the intended use of the system to appropriately scope the test. As an example, for the sample system, a false alarm may be defined at three levels, all requiring significantly different amounts of instrumentation and subsequent data reduction to test. A false alarm may be defined as a track initiation on a track that does not exist, a detection report and corresponding synthetic video on a track that does not exist or a real video sweep that appears as a real target when one does not exist. The latter is nearly impossible to test quantitatively. The declaration of a target is partially a subjective call by the operator and a counting of false alarms may require significant hours of repeated playback of the flight data, to allow a time dependent count of the false sweeps of video. All of the analysis must be done by operators since the information is presented before target reports are collected by the radar and available for digital recording. Some mix of the former two are typically required.

Tracks can be validated in one of two ways. Some testing areas allow for the case where all the air tracks are equipped with IFF. For systems such as the sample system, the detection reports and tracks can be validated by correlating the IFF track with the non-IFF detections and tracks. All the remaining detections and tracks are false alarms. In other cases, it is necessary to provide data recording at the controlling site for the test airspace. Detections and tracks are validated by comparing the geographic location of the ground based truth data and the airborne data. This technique can be done manually via video recordings for a few tracks but can be done more easily by merging the two sets of data using time tagging of the two sets of space-positioning data and later comparing the two data bases.

For the case of the sample system, it will be assumed that all air targets are known and are equipped with IFF and all the data required are recorded on-board the AEW platform. In addition, the sample system uses an automatic correlation of the IFF and the radar information in its tracking algorithm in cases where IFF information exists on a track. In this case, the tracks and track reports, with the corresponding synthetic video, are easily severable from the total data file of all the target reports and track files. Reduction of this data requires only that the tracks and track reports be sorted geographically to analyze only those tracks within the controlled airspace and then that the correlated tracks and reports be deleted from the count of the total track reports and tracks to give the false alarm rates within the test airspace in both categories. It must be noted that this process assumes the correct correlation of the IFF and radar tracks and that the IFF tracking algorithm is performed perfectly. If the system false alarm rate is acceptable, given the above described process, it is possible to eliminate further analysis. If the false alarm rate is not adequate, the next step is to perform a manual analysis of the performance of the IFF tracker (IFF track location is consistent with the IFF reports) and a comparison of all the non-correlated track reports in the locality of the IFF tracks to determine if the correlation of radar and IFF tracks is causing the discrepancy.

4.1.6.3. Instrumentation

The instrumentation for this test is the same as described for the maximum detection range test procedure.

4.1.6.4. Data Required

Record the digital data described in the maximum detection range test procedure. Record qualitative comments concerning the affects that the false alarm rate has upon the situational awareness of the operator and his or her ability to correlate video to valid tracks.

4.1.6.5. Procedure

Select an area of Restricted Airspace for which the controlling agency can provide a complete accounting of airborne users and schedule as necessary to ensure that only valid IFF equipped aircraft are in the area. Position the AEW platform at a range that ensures adequate detection of the targets using the AEW radar. Use should be made of the data collected during the maximum detection range tests to confirm this range. As an example, a range where the farthest edge of the Restricted Area is at 75% of the $P_d(0.5)$ range may be a good choice for some systems.

Have the controlling agency confirm that the target aircraft all have working IFF systems upon check-in to the area. It is necessary for the targets to limit their flight profiles such that they do not have periods of terrain masking. In mountainous areas, more in-depth analysis will be required to ensure that the view of the targets is not restricted by terrain masking at any time during the test. Preference should be given to airspace for which elimination of surface vehicles over land is available. At least three test areas are required, one over-land, one near-land and one over-water. Refer to the maximum detection range test procedure for the definitions of these environments. Consideration should also be given to varying the EMI environment as described in the maximum detection range test section. The most severe environment will be one with high clutter and high EMI. If this scenario is tested first, and the performance is found to be acceptable, it may be possible to eliminate some scenarios.

Document the EMI environment, radar configuration and clutter environment as described in the maximum detection range test section. Have the controlling agency for the working area provide the IFF codes for each target in the area as they arrive and leave. Begin collecting the digital data and observe the tracking of the IFF validated targets in the working area. Make qualitative comments concerning the effects of the false alarms on the operator's ability to determine if a valid target is present and then to track the target. Repeat the test for the other clutter environments and other EMI environments as required.

4.1.6.6. Data Analysis and Presentation

Filter the digital data to delete all reports and tracks outside of the working area. Confirm that all IFF tracks that the controlling agency was tracking also have valid tracks for corresponding periods provided by the AEW radar. For each scan of the radar antenna, provide a count of the total number of radar target reports, the total number of radar-only tracks, the total number of IFF/radar tracks, and the total number of detections which were correlated to IFF/radar tracks. The difference between the total number of radar target reports and the correlated radar reports is the number of false detections for that scan. The number of radar-only tracks is the number of radar track false alarms. Calculate the average and variance of these two parameters.

If the operator provided negative comments concerning the qualitative effects of the false alarm rate or the calculated parameters did not meet with the specified requirements, further analysis is required. Each IFF track must then be spatially filtered to identify detections and radar tracks in the immediate vicinity of the track. The dimensions of this filtering are dependent upon the beamwidth and range accuracies of both the IFF and radar. Typically a filter can be used which is on the order of twice the beamwidth accuracy of the least accurate of the two systems and on the order of 2 to 10 times the range accuracy of the least accurate ot the two systems.

At each sweep, the detections that fall within the window are checked to confirm whether or not they were likely detections of the actual, IFF-equipped targets. This determination is typically made based upon the geographic location and doppler information. Likely matches are eliminated from the talley of false alarms for that sweep. The radar-only tracks that fall within the window are also checked to see if they are likely to represent the same aircraft as the IFF track. If this is found to be likely for a track, it is eliminated from the count of track false alarms.

4.1.6.7. Data Cards

Sample data cards are provided as card 4.3.

FALSE ALARM CARDS

Date:_________ Flight Number:_________ Profile:_______

Aircrew Assignments:

Target Data:

Target No.	Type	Call Sign	Time In	Time Out	IFF Code
1					
2					
3					
4					

Radar Configuration:

Data Extraction Points:____

Qualitative comments concerning the effects of false detections and false tracks upon the operator's ability to detect and track valid targets:

Data Card 4.3: *Track-While-Scan Low Pulse Repetition Frequency False Alarm Rate*

4.2. TRACK-WHILE-SCAN HIGH PULSE REPETITION FREQUENCY RADAR TEST TECHNIQUES

4.2.1. Range Ambiguity Resolution

4.2.1.1. Purpose

The purpose of this test is to assess the ability of the TWS, high PRF AEW radar ranging algorithm to automatically resolve range ambiguities.

4.2.1.2. General

As described in section 2.1.5.2. a high PRF radar, is by definition, ambiguous in range. One of the major benefits afforded by an AEW system is the situational awareness it provides. This benefit is only possible if at least a two-dimensional position is available for each radar target. Thus, it is essential that the AEW radar consistently and effectively resolve the range ambiguity for each target within its search volume. As also described in section 2.1.5.2., the sample system uses one of the standard resolution techniques, PRF hopping, coupled with the Chinese Remainder Theorem, to analytically calculate the true target range in real time.

From the perspective of the operator, the functioning of the range ambiguity technique should be transparent. As long as the system is functioning properly, the ambiguity is consistently resolved and the operator will see no difference between the output of a high or low PRF radar. This feature may be used to simplify the testing of the ambiguity resolution technique. The test is performed identically to the TWS, low PRF maximum detection range test technique described in section 4.1.2. When this test is performed, problems with the ambiguity resolution technique may take several forms.

In one extreme case, the ambiguity resolution may be completely dysfunctional. In this case, false radar video will develop all along the true target line of bearing. The false, ambiguous detections will form a wedge, equal in angular width to the antenna beam width. The pattern of the false pulse-by-pulse detections will vary with the PRF since the range ambiguity varies with the PRF. Another possibility is that the technique will fail intermittently, resulting in an irregular, ambiguous pulse-by-pulse pattern.

If any of these symptoms are noted, a more in-depth analysis of the collected digital data will be necessary to isolate the cause. The instrumentation necessary to trouble-shoot the problem is significantly more complex and costly than is necessary for the TWS, Low PRF maximum detection range test technique described in section 4.1.2. and so a decision must be made to collect the least costly data in the expectation that the more detailed data will not be needed, or to instrument with the more complicated and costly instrumentation in anticipation of problems. The choice must be tempered by the expected risk of finding a faulty range ambiguity algorithm, the criticality of the test asset schedule and other factors as described in section 3.0. The instrumentation suite necessary to trouble-shoot range ambiguity problems effectively is described at the end of section 3.0. As mentioned there, the data volume will be extensive, is usually limited to geographic areas less than the full radar search volume, and will require extensive post-flight analysis.

4.2.1.3. Instrumentation

The instrumentation for this test is the same as described for the maximum detection range test procedure.

4.2.1.4. Data Required

Record the digital data described in the TWS, low PRF maximum detection range test procedure. Record as notes qualitative comments concerning the presence of any false video along the target azimuth as well as its appearance. Video and still photographs, annotated with voice may be particularly effective for documenting the presence of range ambiguities.

4.2.1.5. Procedure

Perform the test as described in the TWS, low PRF maximum detection range test procedure. Document as notes, any occurrences of false radar video which is repetitive in range. Record the ambiguous radar video using the video camera and still camera.

4.2.1.6. Data Analysis and Presentation

If the maximum detection range is adequate, the detection levels are consistent through the entire target run and no range-repetitive false video are noted along the target bearing, then no further data reduction is necessary. If problems are noted, then the recorded I&Q data must be examined for each radar pulse. The ambiguity will be evident at the pulse-by-pulse level as ambiguous radar detections redundant at ranges dependent upon the PRF used for each pulse. The I&Q data may be used to drive simulations of the range ambiguity algorithm, to determine the exact cause.

4.2.1.7. Data Cards

Sample data cards are provided as card 4.2.

5.0. SEARCH-WHILE-TRACK RADAR TEST TECHNIQUES

5.1. SEARCH-WHILE-TRACK LOW PULSE REPETITION FREQUENCY RADAR TEST TECHNIQUES

5.1.1. Antenna Scanning Scheme

5.1.1.1. Purpose

The purpose of this test is to assess the ability of the TWS, high PRF AEW radar to steer the radar beam as required to adequately perform the AEW mission.

5.1.1.2. General

The major benefit of the TWS antenna is the flexibility that the "beam on demand" provides. The test technique needed to evaluate the antenna scanning scheme is highly dependent upon the exact scheme that is used in the radar. As such, the exact test technique must be developed with the characteristics of the test radar in mind. For illustrative purposes, a simple scheme is used which exploits one particular use of the flexibility of the steerable radar beam. In the sample system, the antenna scans the 360° radar volume at a constant angular rate as long as the detection level for all targets within the search volume is 100%. During this special case, the scanning is similar to the mechanically scanned, rotating antenna used in the development of the test techniques of section 4.0. The steerable beam is exploited whenever any target begins to take misses. In this case, the radar is designed to search the area of uncertainty around the target location at twice the update rate. If upon re-establishing contact, it is determined that the target is performing a maneuver, the updates are continued at twice the rate until the target is established once more in a straight-line track. In this way, the expected effect of the steerable beam may be quantified as an increase in the effective track continuity and an increase in the radar's ability to track through turn rates greater than the mechanically rotating antenna track-while-search system.

The testing is performed similarly to the straight-line tracking test of section 4.1.3. and the maneuvering target tracking test of section 4.1.5. As long as the track continuity is adequate in the straight-line and maneuvering track scenarios, no additional effort is required. If the straight-line or maneuvering track continuity are inadequate, a more in-depth analysis of the collected digital data will be necessary to isolate the cause. The instrumentation necessary to trouble-shoot the problem is significantly more complex and costly than is necessary for the TWS, Low PRF straight-line tracking test and maneuvering target tracking test techniques described in sections 4.1.3. and 4.1.5., and so a decision must be made to collect the least costly data in the expectation that the more detailed data will not be needed, or to instrument with the more complicated and costly instrumentation in anticipation of problems. The choice must be tempered by the expected risk of finding a faulty range ambiguity algorithm, the criticality of the test asset schedule and other factors as described in section 3.0. The instrumentation suite necessary to trouble-shoot antenna scanning scheme problems includes a digital recording of the antenna beam steering commands in addition to the data outlined in sections 4.1.3. and 4.1.5. It is assumed that significant ground testing was performed to verify that the antenna steering commands effectively command the beam to the correct azimuth.

5.1.1.3. Instrumentation

The instrumentation for this test is the same as described for the straight-line tracking test procedures except that the antenna steering commands may also be digitally recorded.

5.1.1.4. Data Required

Record the data as described in the TWS, low PRF straight-line tracking test procedure and optionally the antenna beam steering commands.

5.1.1.5. Procedure

Perform the test described in the TWS, low PRF straight-line tracking test procedure. Next, perform the test as described in the maneuvering target tracking test except that the target maneuvers should be at greater acceleration rates and for more degrees of heading change. The sample data card of this section includes a sample set of maneuvers which should be performed by the target. Following each maneuver, the target should fly straight and level for a sufficient time for the tracker to stabilize, before starting another maneuver.

5.1.1.6. Data Analysis and Presentation

Perform the data analysis as described in the straight-line tracking test procedures of section 4.1.3. and 4.1.5. If problems are noted with track continuity, then examine the digital data to determine if during the periods of target maneuver and poor tracking performance, the radar commanded the radar beams at the appropriate locations and rates in accordance with the design rules. If not, the beam steering software is faulty. If the beams were commanded to the correct location, then an in-depth analysis of the digital data is necessary to determine if adequate detection levels were present to support tracking.

5.1.1.7. Data Cards

Sample data cards are provided as cards 4.2 and 4.3. An additional data card is provided as card 5.1.

Antenna Scanning Scheme

Date:________ Flight Number:________ Profile:_______

Aircrew Assignments:

Radar Configuration:

Data Extraction Points:____

Maneuver Number	Check When Compete	Acceleration Rate	Degrees Of Turn	Comments:
1		2g	90°	
2		4g	90°	
3		6g	90°	
4		2g	180°	
5		4g	180°	
6		6g	180°	
7		2g	360°	
8		4g	360°	
9		6g	360°	

Qualitative comments concerning track continuity during target maneuvering :

Data Card 5.1: *Scan-While-Track Low Pulse Repetition Frequency Antenna Scanning Scheme*

6.0. CONCLUSIONS AND RECOMMENDATIONS

These test techniques should be used as a generalized baseline for the development of specialized tests for new systems. A basic knowledge of system theory and the characteristics of the test article are assumed. During the development of the techniques presented here, frequent license was permitted in the selection of test ranges, speeds, altitudes, as well as the specifics of the design of the sample system under test. It cannot be overemphasized that the details of the test must be specific to the system and platform under test. It is intended that the test procedures and specific examples presented give the reader a flavor for the requirements of the sample system, enabling him or her to then choose test points and conditions for other systems. One final point must be stressed. Every detail of each individual test, as well as the order and precedence, must be thought through and planned before the flight and then the plan must be flown, if usable data is to be consistently obtained.

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14. Abstract

During periods when military budgets and aircraft fleet sizes are shrinking, systems that serve to cost effectively increase the utility of the remaining weapons can still undergo procurement growth. The increased situational awareness and battle field management provided by Airborne Early Warning (AEW) radar is one such force multiplier. The primary role of an AEW aircraft is the long-range detection of airborne targets. As potent new airborne threats, such as low flying cruise missiles, reduce the timelines that traditional air defense systems have to react, the utility of an AEW system's long-range surveillance capabilities to recover the lost time is clear. Fundamentally, these new targets stress the principal performance capabilities of an AEW radar sensor leveling new requirements on these systems to deal with this advanced threat. These increased requirements have led to world-wide, substantive work in the development of radar upgrades to existing AEW aircraft, such as the U.S. Navy's E-2C Hawkeye and the U.S. Air Force's E-3A AWACS, as well as new systems and platforms, such as the Swedish Air Force's ERIEYE. The required increases in sensitivity, resolution, and the associated data rates that stem from these performance improvements will have profound impact on the way these systems are operated and how they perform in various environments. As these increasingly capable systems evolve, AEW radar will be expected to take on additional missions and perform other surveillance functions in the pursuit of dominant battle field awareness. Unfortunately, little or nothing has been written to document the largely unique techniques needed to perform the system level flight testing of these new AEW radars. The procedures have largely been passed from one individual to the next without the benefit of substantive documentation. The purpose of this volume is to document the theory and procedures necessary to perform the developmental flight testing of the several major categories of AEW radar.

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