

AD-A163 941

DTIC FILE COPY



AIRBORNE BISTATIC RADAR
LIMITATIONS AND SAMPLE CALCULATIONS

THESIS

William P. Thomson
Captain, USAF

AFIT/GE/ENG/85D-49

This document has been approved
for public release and sale; its
distribution is unlimited.

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DTIC
ELECTE
FEB 13 1986
S A D

86 2 12 088

AIRBORNE BISTATIC RADAR
LIMITATIONS AND SAMPLE CALCULATIONS

THESIS

William P. Thomson
Captain, USAF

AFIT/GE/ENG/85D-49

DTIC
ELECTE
S **D**
FEB 13 1986
A

AIRBORNE BISTATIC RADAR
LIMITATIONS AND CALCULATIONS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Electrical Engineering

William P. Thomson, B.S.
Captain, USAF

December 1985

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A1	



Acknowledgments

I am deeply indebted to Major John Reed, RADC/OCDE for his assistance in providing the background information necessary in this study. I am also indebted to my thesis advisor, Major Ken Casto, for his time and assistance in bringing this study to a successful conclusion. Finally, I wish to thank Marilyn Thomson for her unselfish assistance.

William P. Thomson

Table of Contents

	Page
Acknowledgments	ii
List of Figures	v
List of Tables	viii
Abstract	ix
I. Introduction to Bistatic Radar	1
Airborne Bistatic Radar	1
Assumptions	1
The Problem	2
Analysis of the Problem	2
Limiting Regions	3
Doppler Effects.	3
Signal to Clutter Ratio.	3
Demonstration of the Model	4
Findings and Conclusions	4
II. Bistatic Radar	5
Background	5
Historic Background of Radar Systems	6
Problem.	7
Definition of Key Terminology.	8
Major Components	9
Signal Properties.	10
Physical Properties of the Transmitted Waveform	14
Advantages	15
Summary of Current Research.	18
III. Development of the Bistatic Model.	20
Defining the Parameters	20
Radar Range Equation	22
Bistatic Geometry	23
Ability of System to Perform	27
Limiting Regions	31
The Power Limited Region	31
Isorange Formula Development	33
Isorange Blind Zone (ISOMIN)	36
Maximum Isorange (ISOMAX).	36
Incrementing the Isoranges	38
Development of the Bistatic Doppler Equation Model	40

	Page
Clutter	46
Clutter Parameters	46
Signal to Clutter Ratio	47
Clutter Cell Area	49
Surface Cross Section Per Unit Area.	50
Doppler Spread of Clutter Cell.	52
Summary	54
IV. Exercising the Model	56
Introduction.	56
Limiting Regions.	56
The Power Limited Region.	56
Waveform Limited Regions.	60
Evaluation of the Blind Zone (ISOMIN).	60
Evaluation of the Maximum Range (ISOMAX)	62
Doppler Maps	63
Signal to Clutter Calculations.	72
Doppler Spread of the Clutter Cell.	75
Sample Scenario	84
V. Summary, Conclusions and Recommendations.	89
Summary	89
Conclusions	90
Recommendations	91
Appendix A: Fortran Program Listing	93
Bibliography	112
Vita	114

List of Figures

Figure	Page
1. Search With Multiple Receiver Antenna Beams	12
2. Isorange Curves	16
3. Isodoppler Curves	16
4. Bistatic Coordinate System	22
5. Ovals of Cassini	25
6. Ellipse of Constant Range	28
7. Pulse Reception Characteristics	28
8. Rotation of the Bistatic Model	34
9. Isorange Detection Region	37
10. Geometry of the Clutter Cell	47
11. Mean Clutter Cross Section Per Unit Area	51
12. Clutter Power in the Frequency Domain	52
13. Geometry of Common Beam Area	53
14. Computer Model Menu	54
15. Bistatic Coverage and Exclusion Regions	55
16. Bistatic Model Parameter Menu (Generic Set)	57
17. Generic Detection Region (Power = 0.01 Megawatts)	57
18. Detection Region (Power = 0.0095 Megawatts)	58
19. Detection Region (Power = 0.0090 Megawatts)	58
20. Detection Region (Separation = 190 KM)	59
21. Detection Region (Separation = 160 KM)	59
22. Airborne Receiver to Ground Transmitter	60

Figure	Page
23. Detection Region for Pulse Width 30 Microseconds	61
24. Effects of Pulse Width on Blind Zone	63
25. Minimum and Maximum Isoranges (Increased PRF: 30000 HZ).	64
26. Minimum and Maximum Isoranges (Decreased PRF: 20000 HZ).	64
27. Minimum and Maximum Isoranges (Multiple PRF: NPRF = 7).	65
28. Minimum and Maximum Isoranges (Single PRF: NPRF = 1).	65
29. Doppler for Transmitter and Receiver Separating	66
30. Doppler for Transmitter and Receiver Constant Separation	67
31. Doppler for Transmitter and Receiver Closing	67
32. Doppler for Transmitter and Receiver Orthogonal	68
33. Transmitter and Receiver, Equal Velocities	69
34. Transmitter and Receiver, Unequal Velocities	69
35. Receiver Separating from Ground Transmitter	70
36. Receiver Closing on Ground Transmitter	70
37. Receiver Orthogonal to Ground Transmitter	71
38. Receiver 45 Degrees from Ground Transmitter	72
39. Signal to Clutter Ratio Generic System	73
40. Signal to Clutter Ratio, Target RCS = 100 Sq M.	73

Figure	Page
41. SCR: Ground Transmitter, Small Target	74
42. SCR: Ground Transmitter, Target RCS = Sq M.	75
43. Doppler Spread Generic, Separating	76
44. Doppler Spread, Constant Separation	77
45. Doppler Spread, Closing	77
46. Doppler Spread, Orthogonal	78
47. Doppler Spread, Arbitrary, Equal Velocities	79
48. Doppler Spread, Arbitrary, Unequal Velocities	79
49. Doppler Spread, Air to Ground, Closing	80
50. Doppler Spread, Air to Ground, Separating	81
51. Doppler Spread, Air to Ground, Orthogonal	81
52. Doppler Spread, Air to Ground 315 Degree Heading	82
53. Doppler Spread, Air to Ground 243 Degree Heading	83
54. Possible Air to Air Scenario	84
55. Change in Bistatic Detection Regions	85
56. Doppler Spread, Closing (Separation = 200 KM)	86
57. Doppler Spread, Closing (Separation = 175.3 KM).	87
58. Doppler Spread, Receding (Separation = 175.0 KM).	87
59. Doppler Spread, Receding (Separation = 200 KM)	88

List of Tables

Table		Page
I.	Comparison of Pulse Width, Isomin and Ellipsoid Width	62
II.	Signal to Clutter Values Generic Waveform	74
III.	SCR Values Generic Waveform, Ground Transmitter	75
IV.	Doppler Shift Versus Velocity	84

Abstract

This thesis examined the effects of system configuration and transmitted waveform as applied to an airborne bistatic radar. The study concentrates on the limiting effects of the transmitted signal parameters, the signal to clutter ratio, and the doppler spread of the receiver beam.

The analysis was performed by constructing a computer model to graphically display the results of the applicable equations. The equations developed in this study are: The power limited region equation, the isorange equation, the isodoppler equation, and the signal to clutter ratio. These equations and those of ellipsoidal geometry were used to develop the bistatic radar model.

AIRBORNE BISTATIC RADAR

LIMITATIONS AND SAMPLE CALCULATIONS

I. Introduction to Bistatic Radar

Airborne Bistatic Radar

An Airborne Bistatic Radar System is an electro-magnetic detection device, composed of separate transmitter and receiver platforms, used to find range and velocity characteristics of objects by measuring time of flight and doppler shift of the transmitted signal. The receiver is always mounted on an airborne platform.

Assumptions

A basic assumption of this thesis requires that the transmitter and receiver are synchronized in some fashion. Further, it is assumed that the receiver processor has the ability to detect the signal and do whatever processing is required. These assumptions were set by the Tactical Surveillance Division, Rome Air Development Center, Griffiss AFB, NY. This thesis concentrates on the limiting effects of the transmitted signal parameters, the signal to clutter ratio, and the doppler spread of the receiver beam. The signal detection and estimation problem as well as the synchronization problem are under investigation by others.

The Problem

The airborne receiver platform motion is not constrained to any velocity or motion with respect to a transmitter. Therefore, the received signal is subject to the inherent characteristics resulting from bodies with independent motion; in particular, the doppler shift of any signal which would travel between the transmitter and the receiver, or between the transmitter, a target and the receiver platform. This thesis outlines the characteristics of a signal which limit the surveillance area of the receiver platform. A computer model has been developed to incorporate the concepts outlined in this study. The model (see Appendix A) provides an analysis tool for bistatic radar development.

Developments in the radar field have moved rapidly forward with the marriage of the digital computer to the radar detection arena. The terminology in a bistatic radar system is built upon a traditional base. However, new terminology must be introduced to explain the change in the problem and system configuration. The terminology, limitations and major components of the bistatic system are outlined in chapter II. The configuration of the platforms and characteristics of the transmitted waveform are discussed as well as some advantages of a bistatic system. A list of current research is also provided.

Analysis of the Problem

The defining parameters and equations are developed in chapter III. In particular, the range, geometry and system

performance equations are developed to demonstrate the system configuration as well as the ability of the system to perform.

Limiting Regions. The limiting regions of the bistatic radar are defined by two equations. The power and the isorange equations are developed to explain the viewing area of a bistatic radar and its unique blind zone. For example, there is a minimum and a maximum range associated with the isorange equation which is independent of the power equation.

Doppler Effects. The bistatic doppler equation is not the same as the monostatic radar doppler equation. The motion of the three objects (receiver, transmitter, and target) must be considered in their relative radial velocities with respect to each other. The doppler equation must also account for the secondary doppler shift (and relative change in wavelength) as the signal travels from the transmitter, strikes the target, and is reradiated to the receiver platform.

Signal to Clutter Ratio. The signal to clutter power ratio (SCR) is defined and parameters of interest are explained. The clutter cell area is defined and its affect on the SCR is shown. A surface cross section per unit area is modeled from previous work and incorporated into the model.

Finally the doppler spread of the clutter cell is developed. The equations for the doppler spread show that the bistatic system is dynamic and dependent upon the motion and beam shapes of the transmitter receiver pair.

Demonstration of the Model

The results of the analysis were put into an interactive computer model which was exercised to demonstrate some of the features outlined in chapters II and III. Chapter IV contains the results of the simulation. The waveform limited regions are shown to be dependent upon the pulse repetition frequency (prf), the pulse width and the prf multiple. The effects of these variables are shown in graphical form. Doppler contour maps of the system are shown to explain the effects of the transmitter receiver target motion. The maps demonstrate the effects of the relative velocities of the transmitter and receiver on the ground plane.

Signal to clutter tables and graphs are provided. The effect of changes in target radar cross section on the SCR is demonstrated. The doppler spread of the receiver beam is also shown in graphical form. It is demonstrated by the graphs that the effects of the platform motion as well as the receiver look angles have predictable results. The doppler spread is shown to be a well behaved phenomenon. Finally, a sample air to air senario is provided to show the dynamic nature of the system.

Findings and Conclusions

A summary of the detection regions and the minimization or maximization of the detection regions is provided in chapter V. ~~Several recommendations for follow on analysis~~ are provided.

II. Bistatic Radar

Background

The idea of a passive radar excites the imagination of the Air Force information gathering community. If it were possible to build a radar system which used separate transmitter and receiver locations, extra protection would be afforded to the radar receiver because the radar receiver would not broadcast its presence. Further, the passive radar receiver would be less vulnerable to classic anti-radar techniques such as anti-radar missiles or electronic counter measures. A passive radar system would require the presence of a usable host signal. The host signal would be cooperative if the transmitter and receiver were working together. A non-cooperative host would be a transmitter whose broadcast energy were being used without the transmitter's knowledge.

Several studies have been commissioned to explore methods of realizing a passive bistatic radar system. For example, the study of bistatic radar cross sections (5; 6; 8), separate host receiver synchronization methods, (1; 3; 4; 10), and a synthetic aperture mapping demonstration (1) are available. XonTech explored the possibility of using a non-cooperative host acquisition technique and delineated the receiver criteria for using such a separate host receiver system (4:21).

Historic Background of Radar Systems. The historic background of radar systems is flecked with use of multi-static systems. The early systems developed in Germany and England were bistatic. An array of receive antennas were placed at known distances from the transmitter antenna. The radar returns were monitored and useful information was obtained by triangulation between several receivers. The use of fence radar systems employ this technique. Some of the Early Warning nets used this technique (12:36-2).

During the Second World War, technological breakthroughs eliminated the need for separate receiver and transmitter antenna. As knowledge of radar waves increased, techniques were developed for protecting the receiver from the transmitter antenna power during transmission. Techniques used included the use of recirculators and duplexers. The elimination of the need for the separate transmitter and receiver antennas led to the development of the monostatic radar. These systems were attractive due to the improvement in calculation of range and doppler information. The classical radar range and doppler equations (11:4) provided useful range and velocity values. The radars were useful in developing air control radar systems. As more radar propagation knowledge was gained, it became feasible to mount a radar on an airborne platform. The radar was used to provide navigation and surveillance information (14:6).

Historically, the processing of the radar returns was done with analog computing devices. The marriage of the

digital processor to the radar family has greatly expanded radar system capabilities. The growing level of sophistication of the Electronic Counter Measure (ECM) capabilities has generated a new interest in the Bistatic Radar System. The Bistatic Radar returns are subject to the same type of counter measures, but the ECM, for effective bistatic black-out, would require a system much broader in power and technical complexity (9:24).

Problem

An important aspect of the bistatic radar problem is the interpretation of the data which the system delivers. The bistatic system does not use the classical radar range equation (12:557). Additionally, the system will perceive different doppler shift (change in transmitted signal frequency) effects due to the movement between the transmitter, the target, and the receiver (15:25). The classical model has a doppler shift which is twice the velocity divided by the transmitted wave length ($2V/L$) (14:592). The doppler shift in bistatic model is due to the combined effects of the radial velocity between the transmitter and target divided by the transmitted wavelength (V_o/L_o) and the radial velocity between the target and receiver divided by the wavelength of the reflected frequency (V_l/L_N). The system is best understood using the concepts of isoranges and isodops. The isorange curve gives regions of constant range and is the solution of the bistatic radar range equation for a specific

set of input values. The isodop is a curve of constant velocity which results from the bistatic doppler equation.

The purpose of this study is to build an analytic computer program model to study the airborne bistatic radar case. The model will be used to develop isorange and isodop maps to explore the possible airborne bistatic system configurations (e.g., Air to Air, Air to Ground).

The bistatic radar problem can be solved for many configurations for the transmitter receiver pair. The model developed in this study is general in scope but is limited to pulse doppler radar waveforms. The general case is developed but the specific case study is limited to a High PRF (25,000 Hz), Multiple PRF (4), S-Band airborne receiver. The receiver is assumed to be capable of acquiring and processing the host transmitter waveform. The actual method for acquiring the signal is not a part of this study. This study concentrates on limitations imposed by the signal characteristics.

Definition of Key Terminology

The airborne bistatic radar system is composed of several components of the classic monostatic radar system. The configuration of these components, and more specifically, the roll of these components is the important issue in understanding the airborne bistatic case. The signal (waveform) properties of the host signal transmitting system determine the performance of the radar system. The receiver's acquisition of the signal requires techniques which vary

depending upon whether or not the system is cooperative or non-cooperative. For example, a cooperative system would be in constant contact (e.g., a secure data link) to assure beam synchronization while a non-cooperative system would most likely be constantly chasing the source beam in the "expected" trace region. The bistatic system is sensitive to the power limitations imposed by the classic radar range equation. Assuming the receiver acquires the signal, the signal characteristics have a direct effect on performance (range).

Major Components. The major components of the Bistatic system are the transmitter, target, and receiver. The bistatic receiver is separate from the transmitter by definition (15:1). The role of each component is important in quantifying system performance.

The airborne receiver is the key element of the bistatic system. It is responsible for acquiring the signals emitted by the transmitter. The emitted signal is acquired on two paths: A direct path between the transmitter and receiver and the bistatic reflected path from the transmitter to the target to the receiver. The airborne receiver platform is assumed to be a surveillance - listening - system which flies a constant elevation orbit in a sanctuary zone a considerable distance (100-200 Kilometers) from the transmitter.

The transmitter is any radar (airborne or ground based) which emits a waveform that can be processed by the receiver.

The transmitter may be stationary or mobile.

The target is any object that reflects the transmitted energy and produces a bistatic reflection which is monitored by the receiver. The target has characteristics of cross section and velocity which affect the bistatic radar equations as a function of the radial distance and radial velocities.

Signal Properties. The bistatic system is capable of operating using cooperative and non-cooperative host transmitters. Accordingly, the acquisition and processing of the signals is a prime consideration. A PRIORI knowledge of the signals increases the accuracy of the information gleaned from the output of the receiver. This requires some practical considerations for system performance characteristics which are limited by bandwidth and host transmitter power.

There are several methods for signal acquisition proposed in the literature. A non-cooperative system requires the receiver to search the frequency spectrum for a waveform with the desired characteristics (4:2). The waveform must be capable of being processed by the receiver hardware. For example, a pulse doppler processing system may not be able to process a Continuous Wave Frequency Modulated (CW-FM) signal. A cooperative system could use flight path synchronization (9) or secure data links to periodically update the system synchronization (1).

Synchronization of the beam between the transmitter and the receiver is important (14:577). The transmitter beam systematically sweeps out a volume of space. The bistatic

signal reflections (returns) available during the sweep are limited by the beam shape and power density. A cooperative host-receiver system has the option of a direct data link to enhance signal synchronization and information. Knowledge of the beam sweep pattern will allow the receiver to search in the expected return area. A non-cooperative host system requires the same synchronization. Because the non-cooperative host receiver system is not capable of perfect phase synchronization, the phase information is not available to the receiver processor. The loss of phase limits the overall system performance but the loss of phase information does not preclude the use of non-cooperative hosts in pulse doppler radar applications.

A method to avoid the high cost of beam synchronization is the use of a multiple beam search antenna system (Figure 1). An array of beams searches the volume of space where the transmitter is providing illumination (9:39; 14:577). Beam synchronization is limited to systems where the expected transmitter sweep pattern can be replicated. For example, a scanning search radar system has physical limitations in antenna movement and pointing capabilities. A phased array which could change wavefront direction at whim without consideration of antenna orientation would be a poor host.

Acquiring the bistatic signal return does not guarantee any meaningful results from the receiver data processing system. The bistatic return is subject to multipath and clutter constraints as well as time of flight versus power

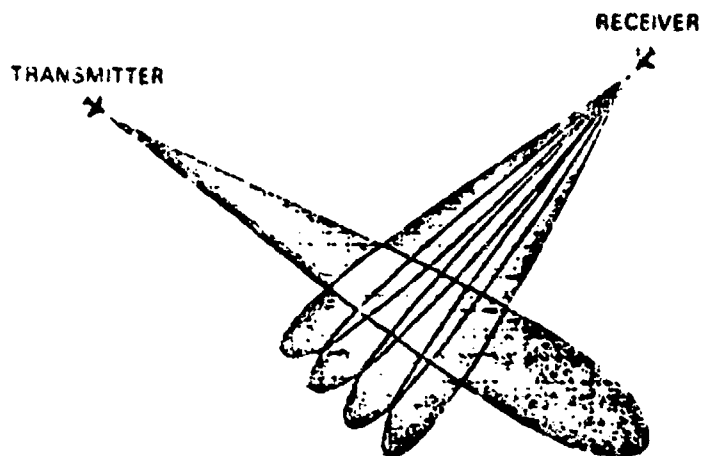


Figure 1 Search With Multiple Receiver Antenna Beams

considerations. Assumptions about the non-cooperative transmitter waveform limit the potential host exploitation. Further, a non-cooperative host which could reconfigure its waveform parameters is a poor host candidate for the bistatic receiver. The ability to capture meaningful data is the prime concern for the receiver.

The extraction of information contained in the bistatic signal return is limited by the transmitter, target and receiver. The bistatic signal return contains information in the time domain which is decoded into range information of the transmitter-target-receiver family. Additionally,

the bistatic signal return contains frequency domain information which decodes into the relative radial velocities of the system components. The frequency domain information is limited by the PRF and pulse width.

The transmitter power limits the detection region of the bistatic system because the receiver is assumed to be completely passive. Reliance on a host limits the range of the system under certain conditions. For example, Westinghouse asserts that under certain conditions (Bistatic baseline separation is less than 1.5 times the nominal Monostatic target detection range) the loss of coverage area relative to the Monostatic radar is insignificant (2:3-124). The passive nature of the receiver limits the radar range equation variables controllable by the receiver (e.g., SNR, front end temperature K, antenna gain, etc.). These variables are usually hardware dependent and not dynamically adjustable.

The Ovals of Cassini are used to describe the power limitations of a Bistatic System (12:36-41). The Ovals of Cassini describe the region where the receiver is capable of detecting useful information. Refer to Figure 5 and accompanying text for a complete development of the Ovals of Cassini.

The transmitter beam characteristics affect the system. The main beam lobe carries most of the power and is most capable of detection. The limitations imposed by jamming of the main lobe will not be as critical due to the bistatic

return geometry because the bistatic return pattern is not the same as the monostatic return (9:23). This study will not consider side lobe returns.

Physical Properties of the Transmitted Waveform. Physical properties of the transmitted waveform are critical in the analysis of the bistatic problem. A class of pulse doppler radar waveforms is examined in this study. The class is limited to a generic waveform which is realizable. The pulse repetition frequency, the pulse width, and receiver bandwidth are critical design parameters. Westinghouse asserts:

These factors, as well as legal frequency allocation requirements, drive radar designs to operating in one restricted frequency band with an instantaneous bandwidth only wide enough to provide the range cell length needed by the system. For typical long range airspace surveillance radars, effective pulse widths in the vicinity of 0.5 to 2 microseconds limits the instantaneous bandwidth to about 0.5 to 2 MHz [2:3-127].

The Pulse Repetition Frequency (PRF) is the frequency at which the transmitter emits pulses. The PRF is the reciprocal of the time between pulses ($1/T$). The use of multiple PRFs (11:114) increases the range effectiveness of the radar.

Clutter is any radar return (monostatic, bistatic, or multistatic) which is not desired. A large signal return due to background could hide a possible target. Clutter echos greatly distort the information being processed by the system. One of the secondary concerns of the bistatic radar range and doppler problem is the need to quantify the

clutter phenomena of the bistatic system. A clutter threshold is usually established to limit the unwanted signal returns on a system. The effects of reducing clutter will have a significant effect on the detection of targets with small radial velocities.

The doppler shift in a bistatic signal return is not the same as the monostatic return. The equations are more difficult because the transmitter and receiver are not co-located. The bistatic doppler shift is a result of a shift due to the radial velocity of the target to the transmitter, and a second shift due to the radial velocity of the target with respect to the receiver.

The solutions to the bistatic range and doppler equations result in solution families. These solution families are more clearly expressed in graphical form using Isorange and Isodoppler contours. The Isorange contour (Figure 2) is the family of possible solutions to a radar range return. Without any prior knowledge of the transmitter/receiver/target configuration, the isorange contour indicates possible locations for the target. The isodoppler contours (Figure 3) are the family of constant velocity curves (as a result of doppler shift).

Advantages

Some advantages of multistatic systems are apparent when applied to information gathering environments. Advantages include:

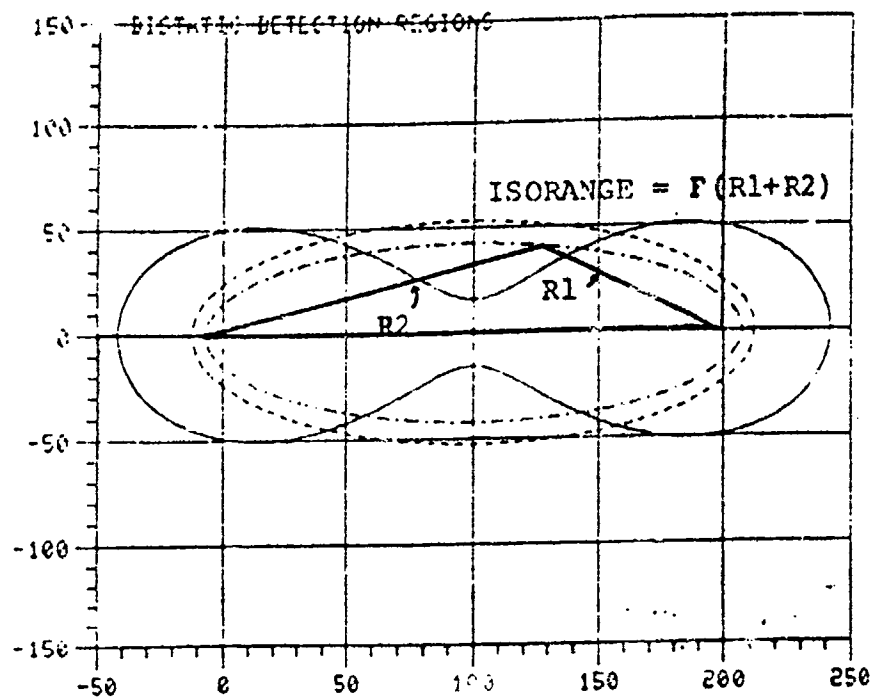


Figure 2 Isorange Curves

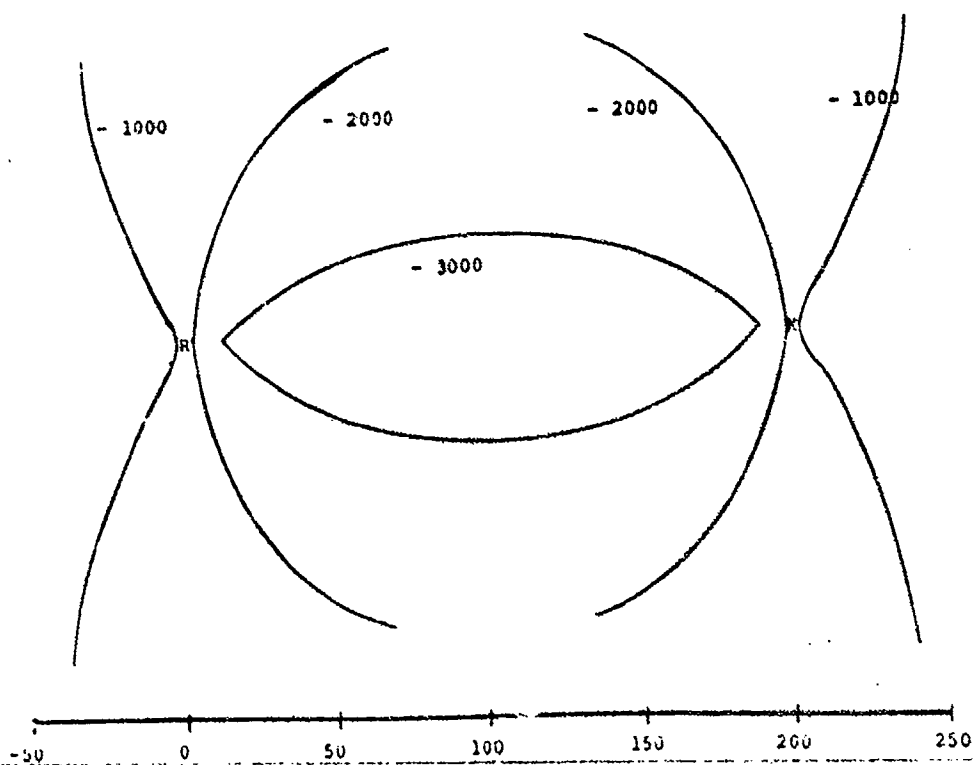


Figure 3 Isodoppler Curves

1. Undetectable position of the Receiver
2. Accuracy in Ranging
3. Operation of the Receiver in Sanctuary
4. Cost Savings

An airborne bistatic system would offer some surveillance advantages in that the radar receiver would not broadcast its presence. Transmitter detection of the receiver is a function of the transmitter's power, coupled with the receiver's distance (two way), the radar cross section (RCS) of the receiver. The receiver could be outside the transmitter's detection region and still be well within the exploitation region.

Farina and Hanle have demonstrated that a multistatic ranging system is more accurate provided the target is within the triangulation perimeter (3:517). The airborne bistatic radar system could operate in the confines of a netted system but would require multiple receivers to do triangulation to improve accuracy. In general, the bistatic radar system will not be as accurate as a monostatic system.

If the radar could operate at great ranges (100-200 KM), the receiver is operating in a relatively safe zone or sanctuary. The limitations of the distance between the transmitter and receiver imposed by power, coupled with the limitations imposed by waveform, describe the safe zone operating limits.

While the receiver would require more computing resources, the savings in design costs, by eliminating the

waveform generator portion of the airborne system, is an attractive trade-off option. Additionally, the savings in receiver platform fuel consumption due to weight elimination and power generation could be attractive.

Summary of Current Research

The Bistatic Radar Problem is a complex, multifaceted arena with many potential areas for investigation. Current issues being studied by the technical community include: Bistatic Cross Sections, Scintillation Effects, Polarization Effects of Returns, Synchronization Techniques, and Signal Acquisition Techniques.

The bistatic radar cross section is not the same as the monostatic radar cross section. The monostatic signal return is a function of the target distance and cross section. The bistatic cross section is generally larger because of the larger forward energy reflection (15:3). The cross section returns are dependent upon the type of material and the type of background. Many technical communities are working to develop models to analytically predict the returns due to targets, ground, sea, and terrain. Specific studies representing key areas of interest include:

1. RCS Prediction of Low Observable Coated Objects (5)
2. Ground Clutter (13)
3. Chaff (8)
4. Sea/Terrain Scattering Coefficients (4)

A Bistatic Synthetic Aperture Radar (SAR) Self Synchronization Technique has been proposed by Westinghouse as a result of their studies of bistatic radar platforms (1). The report outlines a synchronization method which could be used between a receiver and a cooperative host. The concept of a Bistatic SAR was proposed and demonstrated in the T-Bird program (Morenno). The T-Bird Program demonstrated the ability to gather data via a separate airborne transmitter receiver pair.

III. Development of the Bistatic Model

Defining the Parameters

The bistatic model used in this study assumes the use of a pulse doppler radar system. The model assumes the receiver hardware is capable of detecting and analyzing the radar return. The parameters used in the model are the common variables affecting any pulse doppler signal processing system. The model consists of a computer program which uses the parameters, formulas, and concepts explained in this chapter (see Appendix A for a complete listing). The computer program assumes the default parameters of the E3A AWACS Waveform but can be modified interactively. The system parameters include:

- Pulse Repetition Frequency (PRF)
- Number of distinct carrier frequencies used (NPRF)
- Pulse Duration (TPULSE)
- Carrier Frequency (FO)
- Signal to Noise Detection Ratio (SNR)
- Transmitter Power (P)
- Gain of the Transmitter Antenna (GT)
- Gain of the Receive Antenna (GR)
- System losses due to physical construction (LOSS)
- Receiver Minimum Signal to Noise Detection Ratio (SNR)
- Average Target Radar Cross Section (RCS)
- Receiver Temperature (T)
- Receiver Bandwidth (BW)
- Signal to Clutter Power Ratio (SCR)
- Doppler Frequency Shift of the Clutter Cell (FSC)
- Area of the Clutter Cell (AC)
- Density of the Clutter Cell (SO)
- Receiver horizon to target depression angle (RSEL)
- Transmitter horizon to target depression angle (XSEL)
- Receiver baseline to target azimuth angle (RSAZ)
- Transmitter baseline to target azimuth angle (XSAZ)
- Transmitter Azimuth Beam width (XSAZ)
- ~~Receiver Azimuth Beam width (RSAZ)~~
- Transmitter Elevation Beam Height (XSEL)

Receiver Elevation Beam Height (RSEL)
Bistatic Angle: Transmitter to Receiver as seen from
target (A-B)
Out Of Plane Azimuthal Angle between beams (PHI)
Receiver Altitude (RALT)
Transmitter Altitude (XALT)

The bistatic airborne system model is developed in the rectangular coordinate system (X, Y, Z). The Receiver/Transmitter/Target set have specific physical relationships (Figure 4). The receiver antenna is the base for all measurements. The receiver antenna is assigned to position $X = 0$, $Y = 0$, $Z = RALT$ (RALT default is 9) because the receiver is assumed to be airborne at a constant surveillance elevation. The target can be anywhere in X, Y, Z space. The direct path between the transmitter and the receiver is known as the baseline in the bistatic model. Therefore, the model assumes the transmitter is located at a point along the X axis ($X = SEP$) and at an altitude $Z = XALT$. This corresponds to position SEP, 0, XALT. Note that all distances used in this model are in kilometers.

The number of parameters makes the assignment of meaningful variables difficult. The use of some self imposed rules helps to aid in clarity. The transmitter variables are prefixed with X and the target variables are prefixed with T. For example, the transmitter azimuth angle is coded XAZ while the target azimuth angle is coded TAZ.

The basis for the mathematical development considers a receiver at reference position 0, 0, RALT (X coordinate,

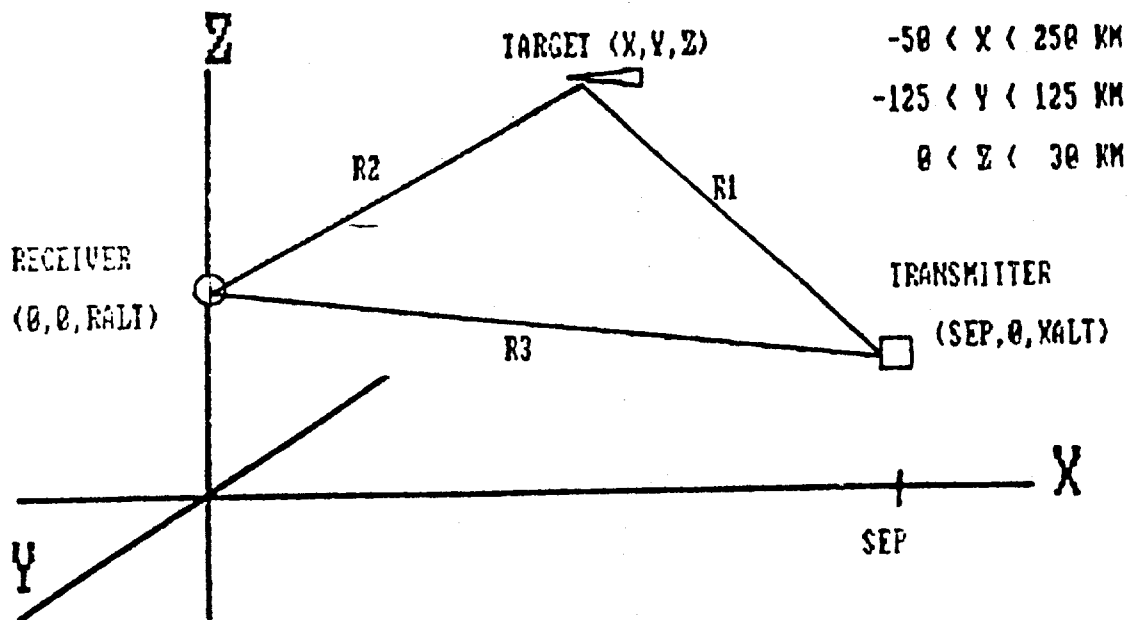


Figure 4 Bistatic Coordinate System

Y coordinate, Z coordinate); a transmitter at position SEP, 0, XALT; and a target anywhere in XYZ space such that:

$$\begin{aligned} -50 &< X < 250 \text{ kilometers} \\ -125 &< Y < 125 \text{ kilometers} \\ 0 &< Z < 30 \text{ kilometers} \end{aligned}$$

Radar Range Equation. Classical analysis of radar problems begins with the radar range equation (12:19). The equation contains the parameters of interest which are affected by any radar system.

$$R^4 = \frac{P_{GT} G_R C^2 R_{CS}}{(4\pi)^3 F_0^2 BW L SNR T K} \quad (3.1)$$

P = Power of the Transmitter (Watts)
 GT = Gain of the Transmitter Antenna
 GR = Gain of the Receive Antenna
 L = System Losses Due to Physical Construction
 SNR = Receiver Minimum Signal to Noise Ratio Detection
 C = Speed of Light (3×10^8 Meters per Second)
 K = Boltzmann's Constant (1.38×10^{-23} Joules per Degree Kelvin)
 $\pi = 3.1416$
 RCS = Average Target Radar Cross Section (Square Meters)
 T = Receiver Temperature (Degrees Kelvin)
 BW = Receiver Bandwidth (Hertz)
 FO = Transmitted Frequency (Hertz)
 R = Distance from Transmitter/Receiver to Target (Meters)

Note that the radar range equation can be rewritten:

$$K = \frac{P \text{ GT } C^2}{4 \pi R_1^2 \text{ FO}^2} * \frac{\text{RCS}}{4 \pi R_2^2} * \frac{\text{GR}}{4 \pi \text{ BW } L \text{ T } \text{SNR}}$$

< Transmitter > < Target > < Receiver >

Note the separation of the parameters into transmitter, target, and receiver dependent areas. These are the parameters which are varied to examine the bistatic case.

Bistatic Geometry. The geometry of the bistatic radar system is ellipsoid. The transmitter and the receiver are the foci of the ellipsoid. The surface of the ellipsoid

forms a family of solutions to the isorange equation problem. The general equation for an ellipsoid (13:51) is:

$$\left(\frac{X-X_0}{A} \right)^2 + \left(\frac{Y-Y_0}{B} \right)^2 + \left(\frac{Z-Z_0}{C} \right)^2 = 1 \quad (3.2)$$

In this case, the parameters B and C are equal because the ellipsoid has no eccentricity. The values of A and B are developed later in the minimum and maximum isorange solution section.

Recall from Figure 4 that the model requires the receiver to be positioned at point 0, 0, RALT and the transmitter to be positioned at some point along the X axis specified as SEP, 0, XALT. If the transmitter is at the same altitude as the receiver (XALT = RALT), equation 3.2 becomes:

$$\left(\frac{X-SEP/2}{A} \right)^2 + \left(\frac{Y}{B} \right)^2 + \left(\frac{Z-RALT}{B} \right)^2 = 1 \quad (3.3)$$

The detection region of the bistatic system is limited by the power of the transmitter. The transmitted waveform must have enough power to travel (Figures 4 and 6) a distance from the transmitter to the target (R1) and then a distance from the target to the receiver (R2) and still provide a large enough signal to noise power ratio (SNR) to insure accurate detection. The maximum detection range is given by a set of curves referred to as the Ovals of Cassini as shown in Figure 5. Any target inside the oval provides

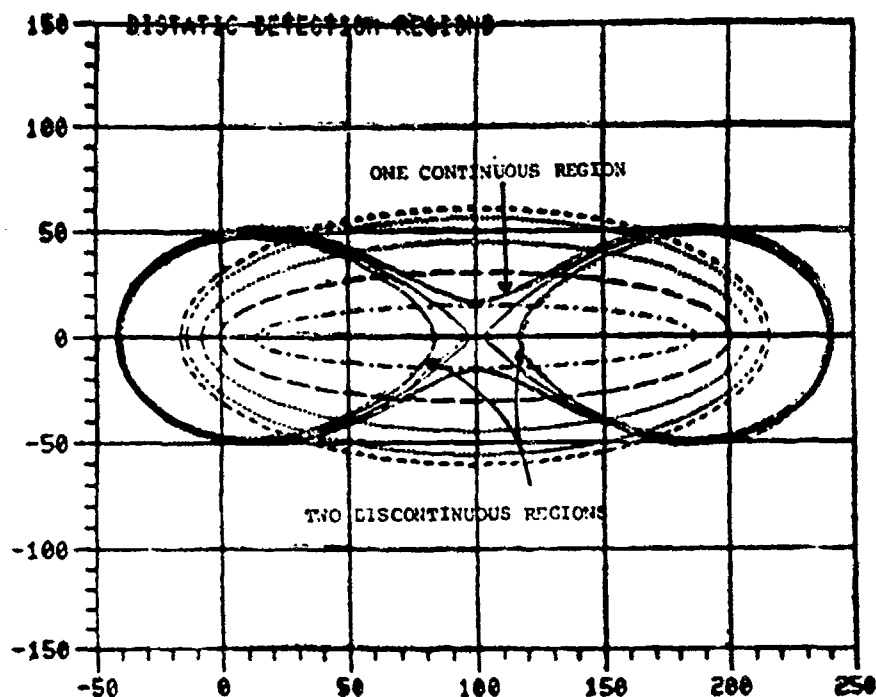


Figure 5 Ovals of Cassini

at least the minimum signal to noise ratio at the receiver antenna. Note that it is possible to have two completely disjoint regions of detection. The transmitter power affects the detection region. The solution set to the ovals of Cassini will yield either two distinct regions, two adjacent regions, or one region.

The bistatic radar cross section of a target varies from the monostatic cross section. Investigation into the error between monostatic and bistatic cross section has shown that the Bistatic Monostatic Equivalence Theorem is valid only for small bistatic angles (15:3). The model allows for changing the RCS, but offers no monostatic bistatic comparison.

The bistatic radar range equation varies from the monostatic by simple substitution of Eq (3.5) into Eq (3.1). The power radiated from the transmitter spreads in a sphere. The gain of the transmitter antenna accounts for the directionality of the density. The radiated power has a specific density which is a function of the square of the distance from the target to the transmitter. At that point, the cross section of the target reflects some of the power. The reflected power acts as if the target were an isotropic radiator. The reflected power spreads in a sphere. The density of the reflected power is a function of the square of the distance between the target and the receiver.

$$R^4 = R_1^2 R_2^2 \quad (3.5)$$

Observe that the maximum range (R^4) is a constant. The Range constant (R^4) is a product of the squares of the transmitter to target range (R_1) and the target to receiver range (R_2). Therefore, the bistatic radar range equation becomes:

$$R_1^2 R_2^2 = \frac{P_{GT} GR C^2 RCS}{(4\pi)^3 F_0^2 BW L SNR T K} \quad (3.6)$$

The transmitter and target coordinates and the Pythagorean Theorem combine to show:

$$R_1^2 = (SEP - X)^2 + Y^2 + (Z - XALT)^2 \quad (3.7)$$

Applying the same to the target receiver pair:

$$R_2^2 = X^2 + Y^2 + (Z - RALT)^2 \quad (3.8)$$

Therefore:

$$R^4 = [(SEP - X)^2 + Y^2 + (Z - RALT)^2] \\ [X^2 + Y^2 + (Z - RALT)^2] \quad (3.9)$$

Ability of System to Perform. The Bistatic Radar Iso-range curves (Figure 6) are calculated by extracting information from the radar return signal. The specific measurements are the Distance (SEP) between the transmitter and the receiver, the Angle (ON) between the transmitter and the target as measured from the receiver, and the time difference (DT, Figure 7) between receiving a direct signal (transmitter to receiver) and the next large return (transmitter to target to receiver).

The geometry of the airborne bistatic radar system yields ellipsoidal isorange curves. The key to understanding the equations is to have a consistent frame of reference. Although the system may consist of three airborne entities (target, receiver, and transmitter), the coordinate system is defined by making the receiver the reference point. This point will be relative in XYZ space by always viewing the receiver as being at the origin of the X and Y axes and at altitude $Z = RALT$ KM (0,0,RALT). All distances will be measured with respect to the receiver. The "BASELINE" is

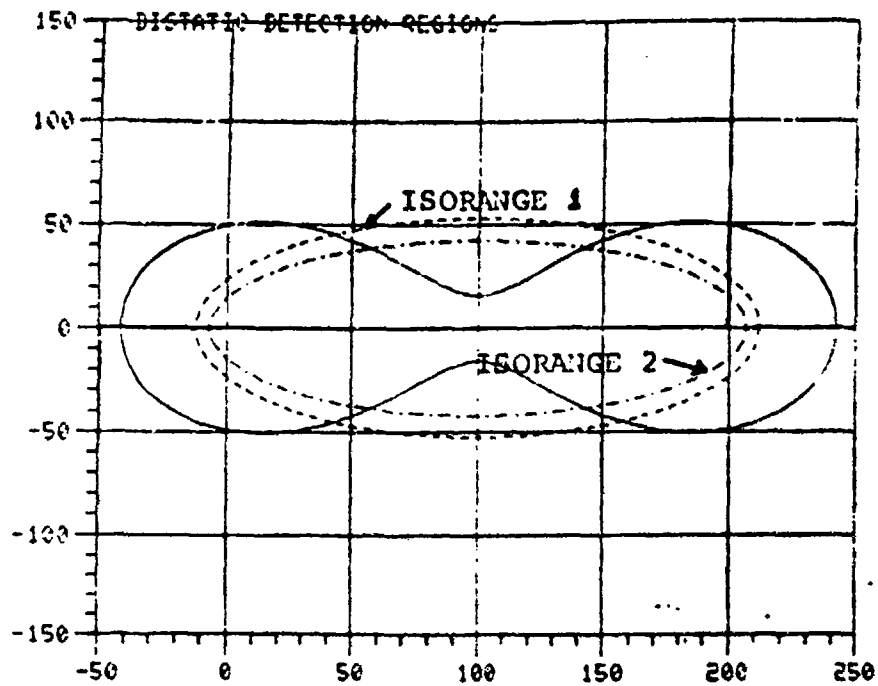


Figure 6 Ellipse of Constant Range

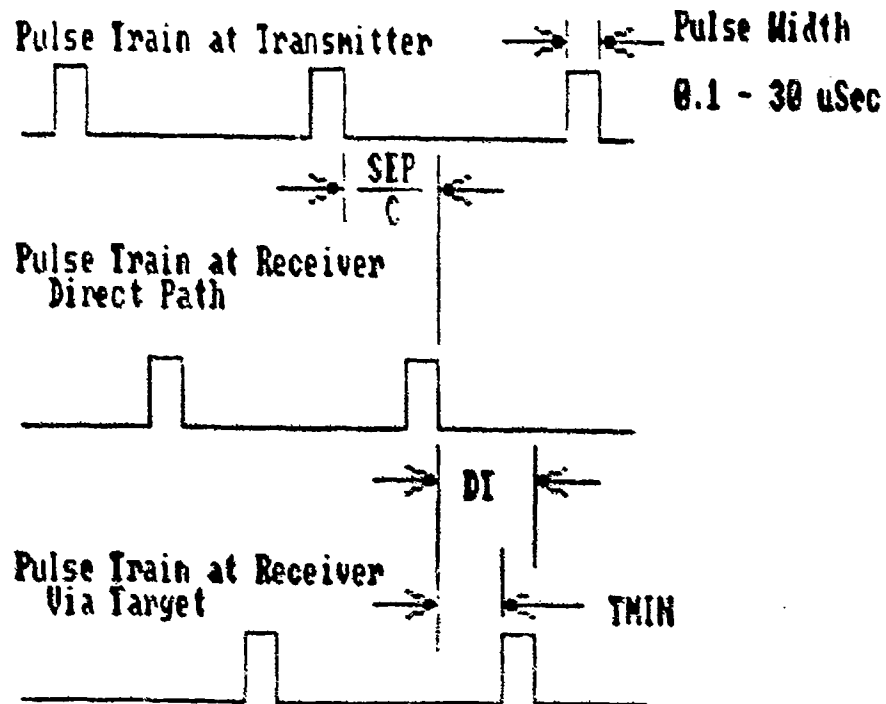


Figure 7 Pulse Reception Characteristics

the imaginary line between the receiver and the transmitter. The baseline lies along the positive X axis. Therefore the transmitter is always located at some separation distance and some altitude point (SEP,0,XALT).

The time required for a signal to travel from the transmitter to the target and then to the receiver is DT seconds longer than the time required to travel directly from the transmitter to the receiver. The relationship of the triangular distances is:

$$R1 + R2 = C * DT + SEP \quad (3.10)$$

This result is a family of solutions ($R1 + R2$) which traces out an ellipsoid. The point on the surface of the ellipsoid is a solution of interest. This family of solutions is called an isorange. Obviously, a different DT measurement results from a different isorange curve.

Figure 7 points out several areas of concern. As DT grows small, separation of the pulses (TMIN) in the presence of noise becomes extremely difficult. Even if there were an absence of noise, separation of the pulses is difficult as TMIN approaches zero. At some point, the two pulses will overlap. The receiver is unable to extract any information from the signal. This occurs when the distance between the target and receiver grows small ($SEP = R2$) or when the bistatic angle ($A-B$) approaches 180 degrees. The receiver must be able to detect two separate signals. This

blind area is a disadvantage of the bistatic model. The blind zone is treated in more depth in the ISOMIN Development Section.

The receiver antenna is assumed to be a directional scanning antenna. The receiver knows where it is looking at all times. Therefore, when a signal is detected, the bistatic angle (A-B) is known within the limits of the antenna beam shape. If multiple beams are used, a volume of space can be scanned with greater resolution. Knowing the bistatic angle (A-B) gives a specific solution to the isorange family. The accuracy of solution is directly dependent upon the beam width of the antenna which in turn limits the ability to separate the target and transmitter returns. Several alternate solutions have been offered for solving this problem (9:1).

One possible solution comes from basic geometry. This short derivation is provided to show one possible method for receiver calculation to target location. Knowing (A-B) the calculation of R1 and R2 is possible. Therefore, the target range and direction can be determined. R2 is derived from the Law of Cosines:

$$R3 = \sqrt{SEP^2 + (XALT - RALT)^2}$$

$$R1^2 = R2^2 + R3^2 - 2 R2 R3 \cos (A-B)$$

and because the bistatic relationship to a family of solutions,

$$R1 + R2 = \text{Isorange Constant } (K8)$$

then,

$$R1 = K8 - R2$$

$$(K8 - R2)^2 = R3^2 + R2^2 - 2 R2 R3 \cos (A-B)$$

$$K8^2 - 2 K8 R2 + R2^2 = R3^2 + R2^2 - 2 R2 R3 \cos (A-B)$$

Rearranging,

$$R2 (2 R3 \cos (A-B) - 2 K8) = R3^2 - K8^2$$

and finally,

$$R2 = (R3^2 - K8^2) / (2 R3 \cos (A-B)$$

$$-2 K8)$$

Limiting Regions

The Power Limited Region. Note that the general solution to Eq (3.9) is greatly simplified by limiting the observation to a specific set. In the specific case, the parameters SEP, Z, XALT, and R^4 are constants which are dependent on the transmitter receiver target geometry and hardware. Equation (3.9) is solved for a specific Y in terms of X by use of the quadratic formula (13:32). The solution may yield one of the three region shapes shown in Figure 5 depending upon the values assigned to the constants.

$$\text{Let} \quad C1 = (Z - RALT)^2 \quad (3.11)$$

$$C2 = (Z - XALT)^2 \quad (3.12)$$

Then, from (3.9):

$$R^4 = [(SEP - X)^2 + Y^2 + C2] [X^2 + Y^2 + C1] \quad (3.13)$$

Expanding the terms and rearranging yields:

$$0 = Y^4 + (X^2 + (SEP-X)^2 + C2 + C1) Y^2 + X^2 \\ ((SEP-X)^2 + C1) + C1 [(SEP-X)^2 + C2] - R^4 \quad (3.14)$$

Note that this is in quadratic form:

$$AY^4 + BY^2 + C = 0$$

So:

$$Y^2 = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

And therefore:

$$Y = \pm \sqrt{Y^2}$$

Where:

$$A = 1$$

$$B = X^2 + (SEP-X)^2 + C2 + C1$$

$$C = X^2 [(SEP-X)^2 + C2] + C1 [(SEP-X)^2 + C2] - R^4$$

Let:

$$C3 = C2 + C1 + SEP^2 \quad (3.15)$$

$$C4 = -2 SEP \quad (3.16)$$

$$C5 = C1 C4 \quad (3.17)$$

$$C6 = C1 SEP^2 + (C1 C2) - R^4 \quad (3.18)$$

$$B4 = X^2 - X SEP + C3/2 \quad (3.19)$$

$$CC = X^4 + C4 X^3 + C3 X^2 + C5 X + C6 \quad (3.20)$$

Then solving for solutions of Y:

$$Y = \pm \sqrt{-B4 + \sqrt{(B4^2 - C3)}} \quad (3.21)$$

Isorange Formula Development. It was shown earlier that the solution set to the bistatic range equation resulted in a family of solutions. The family of solutions occupy an ellipsoidal space. That is to say, the solution set is the surface of an ellipsoid. Recall Eq (3.2). This equation can be solved for the roots of one variable (X, Y or Z). For this model, a plane of interest is specified ($Z = Z'$). The general solution set for Y in terms of X is:

$$\left(\frac{Y}{B}\right)^2 = 1 - \left(\frac{Z - RALT}{B}\right)^2 - \left(\frac{X - SEP/2}{A}\right)^2 \quad (3.22)$$

Then,

$$Y^2 = B^2 - (Z - RALT)^2 - \left(\frac{B(X - SEP/2)}{A}\right)^2 \quad (3.23)$$

or, considering both roots as solutions:

$$Y = \pm \sqrt{B^2 - (Z - RALT)^2 - \left(\frac{B(X - SEP/2)}{A}\right)^2} \quad (3.24)$$

This general equation holds only for an airborne to airborne transmitter receiver pair at the same altitude. It is more realistic to assume that the non-cooperative transmitter could be at an altitude of up to 30 kilometers. Allowing for this possibility adds complexity to the equation but only through a rotation and translation of the X and Z axes.

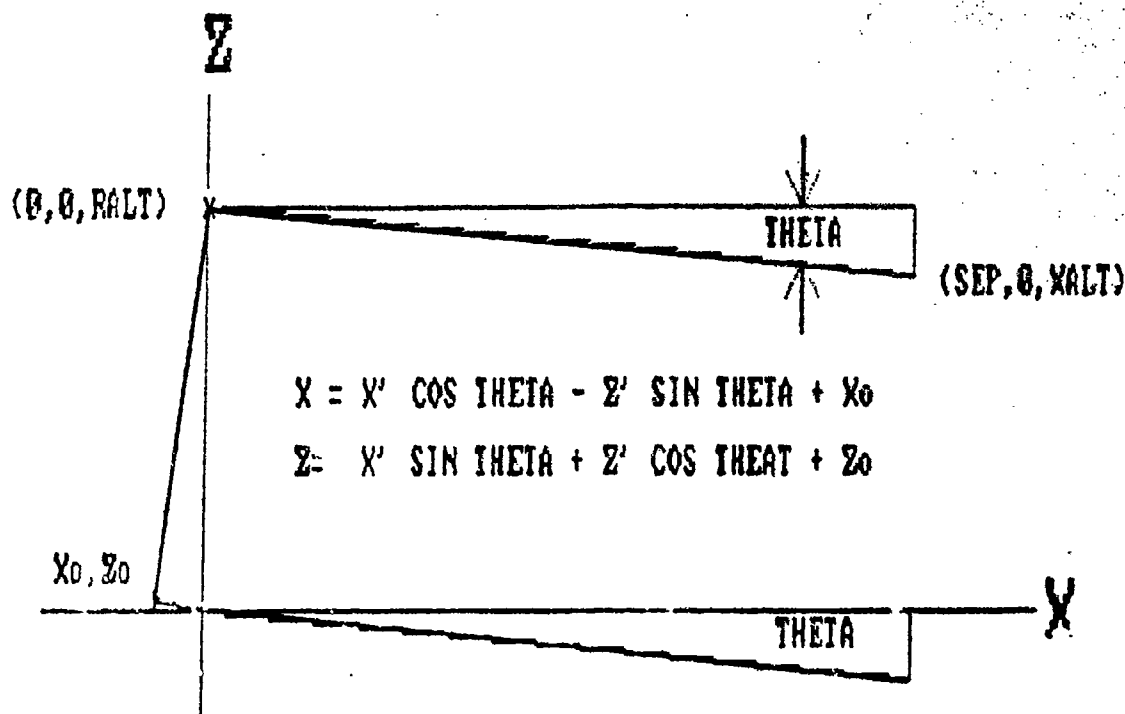


Figure 8 Rotation of the Bistatic Model

The rotation angle is $\theta = \arcsin((XALT - RALT) / SEP)$. This makes the coordinates of the new axis $X = RALT \sin \theta$, $Y = 0$, $Z = RALT (1 - \cos \theta)$. The transforming equations (13.36) are then:

$$X = X' \cos \theta - Z' \sin \theta$$

$$+ RALT \sin \theta \quad (3.25)$$

$$Z = X' \sin \theta + Z' \cos \theta$$

$$+ RALT (1 - \cos \theta) \quad (3.26)$$

Substitution of these transforms into the general equation yields:

$$\begin{aligned} Y^2 = B^2 - (X' \sin \theta + Z' \cos \theta + RALT \cos \theta)^2 \\ - (B/A)^2 (X' \cos \theta - \sin \theta (Z - RALT) \\ - SEP/2)^2 \end{aligned} \quad (3.27)$$

Assigning the following simplifying variables to the constants and dropping the prime notation gives:

$$C12 = \frac{B^2}{A^2} \quad (3.28)$$

$$\sin \theta = S\theta = (XALT - RALT) / SEP \quad (3.29)$$

$$\cos \theta = C\theta = \cos (\arcsin \theta) \quad (3.30)$$

$$C10 = Z \cos \theta - RALT \cos \theta \quad (3.31)$$

$$C11 = Z \sin \theta - RALT \sin \theta + SEP/2 \quad (3.32)$$

The equation in terms of X and Y yields,

$$Y = \pm \sqrt{B^2 - (X S\theta + C10)^2 - C12 (X C\theta - C11)^2} \quad (3.33)$$

Isorange Blind Zone (ISOMIN). The minimum isorange is the solution which yields the direct path between the transmitter and receiver. No target information is available along this path (4; 5; 15). Therefore, a starting point must be found at some practical range. A logical starting point is the edge of the "Isorange Blind Zone".

The blind zone (Figure 9) is the area which results from the receiver being unable to determine where the pulse traveling along the direct path between the transmitter and the receiver stops and the pulse traveling along a reflected path starts. This blind zone will be a function of the pulse duration (TPULSE). The minimum blind zone isorange is twice the pulse duration times the speed of light, plus the separation distance between the transmitter and receiver.

$$R3 = \sqrt{SEP^2 + (XALT - RALT)^2} \quad (3.34)$$

$$ISOMIN = (2 * TPULSE * C) + R3 \quad (3.35)$$

Beyond the blind zone the isoranges need to be incremented at some regular interval up to some limiting factor. The model limit is 300 Kilometers. Often the Pulse Repetition Frequency (PRF) will dictate a maximum isorange.

Maximum Isorange (ISOMAX). The PRF limitation occurs when the transmitted PRF becomes so high that the bistatically reflected pulse is not received until, during or after a second pulse is received on the direct path. At a low PRF,

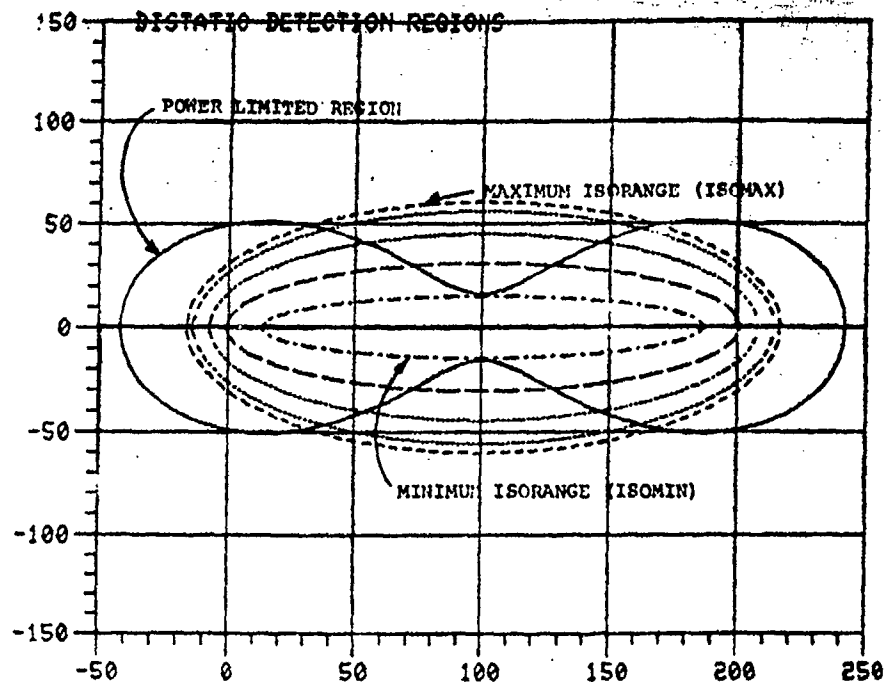


Figure 9 Isorange Detection Region

the direct pulse is received followed some time later by the target reflected pulse. However, when the PRF becomes sufficiently high, the time of reception of the bistatic pulse can be delayed long enough so that it overlaps the next direct pulse. The overlap begins to occur when the leading edge of the second transmitted pulse arrives before the trailing edge of the first bistatically reflected pulse (4:9):

$$R_1 + R_2 + TPULSE \ C > (C / PRF) + R_3 \quad (3.36)$$

This leads to the exclusion region (Figure 9) of the ellipse defined by:

$$R1 + R2 = (C / PRF) + R3 - TPULSE C \quad (3.37)$$

But, if multiple PRFs (NPRF) are used by the transmitter, the exclusion region can extend beyond these bounds (12:114). The maximum isorange (ISOMAX = R1 + R2) is therefore extended to:

$$ISOMAX = (NPRF * C / PRF) + R3 - TPULSE C \quad (3.38)$$

Incrementing the Isoranges. It is often necessary to draw several isorange curves between the minimum (ISOMIN) and the maximum (ISOMAX) isorange curves. Choosing 10 Kilometers as an interval, the first isorange is needed such that $ISOMIN < ISO(I) < ISOMAX$. Letting,

$$Q = INT [ISOMIN / 10]; \text{ Greatest Integer} \quad (3.39)$$

$$ISO(I) = I * Q * 10 \quad (3.40)$$

I is the incremented from 1 to some number (K) such that ISO(I) does not exceed ISOMAX or 300 Kilometers (limit of the model). For each ISO(I), a unique solution set for the equation is determined. From the properties of the ellipsoid (13:38):

$$A = ISO(I)/2 \quad (3.41)$$

and because

$$B^2 = A^2 - (SEP/2)^2 \quad (3.42)$$

$$B = \sqrt{A^2 - (SEP/2)^2} \quad (3.43)$$

For example, to determine A and B for $ISO(I) = ISOMAX$, the term A simplifies to:

$$A = (NPRF * C / PRF + R3 - TPULSE C) / 2 \quad (3.44)$$

Likewise, B reduces to:

$$B = \sqrt{[(NPRF * C / PRF) - TPULSE C] * [(NPRF * C / PRF) + (2 * R3) - TPULSE C]} / 2 \quad (3.45)$$

Note that in most applications, $TPULSE \ll 1/PRF$. This simplification holds for most systems as the prf is reduced to extend the system visibility. The zones are then separated by ellipses whose characteristics A,B reduce to:

$$A = ((NPRF * C / PRF) + R3) / 2 \quad (3.46)$$

and,

$$B = \sqrt{[(NPRF * C / PRF) * [(NPRF * C / PRF) + (2 * SEP)]]} / 2 \quad (3.47)$$

Development of the Bistatic Doppler Equation Model

The doppler shift of a signal for the monostatic system is a function of the frequency of transmission and the velocities of the transmitter, target, and receiver. The velocity of the target is always measured radially from the transmitter to the target. The radial velocity causes a positive (target and receiver are closing), negative (target and receiver are separating) or zero (target and receiver remain at a constant distance) shift in frequency.

The classical doppler model is based on a single frame of reference (transmitter and receiver are co-located). The doppler shift of a transmitted wave propagating through space from the transmitter, striking an object (the target), and being returned to the receiver is twice the radial velocity of the target divided by the transmitted wave length. The shift in the frequency between the transmitted signal and the returned signal is the doppler shift (12:69). Analytically:

$$FD = 2 V / L \quad (3.48)$$

Where:

FD = Doppler Shift (Hertz)

V = Radial Velocity Between Two Objects (Meters per Second)

L = Wave Length of the Transmitted Frequency (Meters)

The frequency, wave length, and speed of light relationship (12:69) is:

$$C = L F_0 \quad (3.49)$$

Therefore,

$$F_D = 2 V F_0 / C \quad (3.50)$$

The bistatic doppler model is not as easily derived. This results because the transmitter and the receiver are not located at the same point in space. In fact, it is conceivable to imagine the transmitter receiver pair separated by large distances (several hundred kilometers). The net doppler shift of the transmitted frequency (F_F) is a function of the radial velocity of the transmitter with respect to the target and a second doppler shift due to the radial velocity of the target with respect to the receiver.

The transmitter will broadcast a signal at a given Frequency (F_0). The target will reflect the signal at some doppler shifted frequency due to the radial velocity of the transmitter target pair (F_{D1}). The reflected signal can be modeled as if it were an isotropically radiated signal at some new frequency ($F_N = F_0 + F_{D1}$). The signal will be acquired at the receiver at some second doppler shifted frequency (F_F) which is a function of the radial velocity of the target/receiver pair (V_1).

$$F_D = V_1 / L \quad (3.51)$$

$$= V_1 F_0 / C \quad (3.52)$$

In the model, the transmitter and target velocities are specified as a vector with magnitude and direction. The velocities are user specified as a magnitude (VT,VX), some angle of azimuth heading (TAZ,XAZ) and some angle depicting rate of climb (TEL,XEL). The azimuth direction is always referenced to the baseline which is the direct path between the transmitter and receiver. The receiver is assumed to be flying a constant elevation surveillance orbit. The transmitter will also have a zero angle for TEL (but is not model limited). The transmitter, whether ground based or airborne, is assumed to be very limited in maneuverability due to the physical characteristics (construction) of the antenna. An obvious exception would be a Phased Array Radar which will not be considered here.

The radial velocities of the transmitter/target (target/receiver) pair are computed for any X,Y,Z point using vectors. The radial velocity is the vector dot product. The velocity vector is dotted into the unit vector separating the two objects.

$$V = \bar{A} \cdot \bar{B}$$

The velocity vectors V1, V2 are decomposed into X,Y,Z components for ease of operation.

$$V_{XZ} = V_X \sin XEL \quad ; \text{ Z component of Transmitter (3.53)}$$

$$V_{XY} = V_X \cos XEL \sin XAZ \quad ; \text{ Y component of Transmitter (3.54)}$$

$$V_{XX} = V_X \cos XEL \cos XAZ \quad ; \text{ X component of Transmitter} \quad (3.55)$$

$$V_{TZ} = V_T \sin TEL \quad ; \text{ Z component of Target} \quad (3.56)$$

$$V_{TY} = V_T \cos TEL \sin TAZ \quad ; \text{ Y component of Target} \quad (3.57)$$

$$V_{TX} = V_T \cos TEL \cos TAZ \quad ; \text{ X component of Target} \quad (3.58)$$

The general form of the dot product (16:535) is:

$$\vec{A} \cdot \vec{B} = a_1 b_1 + a_2 b_2 + a_3 b_3 \quad (3.59)$$

The vector from the receiver to the general point XYZ is:

$$\vec{A} = X \vec{i} + Y \vec{j} + (Z - RALT) \vec{k} \quad (3.60)$$

The vector from general point XYZ to the transmitter is:

$$\vec{B} = (SEP - X) \vec{i} - Y \vec{j} + (XALT - Z) \vec{k} \quad (3.61)$$

Both vectors A and B must be normalized. The normalization is required as only the unit position vector is required. Therefore:

$$\text{Let } A_1 = \sqrt{X^2 + Y^2 + (Z - RALT)^2} \quad (3.62)$$

and

$$\text{Let } B_1 = \sqrt{(SEP - X)^2 + Y^2 + (XALT - Z)^2} \quad (3.63)$$

Recall that the vector between two points has direction as well as magnitude. Because the vector from X, Y, Z to SEP, 0, XALT is the negative of the vector from SEP, 0, XALT to X, Y, Z, a factor of -1 must be included in the transmitter component to insure the doppler shift is negative when separating and positive when closing. The radial velocity of transmitter with respect to the target due to the velocity of the transmitter alone is then:

$$V1R = [(X - SEP) VXX + Y VXY + (Z - XALT) VXZ] / B1 \quad (3.64)$$

The radial velocity of the transmitter with respect to the target due to the velocity of the target alone is then:

$$V2R = [(SEP - X) VTX - Y VTY + (XALT-Z) VTZ] / B1 \quad (3.65)$$

The total radial velocity due to the transmitter target pair is:

$$VTOT = V1R + V2R \quad (3.66)$$

The doppler shift is a function of the frequency and wave length:

$$V = L FD \quad (3.67)$$

$$FD1 = VTOT / L$$

or, by combining and simplification:

$$FD1 = [(SEP-X) (VTX - VXX) + Y (VXY - VTY) + (XALT-Z) (VTZ - VXZ)] / (B1 L) \quad (3.68)$$

At this point the new radiated frequency is the transmitted frequency plus the doppler shift. The new frequency is:

$$FN = FO + FD1 \quad (3.69)$$

And of course, this new frequency has a new wave length:

$$LN = C / FN \quad (3.70)$$

The radial velocity of the target with respect to the receiver due to the velocity of the target (model assumes receiver is zero reference) is then:

$$V2R = [VTX X + VTY Y + VTZ (Z-RALT)] / A1 \quad (3.71)$$

Using the same development, the second doppler shift is:

$$\begin{aligned} FD2 &= V2R / LN \\ &= (-1) [VTX X + VTY Y + VTZ (Z-RALT)] / (A1 * LN) \end{aligned} \quad (3.72)$$

The net doppler shift is:

$$\begin{aligned} FF &= [(SEP-X) (VTX - VXX) + Y (VXY - VTY) \\ &\quad + (XALT-Z) (VTZ - VXZ)] / (B1 L) \\ &\quad - [VTX X + VTY Y + VTZ (Z-RALT)] / (A1 LN) \end{aligned} \quad (3.73)$$

This is the general form of the solution space. A map of the isodoppler contours is desired. An array (TABLE) is set up to hold the general solution set for the region of interest. A plane of interest is examined by specifying the Z plane (altitude) desired. For example, if the plane of interest is the doppler contours of the ground plane ($Z = 0$), the array is scanned for contour information and a table of values is generated. A contour map (isodoppler lines) is constructed by a hand drawing the contour lines on the map. The doppler value equations are nonlinear and do not yield to a simple plotting routine.

Clutter

Clutter Parameters. Clutter is the unwanted radar echo from an object or background (12:470). Clutter is usually the radar return from a ground cell, insects, birds, or possibly a storm cell. The clutter power is often larger than any possible target power signal. This occurs because the radar cross section of a clutter cell is much larger than that of a probable target. The radar designer is concerned with the characteristics of the unwanted signal because techniques are available to enhance the detection of targets if the clutter can be removed. Clutter signal properties can be predicted. Therefore, the designer builds "filters" to modify the signal returns in order to find probable targets. The largest clutter return comes from ground reflections.

The properties of interest are the Signal to Clutter Power Ratio (SCR), the doppler frequency shift (FSC) of the clutter cell, the area (CAP) of the clutter cell and the density (SO) of the clutter cell. Monostatic and bistatic radar are affected by these parameters. However, the calculation and modeling of the system parameters for the bistatic model changes significantly. For example, the bistatic transmitter and receiver beams may have different shapes. Even if the beam shapes were the same, the area illuminated by transmitter would not be the same as the area scanned by the receiver (Figure 10).

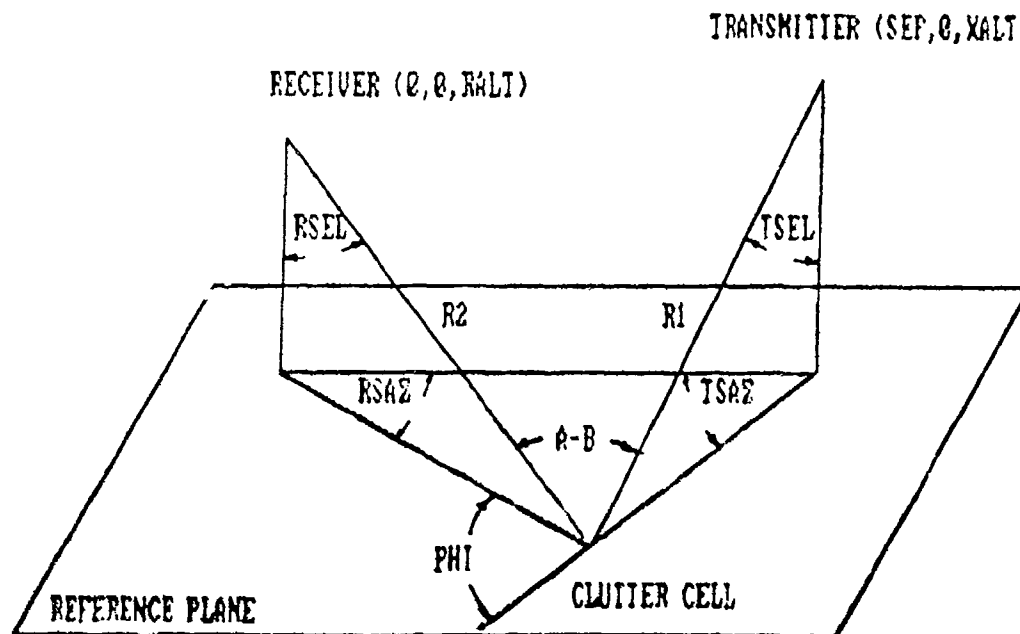


Figure 10 Geometry of the Clutter Cell

Signal to Clutter Ratio. Signal power is radiated from the transmitter to the target and then to the receiver.

The target will reflect an amount of power proportional to its radar cross section. The reflected power has an intensity and doppler shift. The clutter cell behind the target also reflects energy. The signal power (in terms already defined) is:

$$S = \frac{P \text{ GR GT RCS } C^2}{(4\pi)^3 R_1^2 R_2^2 F_0^2} \quad (3.74)$$

The clutter power has the same equation with slight modification. The surface clutter cross section is defined as:

$$\text{RCS} = S_0 \text{ AC} \quad (3.75)$$

Where:

S_0 = Surface Cross Section per Unit Area

AC = Radar Cross Sectional Area of Illumination

The bistatic case modifies AC to mean the common area between the transmitter beam and the receiver beam. Figure 10 illustrates the common area for several possible cells. The Surface Cross Section is determined from a model which results from experimental data (15:20-23). S_0 varies depending upon the composition of the surface. For example, sea and forest clutter have different values. Several bistatic models have been developed to explore the S_0 phenomenon. References (5) and (15) catalogue many models and much of the research in this area.

The clutter power is:

$$C = \frac{P \text{ GR GT AC SO } C^2}{(4\pi)^3 R_1^2 R_2^2 F_0^2} \quad (3.76)$$

Dividing Eq (3.78) by Eq (3.80), the Signal to Clutter Ratio is:

$$SCR = \frac{RCS}{SO AC} \quad (3.77)$$

Clutter Cell Area. The clutter area is dependent upon the beam shapes and the processing equipment. The clutter cell is either beam width limited, resolution time limited, or doppler frequency limited (15:12). This model uses the Resolution time limited cell area developed by Weiner and Kaplan (15:16). The bistatic models for clutter assume the flat earth model. The clutter cell area for low grazing angle conditions ($RSEL < 30$ degrees) is defined as:

$$AC = \frac{R_1 XSAZ}{2 BW} SEC^2 \left(\frac{A - B}{2} \right); XSAZ < RSAZ \quad R_2/R_1 \ll 2 \text{ RAD}$$

or:

$$AC = \frac{R_2 RSAZ}{2 BW} SEC^2 \left(\frac{A - B}{2} \right); RSAZ < XSAZ \quad R_1/R_2 \ll 2 \text{ RAD}$$

Where:

$RSEL$ = Receiver Horizon to Target Depression Angle
(Degrees)

$XSAZ$ = Transmitter Azimuth Beam Width (Radians)

RSAZ = Receiver Azimuth Beam Width (Radians)

A-B = Angle [Transmitter to Receiver as seen from
Target] (Radians)

Using the Law of Cosines and trigonometric identities, it
can be shown that the term:

$$\sec^2 \frac{(A - B)}{2} = \frac{4 R_1 R_2}{2 R_1 R_2 + R_1^2 + R_2^2 - \text{SEP}^2 - (\text{RALT} - \text{XALT})^2} \quad (3.79)$$

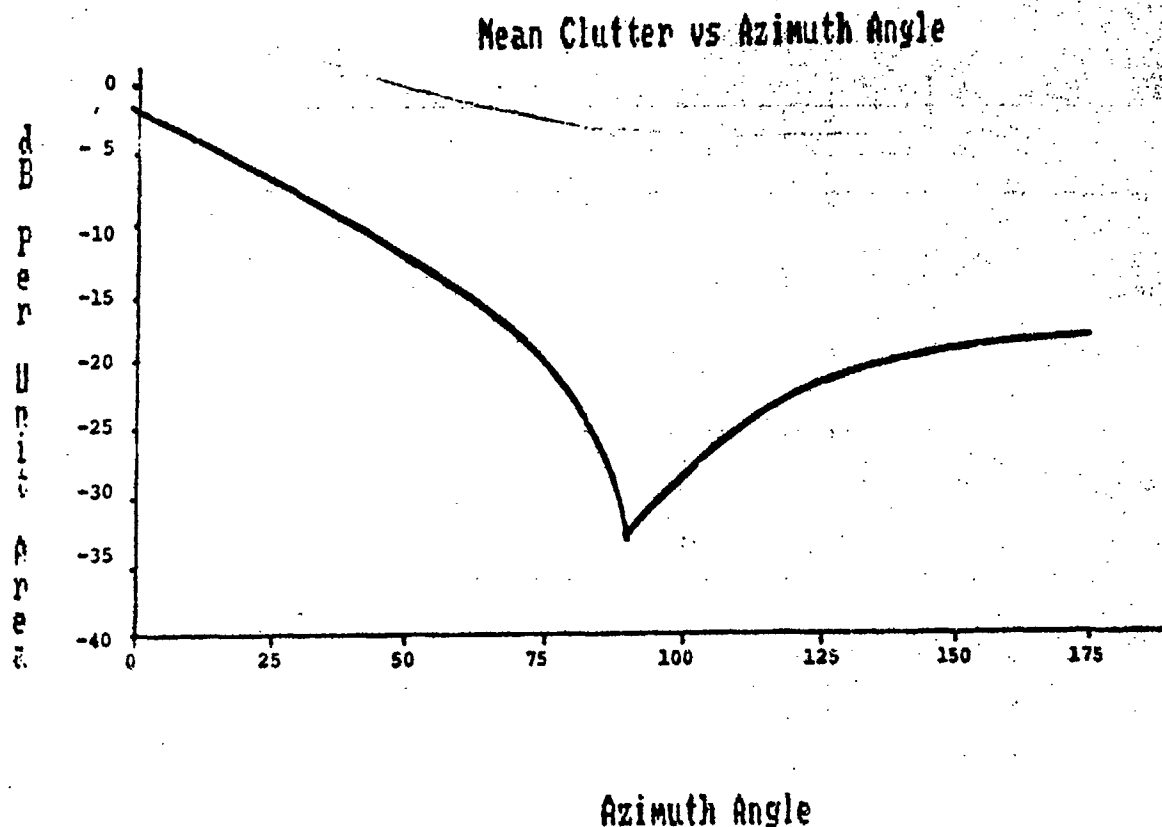
Therefore, AC can be estimated in terms of system position.
It is assumed that the transmitter beam width (XSAZ) is
known or at least a good estimate can be made.

Surface Cross Section Per Unit Area. Figure 11
shows an estimate of the Surface Cross Section Density Model
(13:21). The graph values (for 3G Hz only) have been modeled
by the second order equation:

$$S_0 = \sqrt{(X-90) 3.21111} - 32 \quad ; \quad 90 < X < 270 \quad (3.80)$$

or:

$$S_0 = \sqrt{(90-X) 10.000} - 32 \quad ; \quad 0 < X < 90$$
$$; \quad 270 < X < 360$$



Azimuth Angle

Figure 11 Mean Clutter Cross Section Per Unit Area

Weiner has shown that this general model can be extrapolated to other grazing angles by the addition of a correction term (13:20) to the value obtained from the graph. The correction term is:

$$\text{COR} = \frac{\text{PHI ADJ}}{180} \quad (3.81)$$

Where:

$$\text{ADJ} = -8 \text{ dB} \quad ; \quad (\text{XSEL} + \text{RSEL})/2 < 1.5 \quad (3.82)$$

or:

$$\text{ADJ} = 9.5 \text{ Log}_{10} ((\text{XSEL} + \text{RSEL})/2) - 9.5 \quad ; \quad (\text{XSEL} + \text{RSEL})/2 > 1.5$$

Where:

PHI = Out of Plane Azimuthal Angle Between Beams

XSEL = Transmitter Depression Angle

RSEL = Receiver Depression Angle

Doppler Spread of Clutter Cell. The clutter cell power is concentrated in the frequency domain about the cell doppler shift (Figure 12). By estimating the width of the clutter cell frequency shift, the receiver can dynamically "filter" the returned signal. The ground clutter cell doppler frequency shift varies as the geometry of the common beam area changes. The equations in the Clutter section are used to calculate the doppler shift of any specific point. A method for estimating the difference in the maximum and minimum doppler shifts of any clutter cell is required.

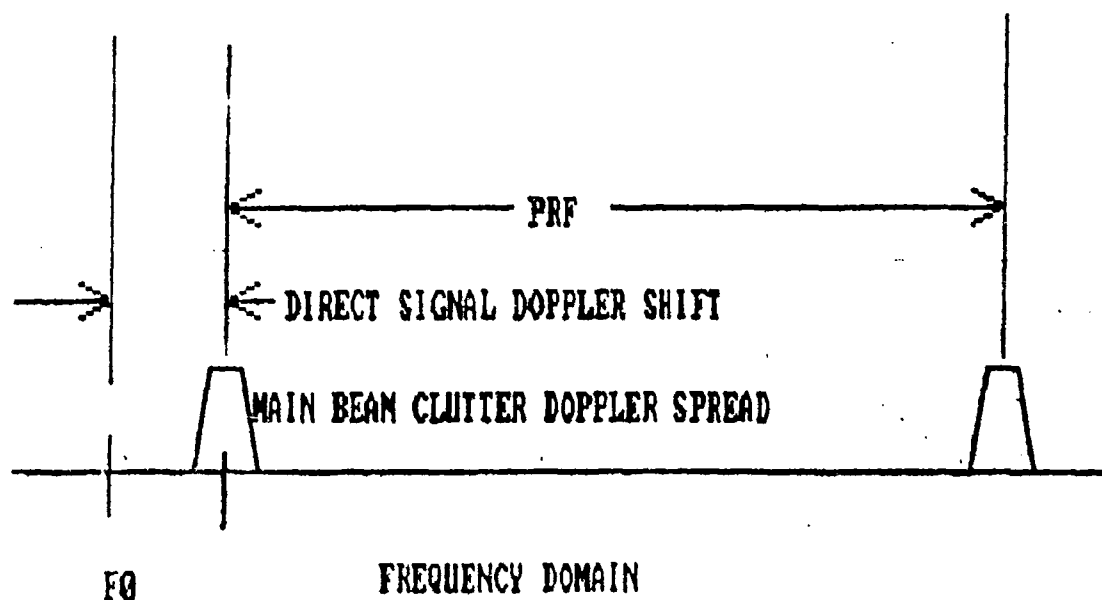


Figure 12 Clutter Power in the Frequency Domain

The model assumes the use of scanning and illumination beams with width (degrees in azimuth) and height (degrees in elevation). The parameters XWAZ, XWEL, RWAZ, and RWEL define the transmitter and receiver beam widths and heights respectively. A simple method for determining the doppler spread is to estimate the spread based on the beam widths. This is done by calculating four points for each beam. These points are approximately on the 3dB contour of the beam (Figure 13). A distance measure is made to each of the eight points. The four smallest distance measures dictate the four points used to estimate the doppler frequency spread. This is done by calculating the doppler shift to the four points using Eq (3.77). The minimum value is subtracted from the maximum value to obtain the estimate of the frequency shift. This method is used in Subroutine DOPSD, Appendix A.

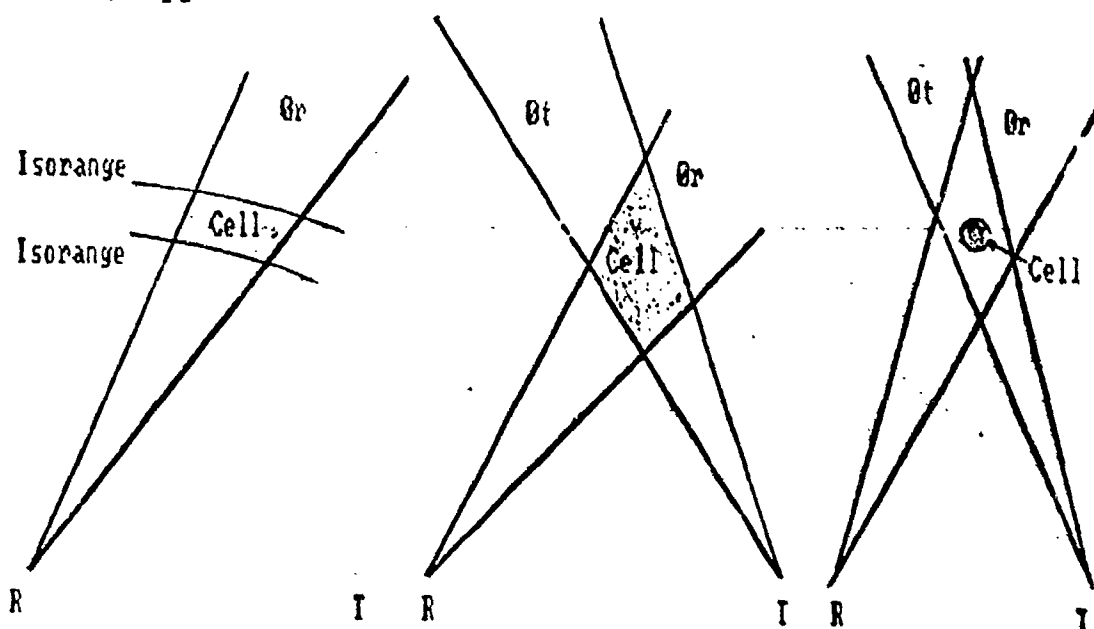


Figure 13 Geometry of Common Beam Area

Summary

The equations developed in this chapter are used in the Bistatic Radar Computer Model. In this chapter the limits of the model were defined. These limits included the X, Y, Z region of interest as well as the transmitter, receiver, and target parameters. These equations are the foundations upon which the computer model was built. The computer model allows the operator to change the values of the system from the default values. Figure 14 shows a sample menu. Based on the values entered by the operator, a plot is generated (Figure 15). This plot shows the isorange and power limitation contours.

```

CURRENT VALUES ARE DEFINED AS:
      TARGET      TRANSMITTER      RECEIVER
1 VELOCITY = 600.00 6 VELOCITY = 1200.00 18 TEMP = 300.00
2 AZ ANGLE = 90.00 7 AZ ANGLE = 61.00 19 SNR = 6.50
3 EL ANGLE = 0.00 8 EL ANGLE = 0.00
4 RCS = 1.75 9 POWER = 0.0100 20 LOSS = 6.50
5 Z PLANE = 0.00 10 ALTITUDE = 9.00 21 SEP = 200.00
      11 GAIN = 40.00 22 GAIN = 40.00
      12 CARRIER = 3.00 23 BU = 1.00
      13 BEAM WD = 1.50 24 BEAM WD = 1.50
      14 BEAM HT = 6.00 25 BEAM HT = 6.00
      15 PRF = 25000 26 ALT = 9.00
      16 PULSE WD = 6.00
      17 PRF = 3
ENTER OPTION NUMBER [1-26] TO CHANGE VALUE
OR 27 TO CONTINUE
OR 28 TO ABORT
  
```

Figure 14 Computer Model Menu

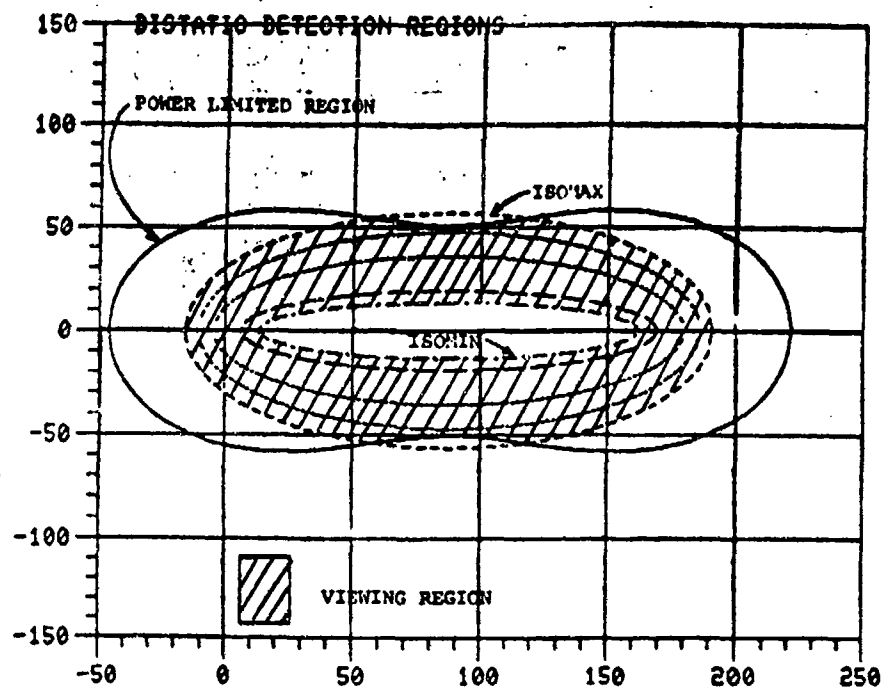


Figure 15 Bistatic Coverage and Exclusion Regions

IV. Exercising the Model

Introduction

This chapter outlines a generic form of the bistatic radar model and demonstrates the effects of changing the parameters of interest. The interactive software provides many of the parameters which may be changed by the user when exercising the model. This chapter demonstrates the effects of transmitter and receiver hardware (power, waveform, etc.), platform motion, and platform orientation on the bistatic detection regions, the doppler effects, the signal to clutter ratio and the doppler spread of the received signal. Finally, a typical scenario is illustrated. For all cases used in this section a generic bistatic set is assumed and changes are shown relative to the generic set. The generic model has parameters as shown in the sample computer menu (Figure 16). The parameter units and range of acceptable values are displayed when changing any of the 26 parameters.

Limiting Regions

The Power Limited Region. The detection region which is limited by the transmitter and receiver hardware is described by the Ovals of Cassini. Figure 17 shows the bistatic detection region for the ground plane ($Z = 0$). Decreasing transmitter power causes a collapse of the ovals as demonstrated in Figure 18. Finally, Figure 19 shows the

CURRENT VALUES ARE DEFINED AS:

TARGET			TRANSMITTER			RECEIVER		
1	VELOCITY	600.00	6	VELOCITY	300.00	18	TEMP	300.00
2	AZ ANGLE	0.00	7	AZ ANGLE	0.00	19	SNR	6.50
3	EL ANGLE	0.00	8	EL ANGLE	0.00	20	LCSS	6.50
4	RCS	1.75	9	POWER	0.0100	21	SEP	200.00
5	Z PLANE	0.00	10	ALTITUDE	5.00	22	GAIN	40.00
			11	GAIN	40.00	23	BU	1.00
			12	CARRIER	3.00	24	BEAM WD	1.50
			13	BEAM HT	1.50	25	BEAM HT	6.00
			14	BEAM HT	6.00	26	ALT	9.00
			15	PRF	25000			
			16	PULSE WD	5.00			
			17	S PRF	3			

ENTER OPTION NUMBER E1-26J TO CHANGE VALUE
OF 27 TO CONTINUE
OR 28 TO ABORT

Figure 16 Bistatic Model Parameter Menu (Generic Set)

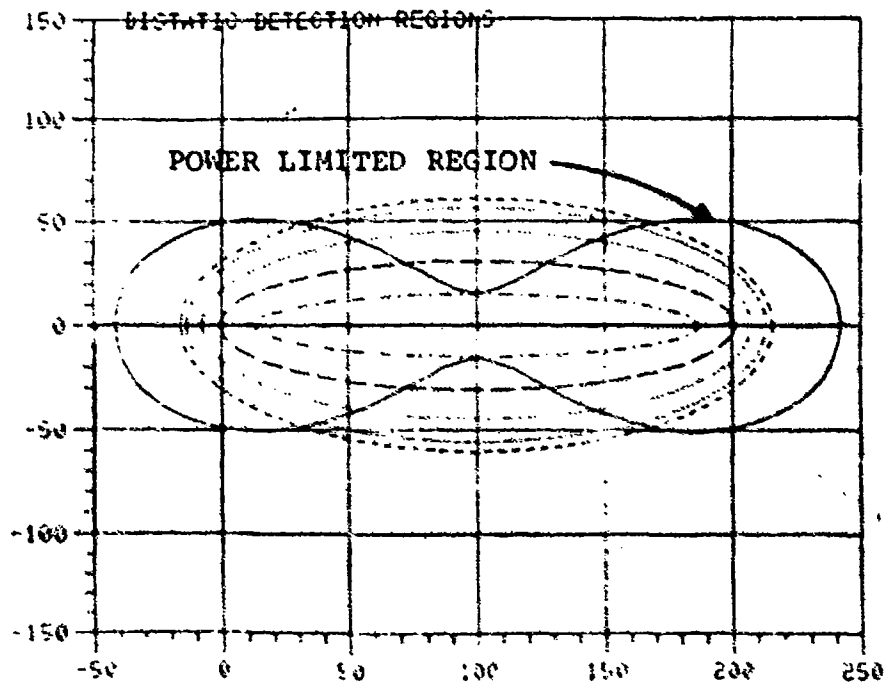


Figure 17 Generic Detection Region (Power = 0.01 Megawatts)

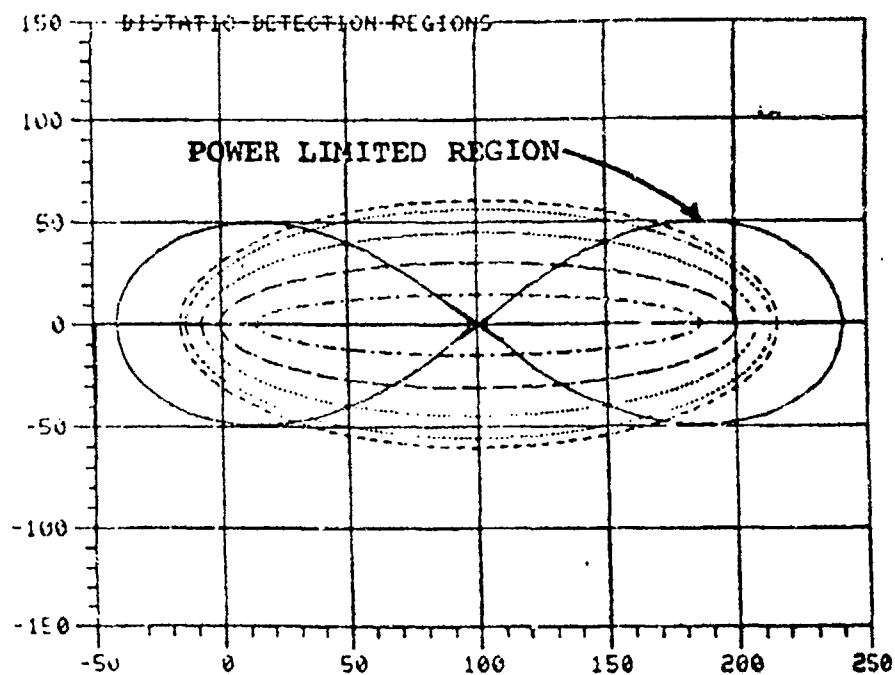


Figure 18 Detection Region (Power = 0.0095 Megawatts)

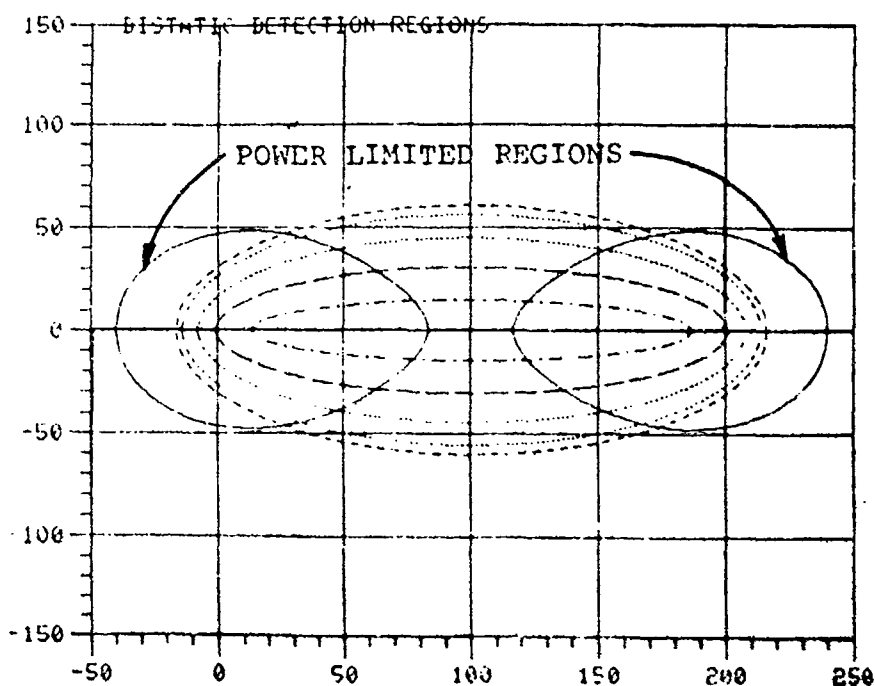


Figure 19 Detection Region (Power = 0.0090 Megawatts)

detection region when an even smaller amount of power is used and the ovals divide into two specific regions.

The shape of the detection region changes as a function of the platform separation distance (SEP). Figures 20 and 21 display the change in the detection region as the separation region between the transmitter and receiver decreases.

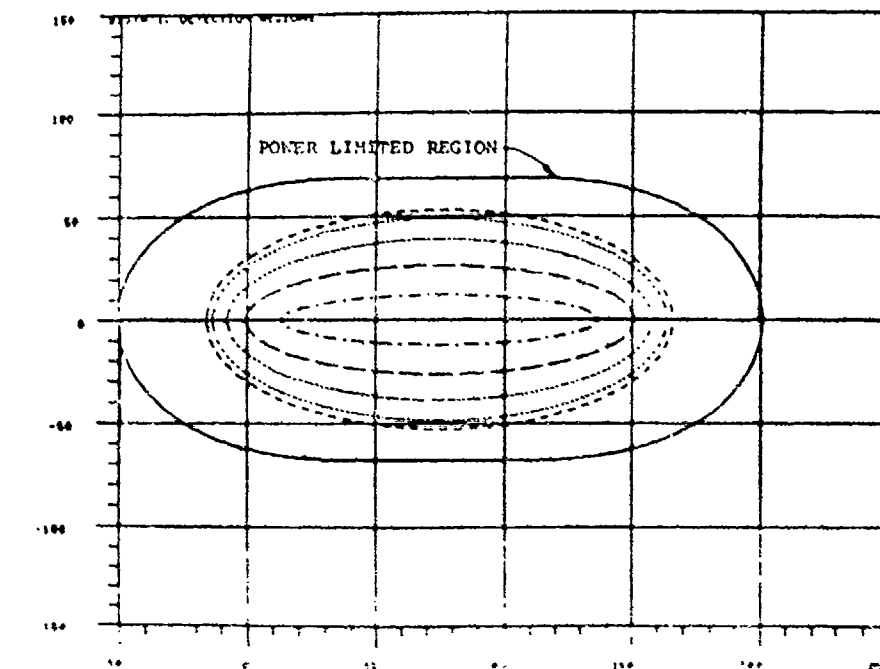
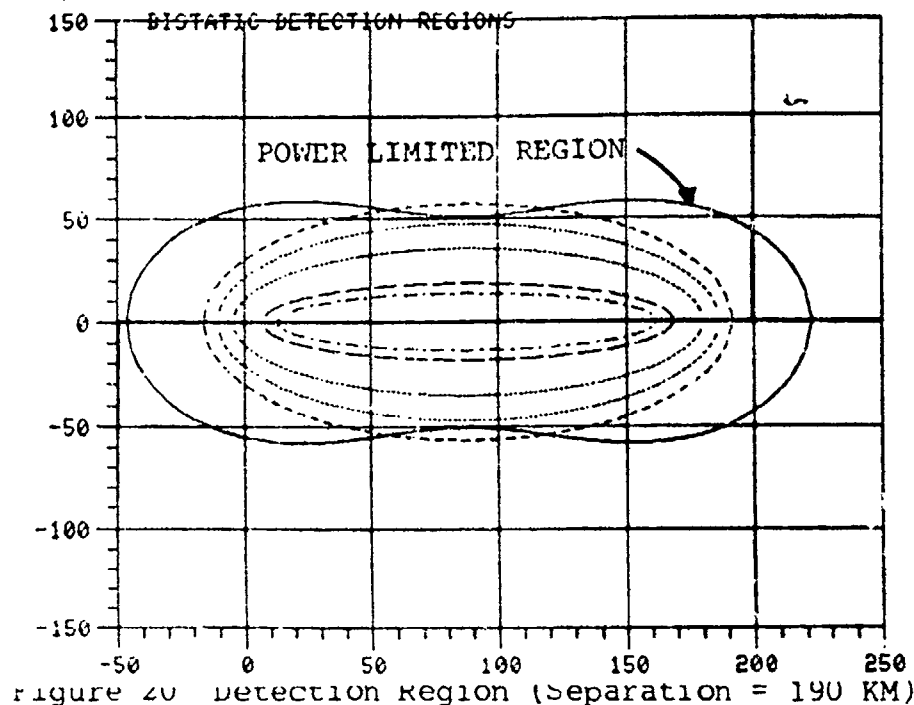


Figure 21 Detection Region (Separation = 160 KM)

Changing any of the parameters which effect the range constant (R^4) yields similar results. Recall from Eq (3.5) (3.6) and (3.9) that the range constant is a function of the transmitter and receiver hardware as well as the target location and cross section. The model takes into consideration varying receiver and transmitter altitudes. Altitude changes affect the geometry of the model by tilting the ovals and ellipsoids producing an asymmetric figure. An example of an airborne to ground pair is shown in Figure 22. The detection region varies but is not quite as dramatic as the change in the waveform limited characteristic regions defined by the isorange curves.

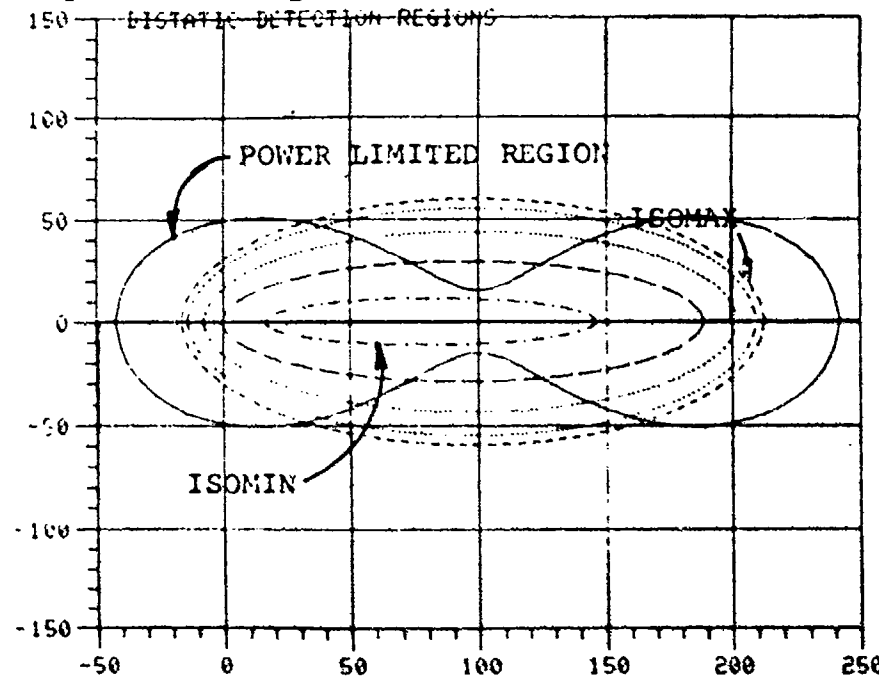


Figure 22 Airborne Receiver to Ground Transmitter

Waveform Limited Regions.

Evaluation of the Blind Zone (ISOMIN). The blind zone is the region between the transmitter and receiver,

defined by an ellipsoid, where the receiver cannot detect any target. Recall from the ISOMIN Development Section Eq (3.38) that the blind zone is defined by the isorange curve (ISOMIN):

$$\text{ISOMIN} = 2 * \text{TPULSE} * C + \text{SEP}$$

The ISOMIN curves shown in Figures 16 thru 22 are for pulse widths of 5 microseconds. It is easily demonstrated that a longer pulse significantly increases the width of the blind zone. Figures 17 and 23 demonstrate the effect of increasing the pulse width from 5us to 30us.

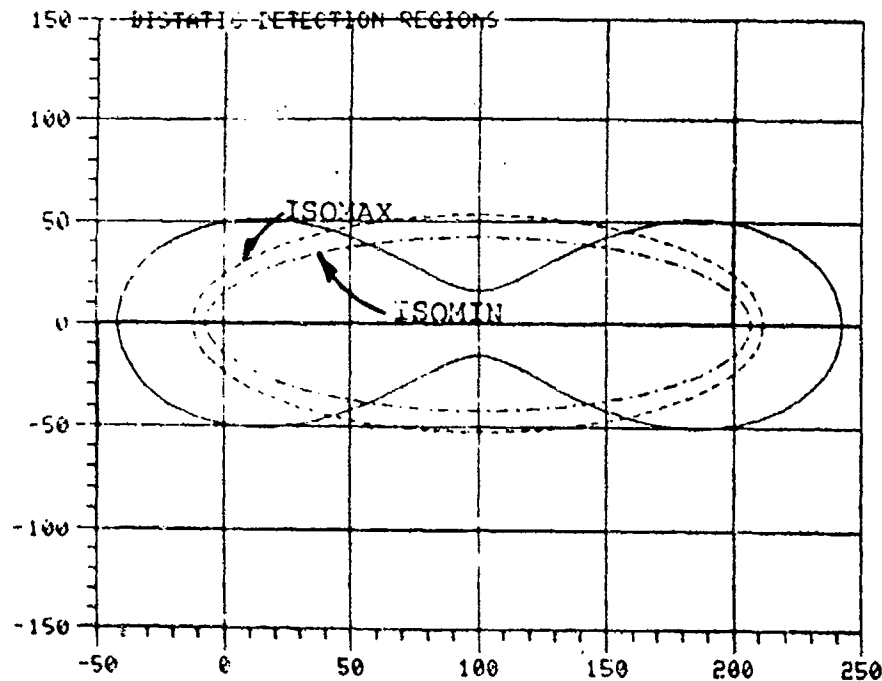


Figure 23 Detection Region for Pulse Width 30 Microseconds

The width of the blind zone ellipsoid can be shown to be:

$$\text{WIDTH} = \text{SORT} (\text{ISOMIN}^2 - R3^2) \quad (4.1)$$

Table I lists the ISOMINs for a constant separation of 200 KM.

TABLE I
Comparison of Pulse Width,
Isomin and Ellipsoid Width

Pulse Width (microseconds)	ISOMIN (kilometers)	Ellipsoid Width (kilometers)
.1	200.06	4.6
1.0	200.60	15.5
5.0	203.00	34.8
10.0	206.00	49.4
15.0	209.00	60.6
20.0	212.00	70.3
25.0	215.00	79.9
30.0	218.00	86.8

When the data is put into graphical form, it is easy to recognize that a small pulse width is desirable to minimize the blind zone.

Evaluation of the Maximum Range (ISOMAX). The maximum visibility of the bistatic system was shown to be a function of the pulse repetition frequency (PRF), the number of distinct pulse repetition frequencies (NPRF), and the pulse width (TPULSE). Examination of Eq (3.44) yields the following observations: increasing the pulse width will lower the maximum range (compare Figure 17 to Figure 23); increasing the prf decreases the viewing area (Figure 17 versus Figure 25); decreasing the prf increases the maximum viewing area (Figure 26 versus Figure 17); and increasing the number of

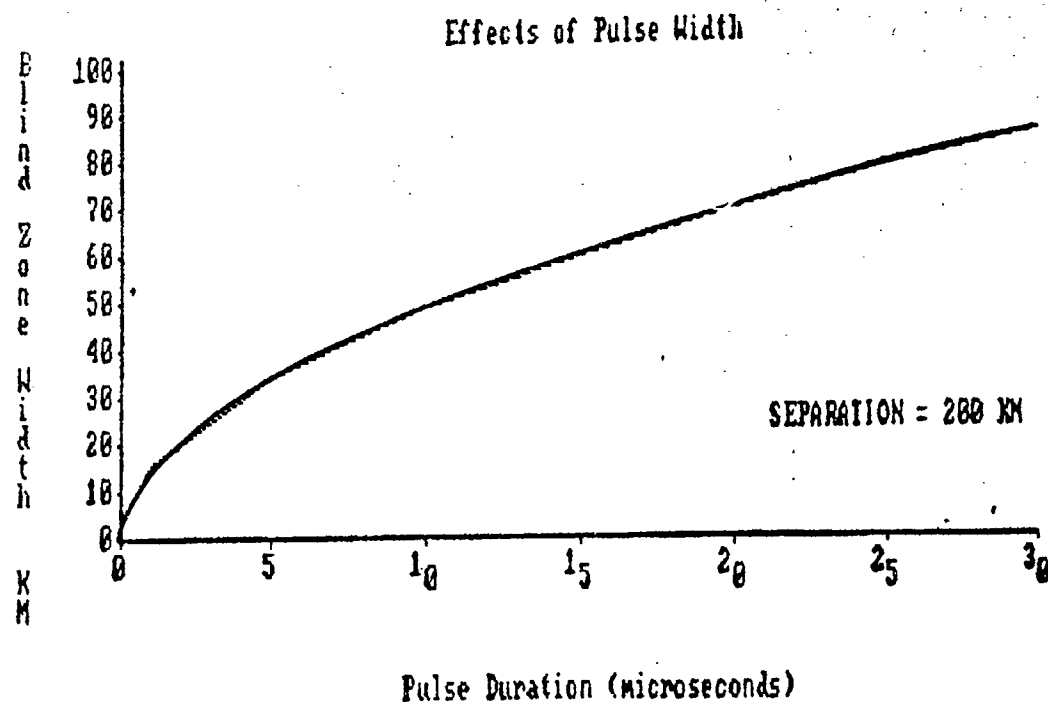


Figure 24 Effects of Pulse Width on Blind Zone

prf multiples increases the maximum range (Figure 27 shows a multiple of 7 as compared to Figure 28 which shows the effects of a single prf).

Doppler Maps. The relative motions of the transmitter, receiver, and target dictate the doppler shift at any given point in X, Y, Z space. A good way to demonstrate this is to view a plane of interest and see the doppler contours on that plane. For example, assume the ground plane is the plane of interest. The doppler shift of any X, Y point ($Z = 0$) is a function of the velocity of the ground plane with respect to the transmitter and receiver platforms.

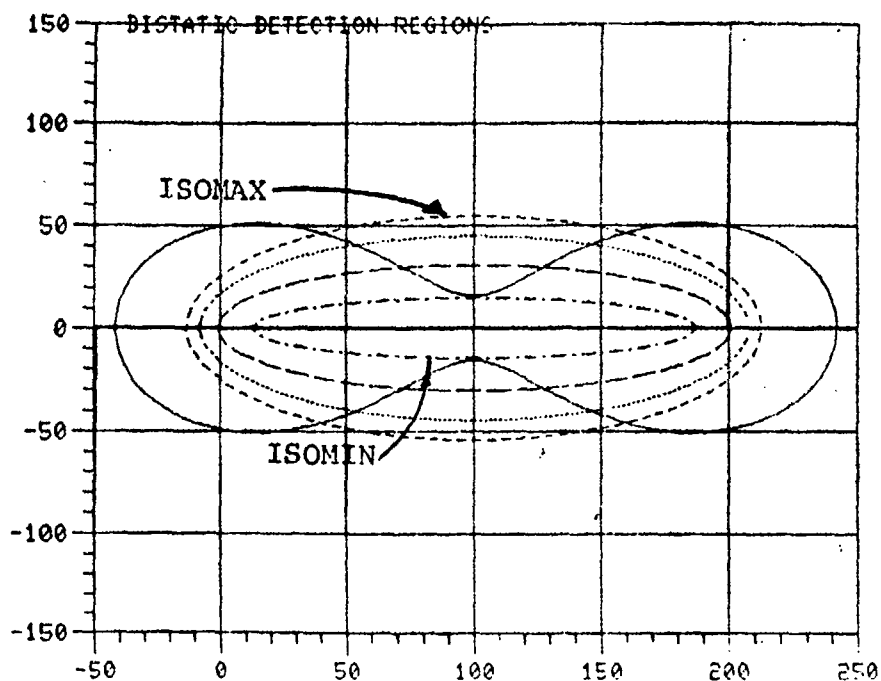


Figure 25 Minimum and Maximum Isoranges
(Increased PRF: 30000 HZ)

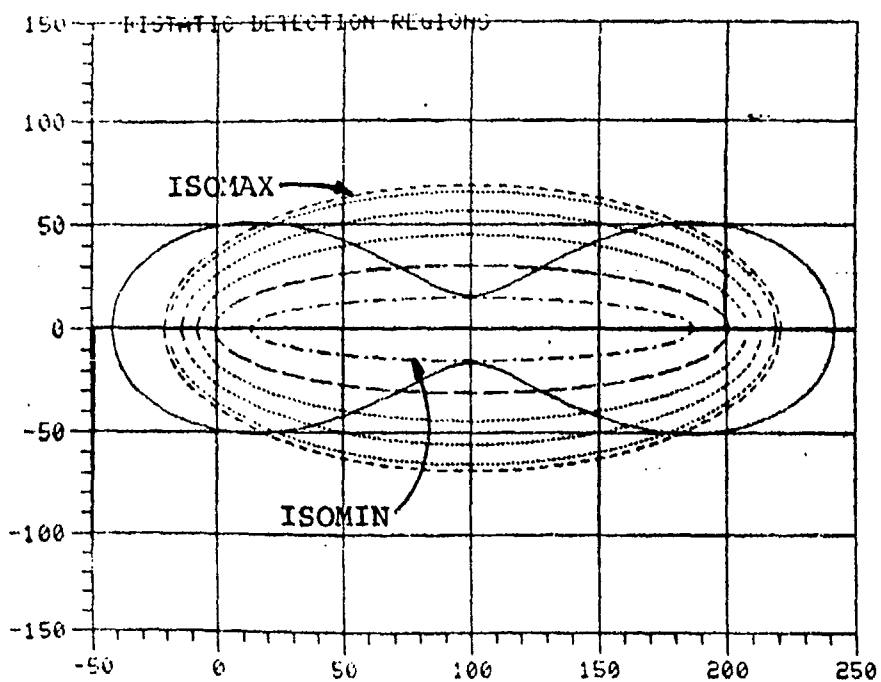


Figure 26 Minimum and Maximum Isoranges
(Decreased PRF: 20000 HZ)

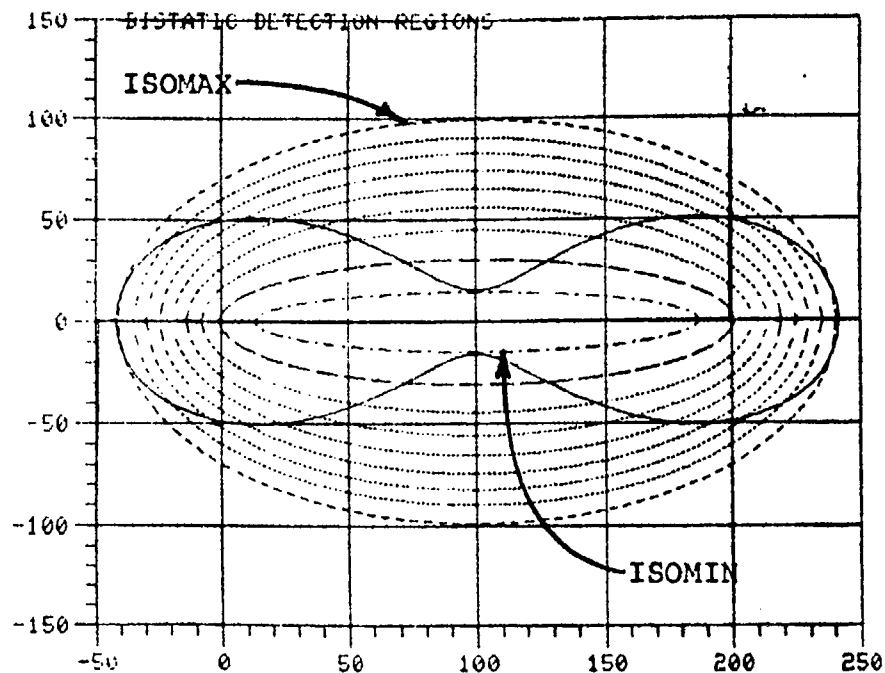


Figure 27 Minimum and Maximum Isoranges
(Multiple PRF: NPRF = 7)

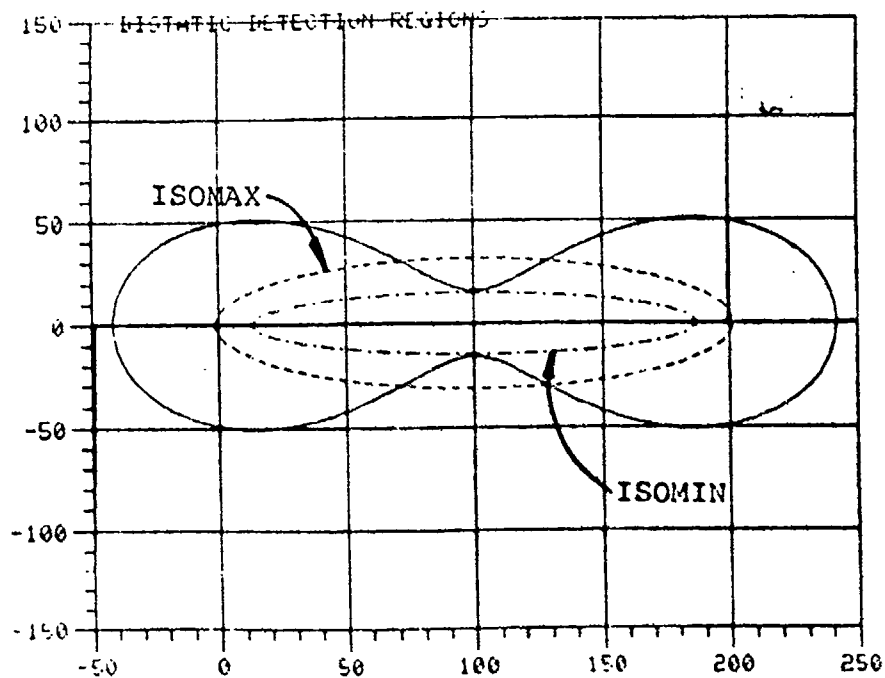


Figure 28 Minimum and Maximum Isoranges
(Single PRF: NPRF = 1)

The doppler map developed by the model is a grid of numbers representing the doppler shift at that particular X, Y point. Because the doppler shift is well behaved, a contour can be drawn by connecting interpolated points on the map. Figure 29 shows the doppler contours for a receiver headed to the left at 600 KPH and a transmitter headed to the right at 600 KPH. The relative separation is 1200 KPH. Figure 30 shows the contours for receiver and transmitter headed left at 600 KPH and remaining a constant distance apart. Figure 31 shows the same pair closing with equal velocity. Figure 32 shows the transmitter receiver pair flying orthogonal (90 degrees with respect to each other). Note the skewing of the doppler contours.

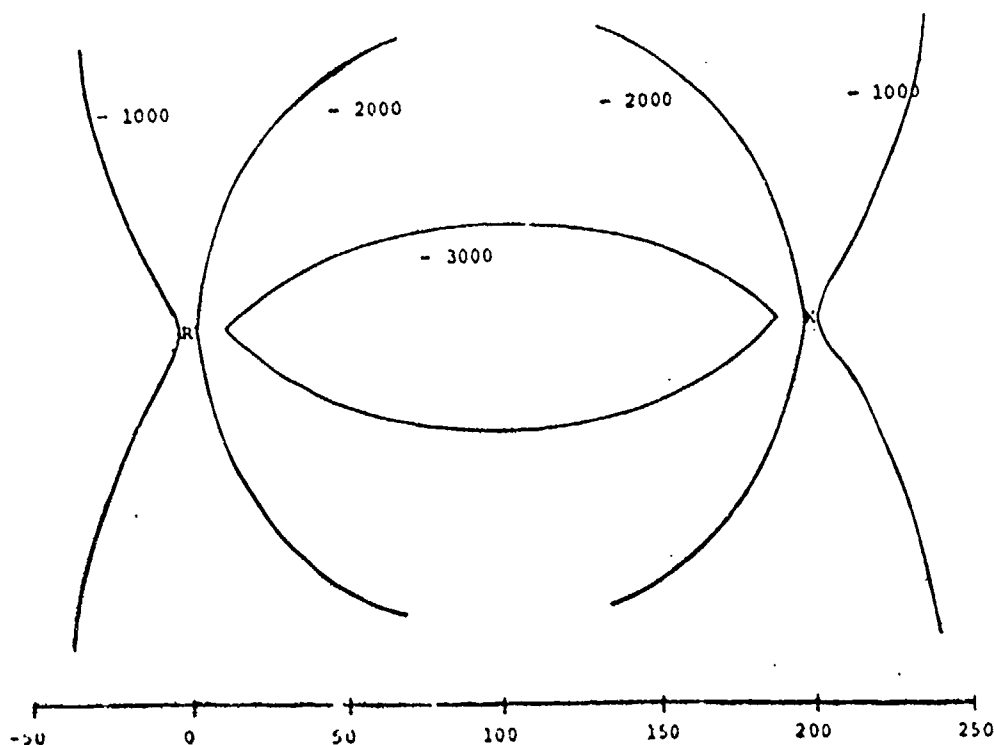


Figure 29 Doppler for Transmitter and Receiver Separating

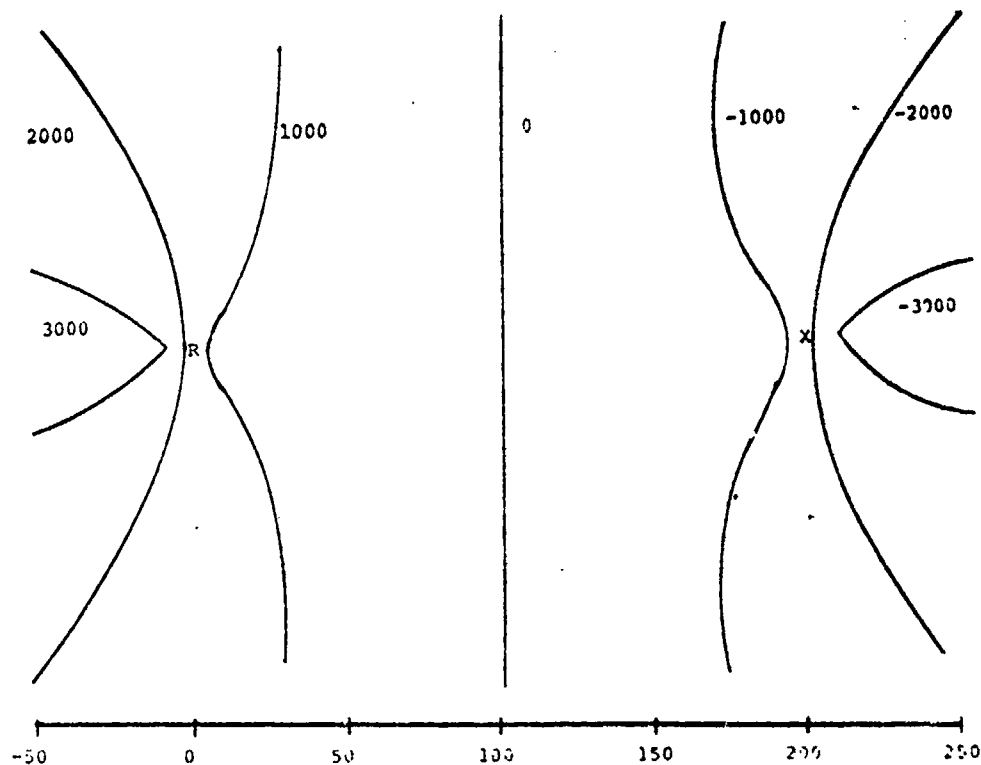


Figure 30 Doppler for Transmitter and Receiver
Constant Separation

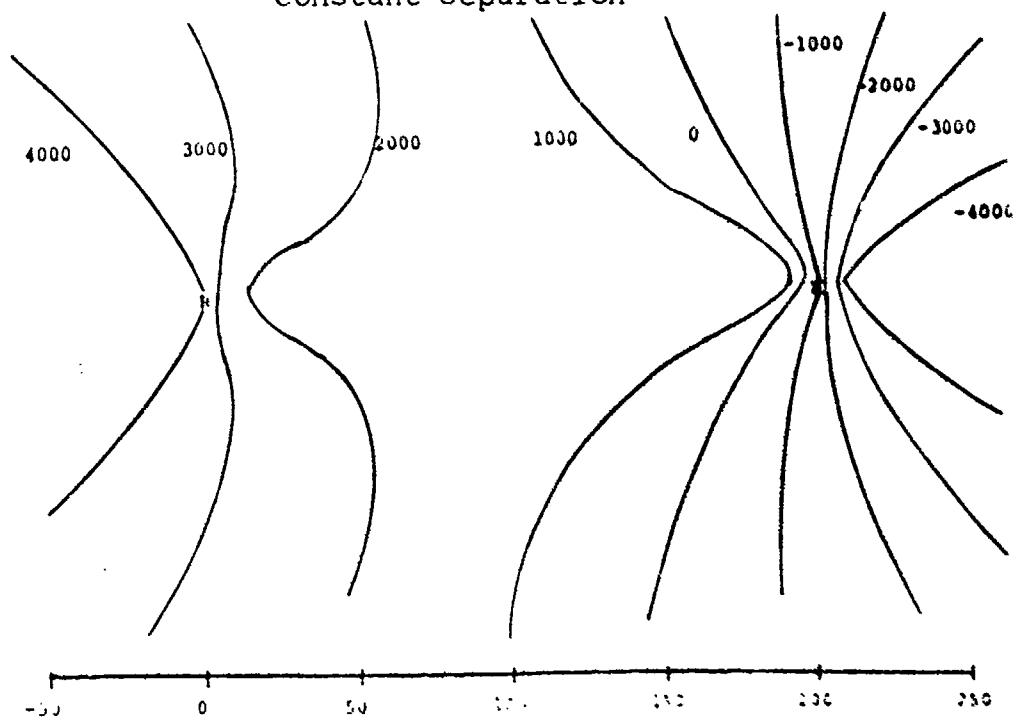


Figure 31 Doppler for Transmitter and Receiver Closing

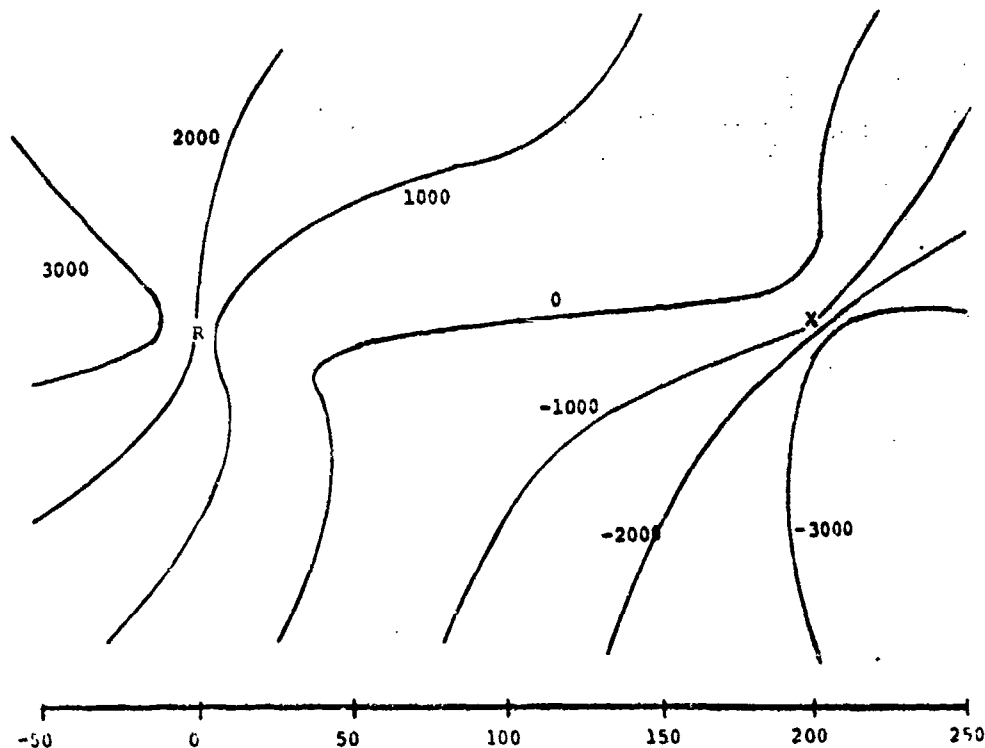


Figure 32 Doppler for Transmitter and Receiver Orthogonal

The transmitter receiver pair will not always fly such regular patterns, nor will they always have the same velocity. Figure 33 shows the effects of equal velocities but arbitrary headings. Figure 34 shows the effects of those same headings but with different receiver and transmitter velocities.

For the case of a ground transmitter, the velocity of the transmitter is the same as the ground plane. The transmitter is at an altitude of 10 meters. The doppler shift is now only a function of the receiver velocity and heading. Figure 35 shows the doppler map for a receiver separating at 600 KPH. Figure 36 shows the receiver closing on the transmitter. Note the change in sign of the contours.

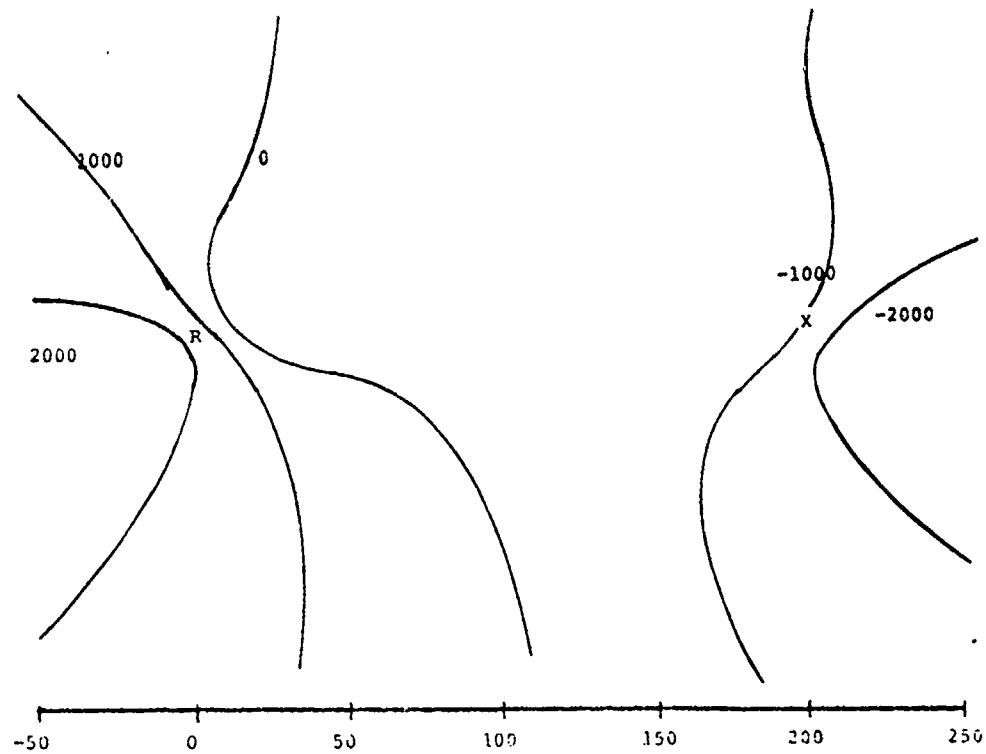


Figure 33 Transmitter and Receiver, Equal Velocities

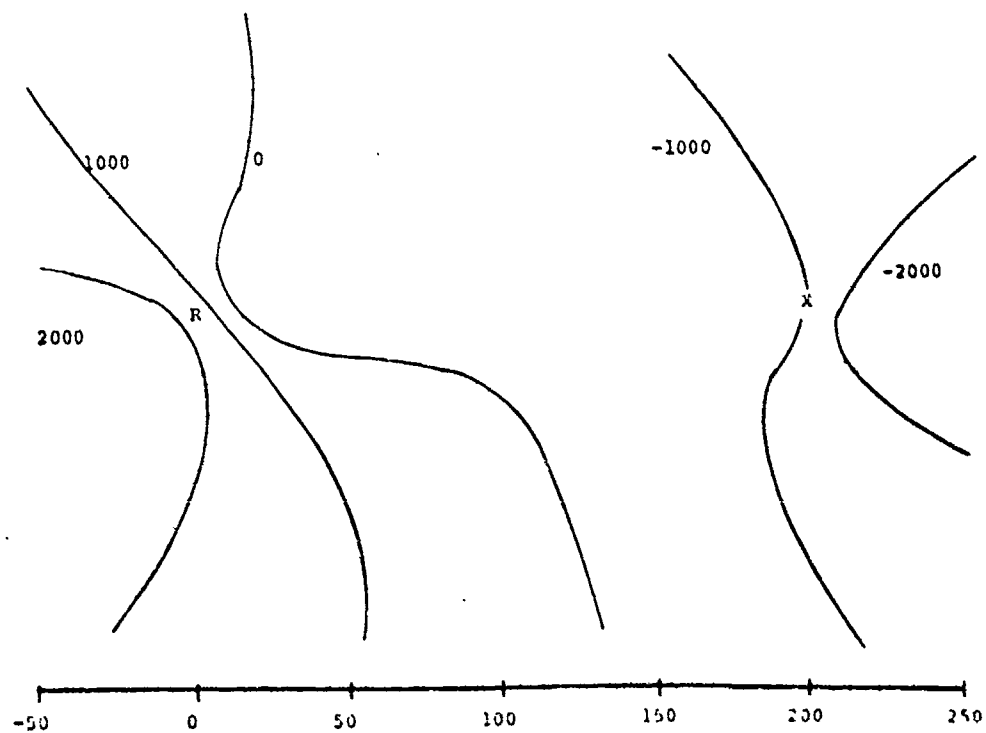


Figure 34 Transmitter and Receiver, Unequal Velocities

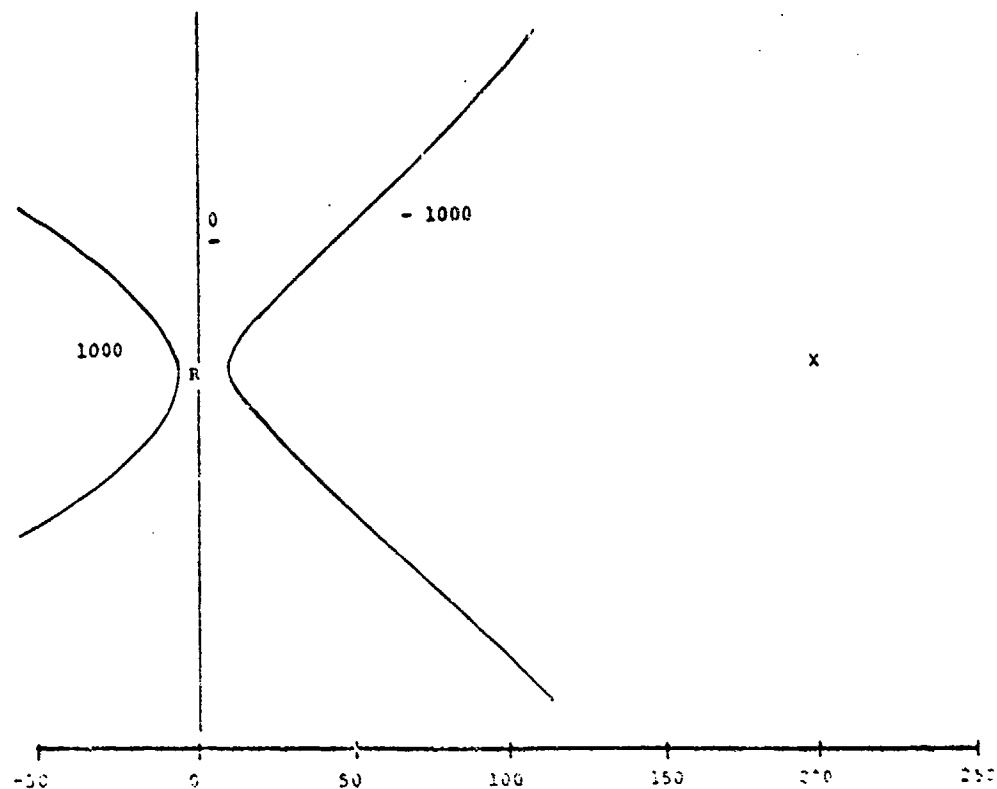


Figure 35 Receiver Separating from Ground Transmitter

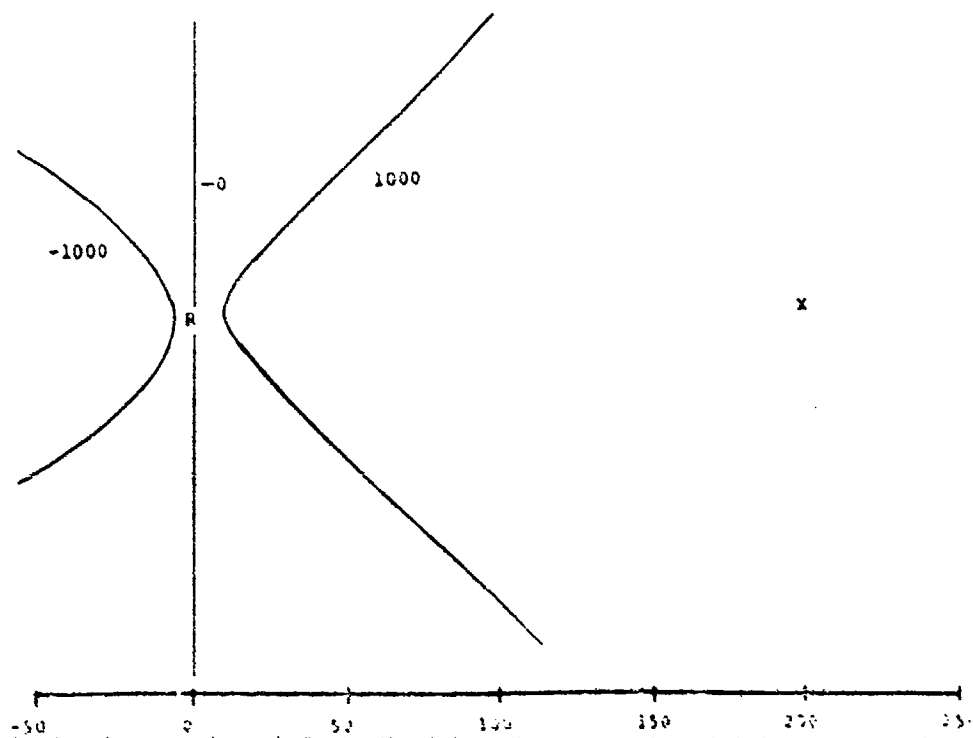


Figure 36 Receiver Closing on Ground Transmitter

Figure 37 shows the contours for a receiver flying orthogonal to the transmitter. Figure 38 demonstrates the skewing of the doppler contours when the receiver is at a heading 45 degrees with respect to the receiver transmitter baseline.

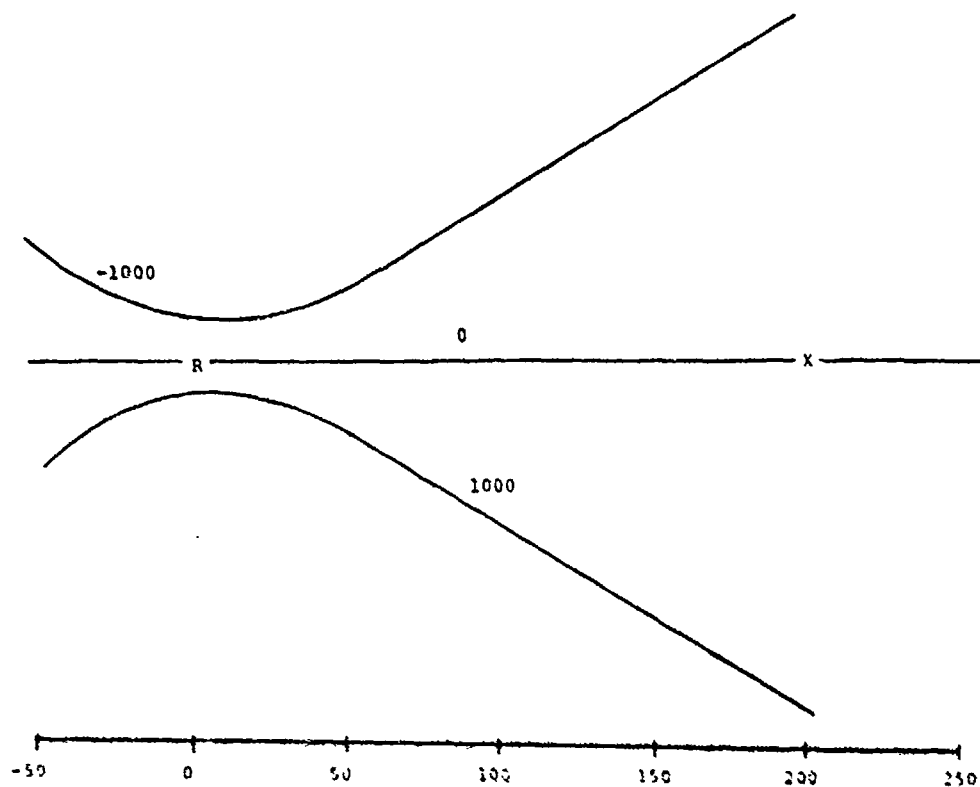


Figure 37 Receiver Orthogonal to Ground Transmitter

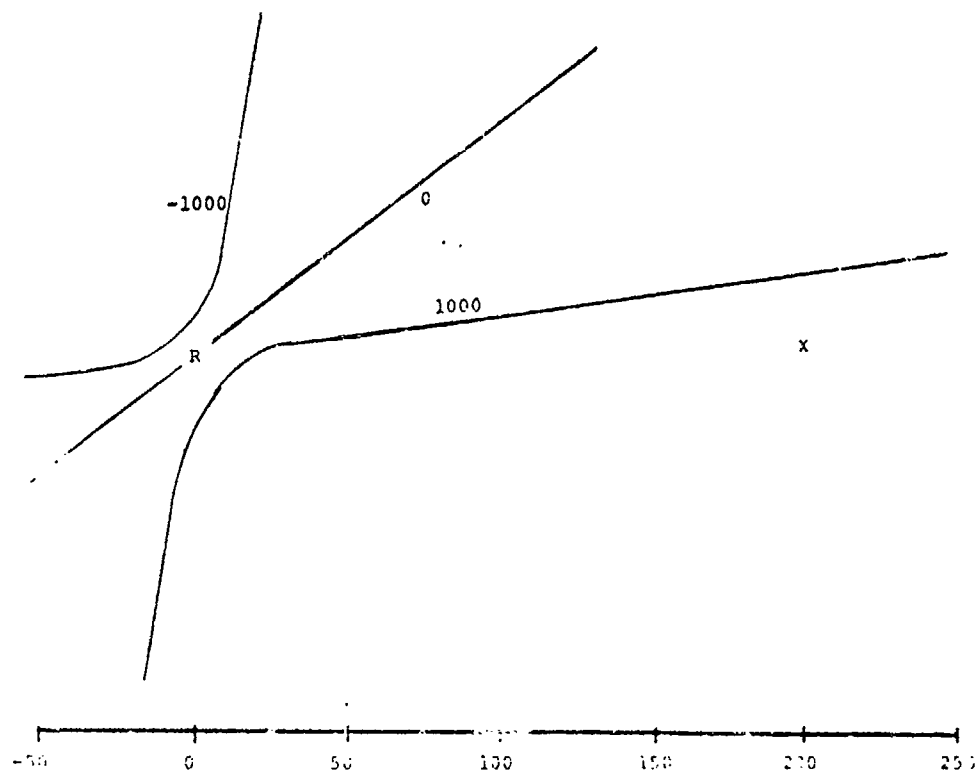


Figure 38 Receiver 45 Degrees from Ground Transmitter

Signal to Clutter Calculations

In Chapter III the Signal to Clutter Ratio (SCR) was developed. The model parameters were varied to demonstrate the effects of changing radar cross section and beam sizes. Figure 39 shows the signal to clutter ratio for the generic waveform. The elevation angle is displayed in 5 degree increments. SCR is shown as a function of azimuth and elevation. Figure 40 demonstrates the change in the SCR when a large target is viewed. Table II lists values for the SCR.

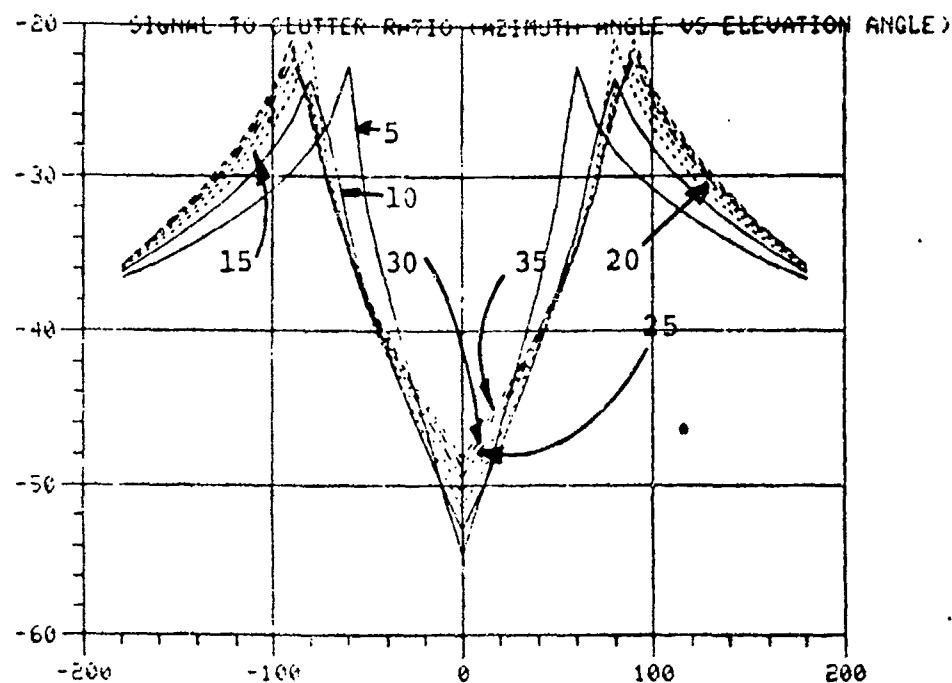


Figure 39 Signal to Clutter Ratio Generic System

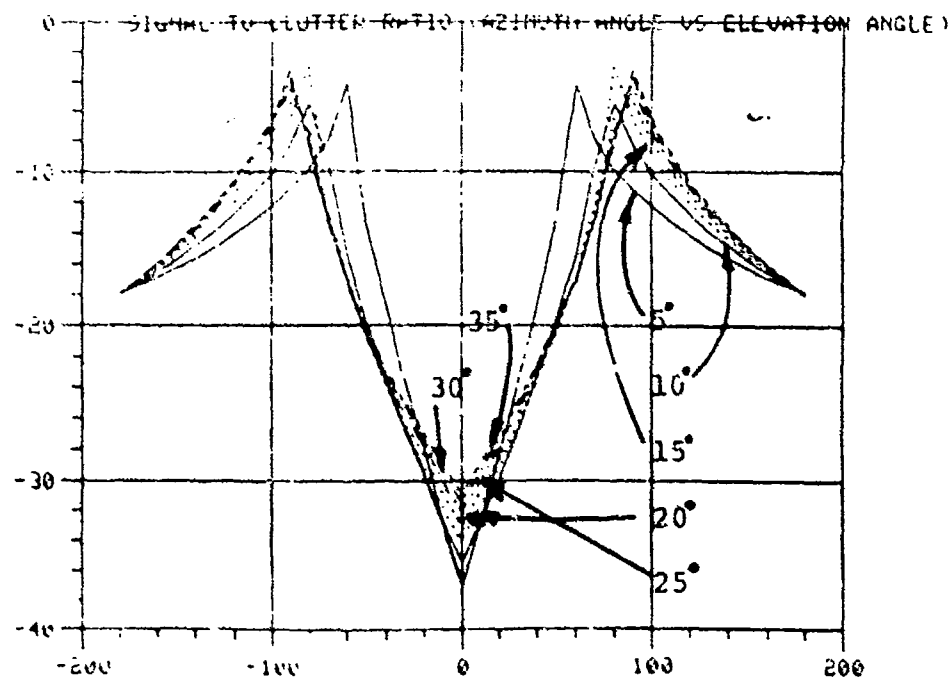


Figure 40 Signal to Clutter Ratio, Target RCS = 100 Sq M.

TABLE II

Signal to Clutter Values Generic Waveform

< Azimuth Angle >													
-180	-150	-120	-90	-60	-30	0	30	60	90	120	150	180	E1
-37.	-35.	-33.	-30.	-23.	-42.	-55.	-42.	-23.	-30.	-33.	-35.	-37.	5.
-36.	-34.	-31.	-26.	-33.	-45.	-53.	-45.	-33.	-26.	-31.	-34.	-36.	10.
-36.	-33.	-30.	-24.	-35.	-44.	-51.	-44.	-35.	-24.	-30.	-33.	-36.	15.
-36.	-33.	-29.	-23.	-35.	-44.	-50.	-44.	-35.	-23.	-29.	-33.	-36.	20.
-36.	-33.	-29.	-22.	-35.	-43.	-50.	-43.	-35.	-22.	-29.	-33.	-36.	25.
-36.	-33.	-28.	-22.	-35.	-43.	-49.	-43.	-35.	-22.	-28.	-33.	-36.	30.
-36.	-32.	-28.	-21.	-34.	-42.	-48.	-42.	-34.	-21.	-28.	-32.	-36.	35.

The use of a ground transmitter changes the SCR slightly.

Figure 41 shows the SCR for a small target, ground transmitter combination. Figure 42 shows the SCR for a large target. Table III lists the values for the generic waveform and a ground transmitter.

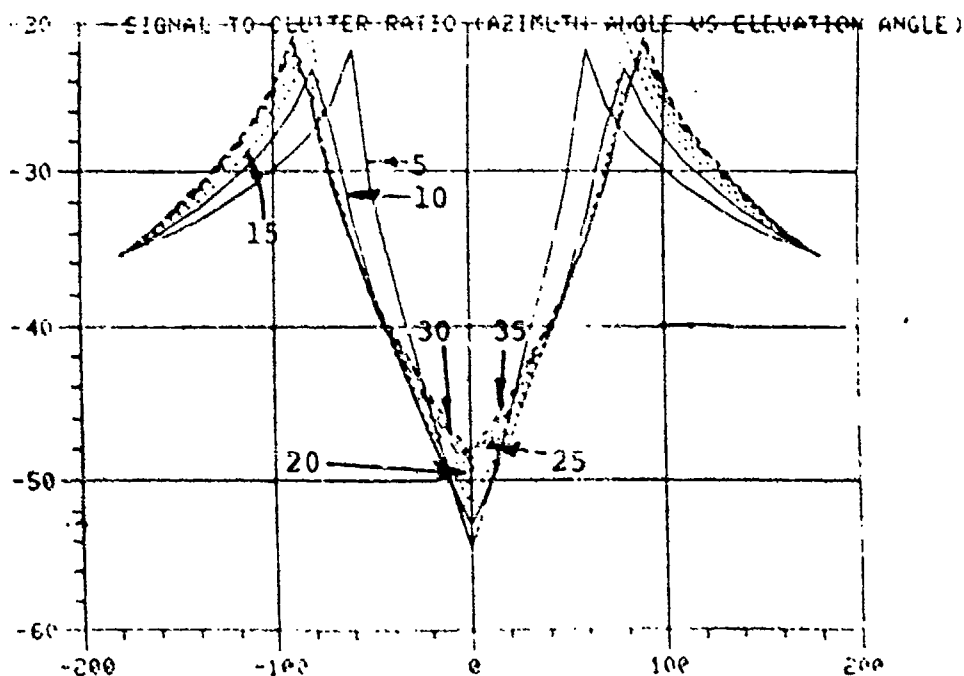


Figure 41 SCR: Ground Transmitter, Small Target

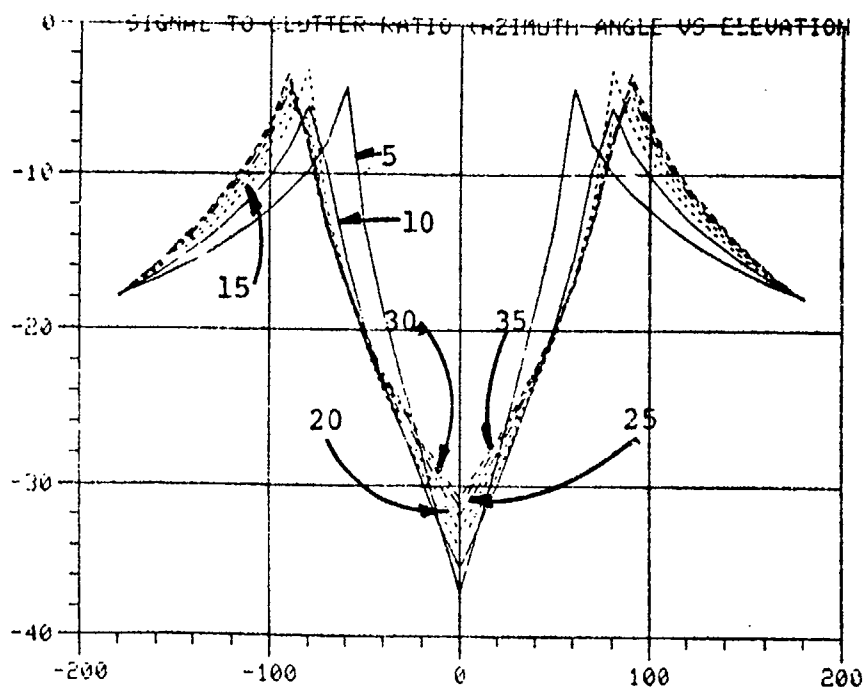


Figure 42 SCR: Ground Transmitter, Target RCS =100 Sq. M.

TABLE III

SCR Values Generic Waveform, Ground Transmitter

< Azimuth Angle >													
-180	-150	-120	-90	-60	-30	0	30	60	90	120	150	180	E1
-37.	-35.	-33.	-30.	-23.	-42.	-55.	-42.	-23.	-30.	-33.	-35.	-37.	5.
-36.	-34.	-31.	-26.	-33.	-45.	-53.	-45.	-33.	-26.	-31.	-34.	-36.	10.
-36.	-33.	-30.	-24.	-35.	-44.	-51.	-44.	-35.	-24.	-30.	-33.	-36.	15.
-36.	-33.	-29.	-23.	-35.	-44.	-50.	-44.	-35.	-23.	-29.	-33.	-36.	20.
-36.	-33.	-29.	-22.	-35.	-43.	-50.	-43.	-35.	-22.	-29.	-33.	-36.	25.
-36.	-33.	-28.	-22.	-35.	-43.	-49.	-43.	-35.	-22.	-28.	-33.	-36.	30.
-36.	-32.	-28.	-21.	-34.	-42.	-48.	-42.	-34.	-21.	-28.	-32.	-36.	35.

Doppler Spread of the Clutter Cell

The doppler spread of the clutter cell is a function of the beam shape and the platform velocities. The clutter cell doppler spread for a separating receiver transmitter pair

is shown in Figure 43. The doppler spread is shown for elevation look angles of 5, 10, 15, 20, 25, 30, and 35 degrees. Note that the greater the depression angle, the less the doppler spread.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

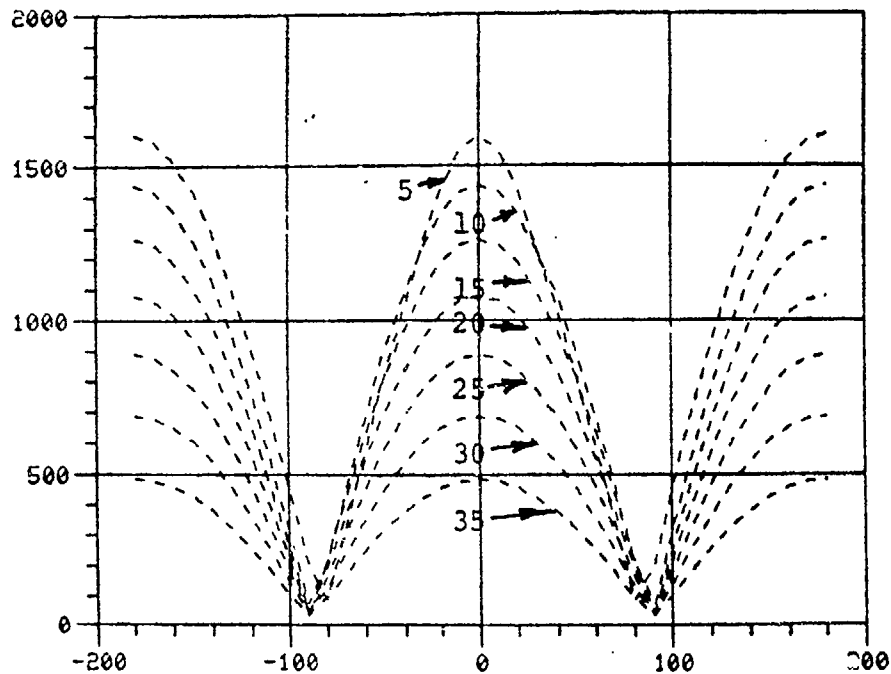


Figure 43 Doppler Spread Generic, Separating

Figure 44 shows the doppler spread for a synchronous flight pair where the transmitter and receiver are at a constant separation distance. Figure 45 shows the doppler spread for a transmitter receiver pair closing.

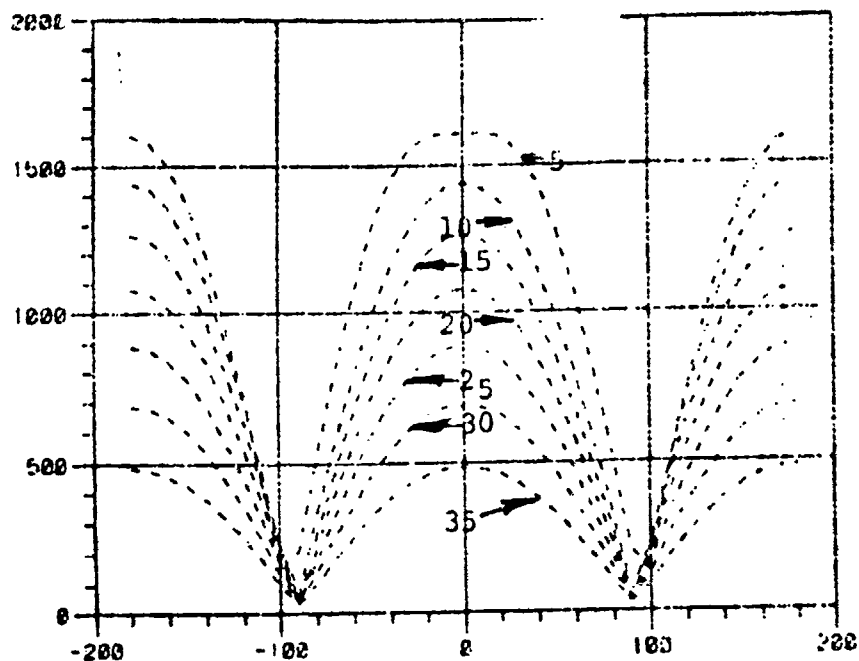


Figure 44 Doppler Spread, Constant Separation

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

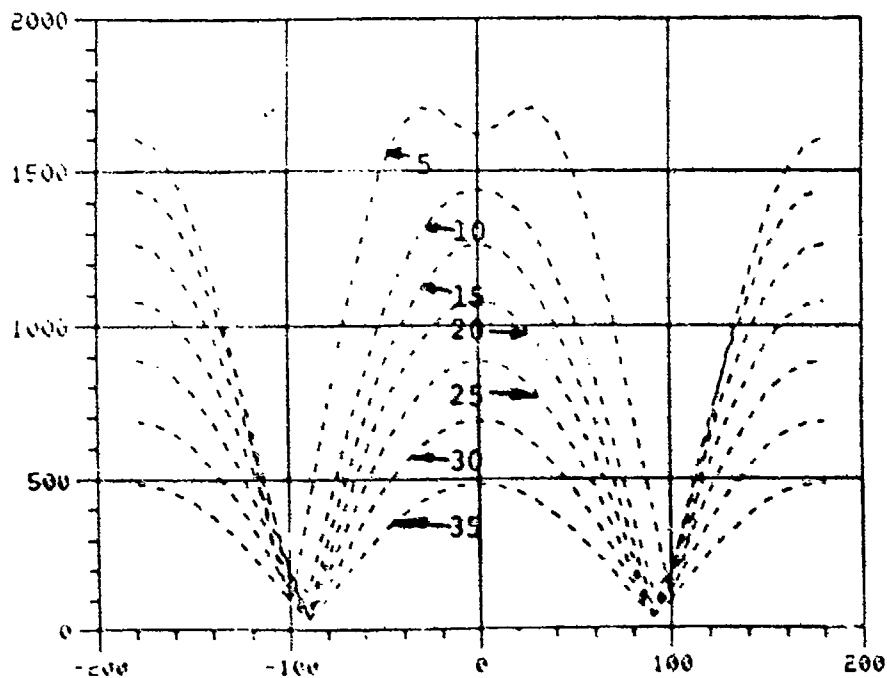


Figure 45 Doppler Spread, Closing

The doppler spread varies with the flight path orientation. If the transmitter and receiver are flying orthogonal, the doppler spread skews as shown in Figure 46. Figure 47 shows the doppler spread for a transmitter receiver pair flying arbitrary headings of 53 degrees and 315 degrees respectively. Figure 48 shows the doppler spread for transmitter and receiver having the arbitrary headings and different velocities.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

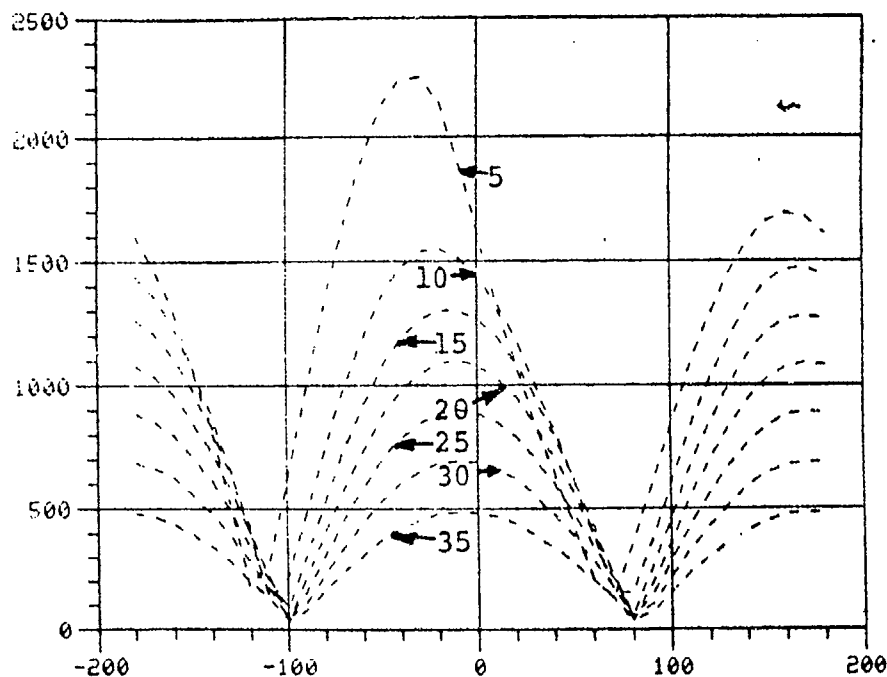


Figure 46 Doppler Spread, Orthogonal

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

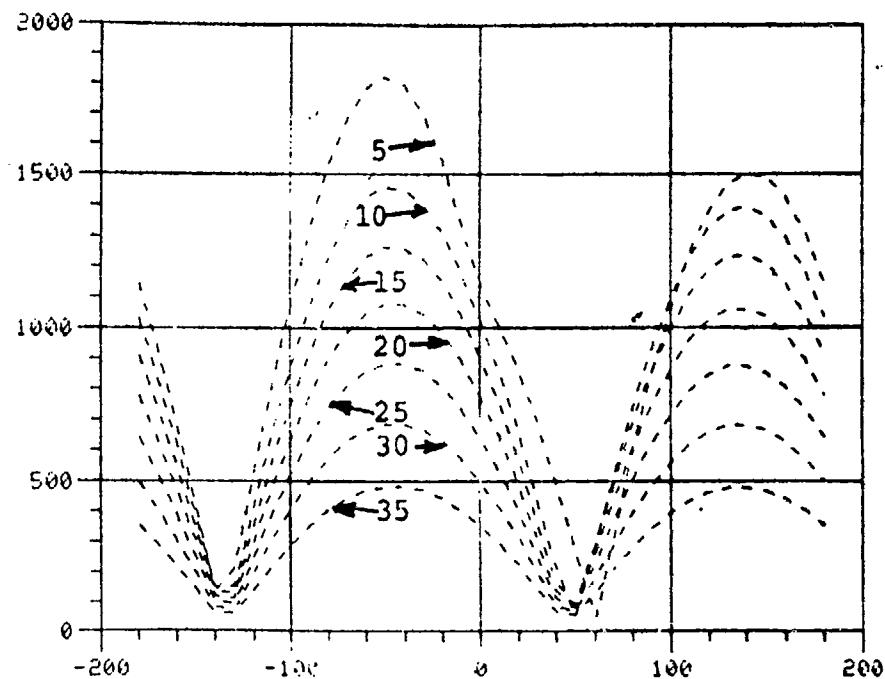


Figure 47 Doppler Spread, Arbitrary, Equal Velocities

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

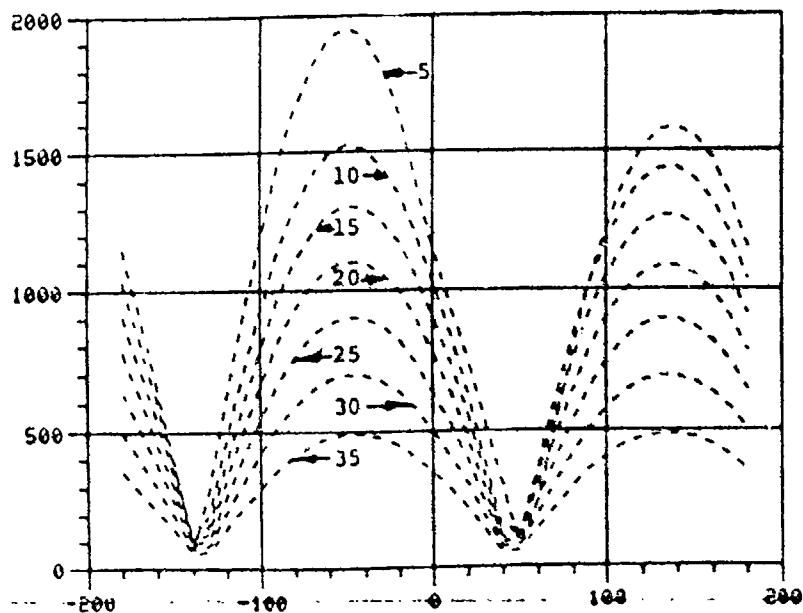


Figure 48 Doppler Spread, Arbitrary, Unequal Velocities

The doppler spread for a ground transmitter to airborne receiver is dependent upon the beam shapes of both platforms but only the velocity and heading of the receiver. Therefore, the doppler spread of the air to ground system is better behaved. Figure 49 shows the doppler spread for a closing receiver while Figure 50 shows the doppler spread for a separating pair. Note that a closing and separating system have the same spread. It should be realized that the doppler spread is the same but the doppler shift of the clutter cell is not at the same place in the frequency spectrum. If the receiver flies orthogonal to the transmitter, the doppler spread of the beam shifts as shown in Figure 51.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

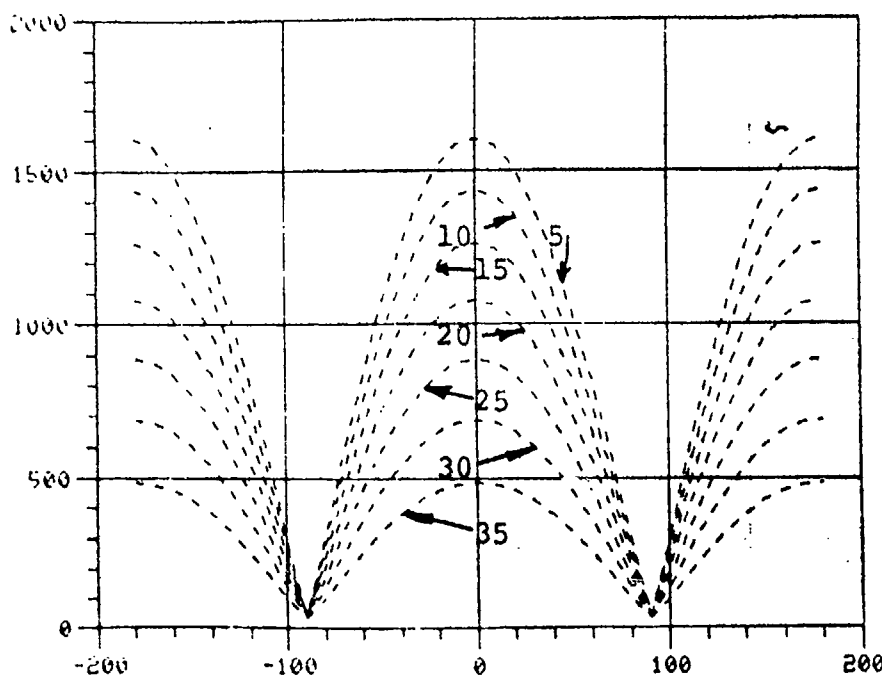


Figure 49 Doppler Spread, Air to Ground, Closing

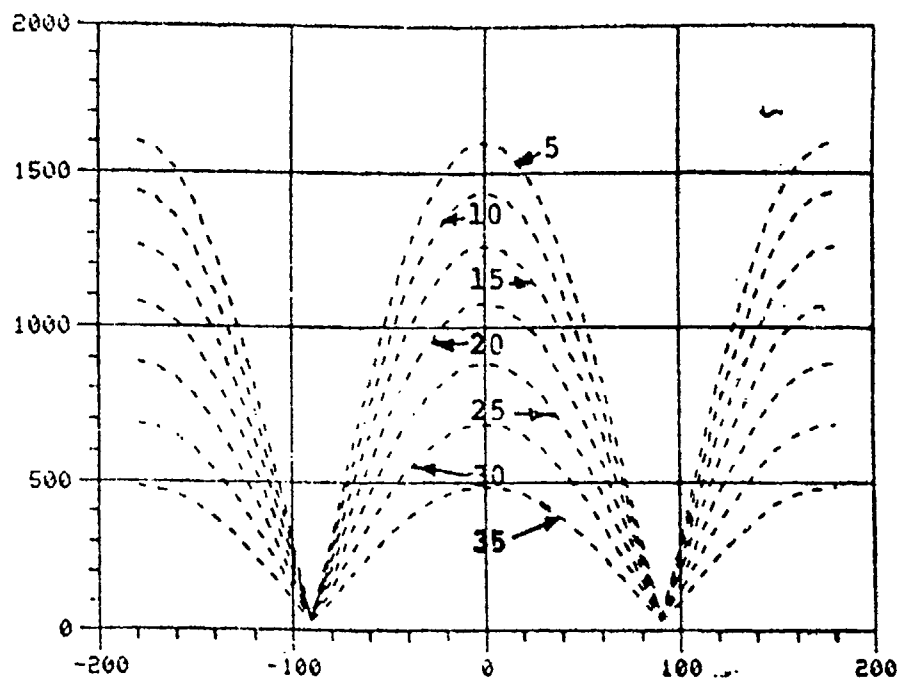


Figure 50 Doppler Spread, Air to Ground, Separating

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

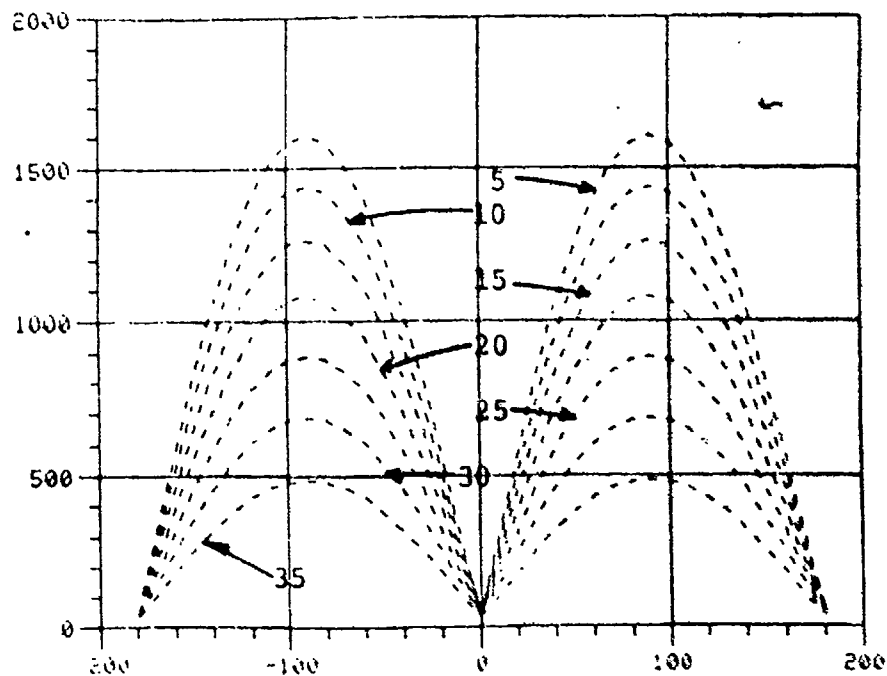


Figure 51 Doppler Spread, Air to Ground, Orthogonal

The air to ground system doppler spread shifts with respect to the heading of the receiver. Figure 52 shows the shift for a heading of 315 degrees with respect to the transmitter receiver baseline while Figure 53 shows the doppler shift for a heading of 243 degrees.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

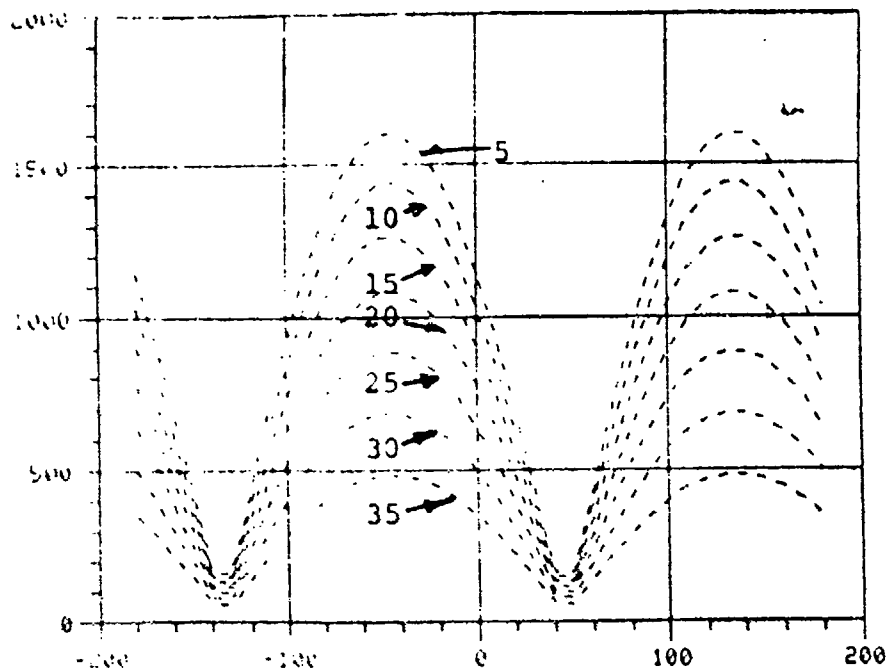


Figure 52 Doppler Spread, Air to Ground, 315 Degree Heading

VI
DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

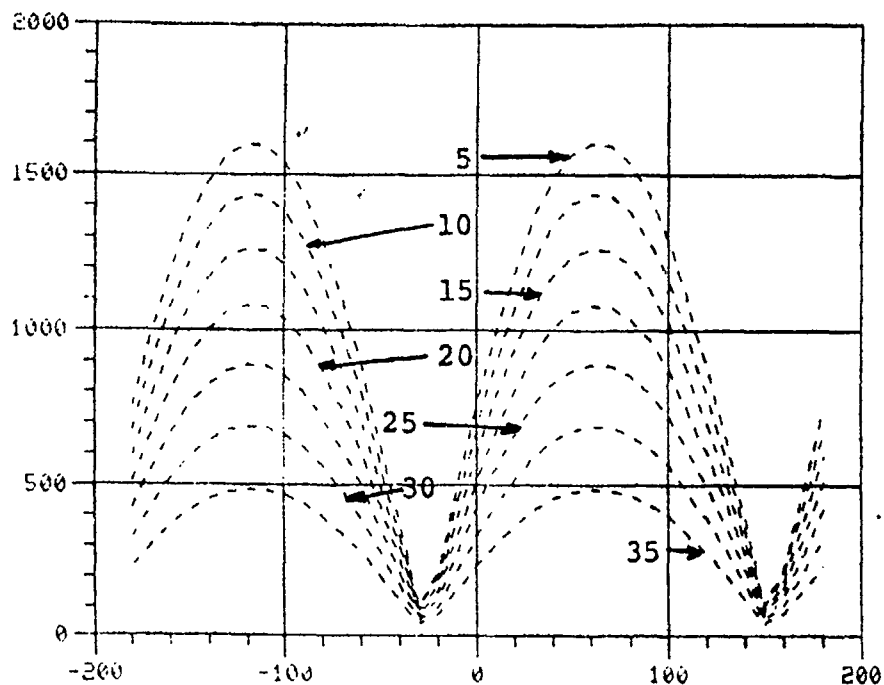


Figure 53 Doppler Spread, Air to Ground,
243 Degree Heading

The doppler spread of the beam is best understood by comparing the several relative velocities. Table IV gives values for several bistatic doppler shifts. Because the shift can be either positive or negative, the potential target could be closing or receding within the clutter spread. Obviously, minimizing the spread of the beam improves the visibility of slow moving targets. Table IV values are for a 3 Gigahertz carrier.

TABLE IV

Doppler Shift Versus Velocity

Doppler Frequency Shift (Hz)	Kilometers Per Hour	Miles Per Hour	Nautical Miles Per Hour
2000	720	446	389
1500	540	335	292
1000	360	223	194
500	180	112	97
269	97	60	52

Sample Scenario

Suppose that the doppler spread and the bistatic detection regions for a possible surveillance scenario are of interest. Assume two similar radar platform headed in opposite directions, passing side by side separated by 175 kilometers when orthogonal as shown in Figure 54.

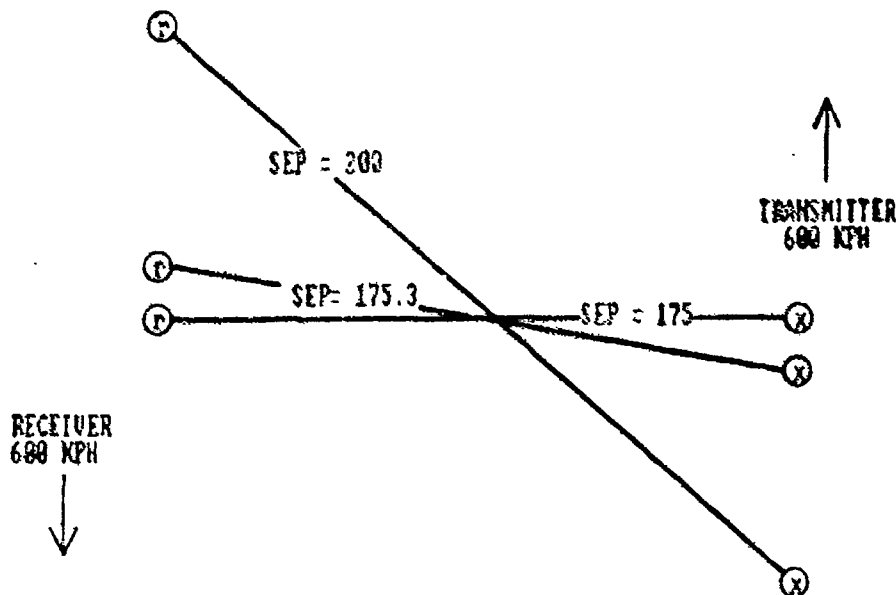


Figure 54 Possible Air to Air Scenario

Figure 55 is a composite of three bistatic detection region graphs to show the area of coverage from the time the base line is 200 Kilometers until the platforms are at right angles separated by 175 Kilometers. As the platforms separate, a mirror image (with respect to the graph base line) of the detection region is traced out. The time between curve one and curve two is 261 seconds. The time between curve two and curve three is 30 seconds. Note changes in both areas which are visible and blind to the receiver.

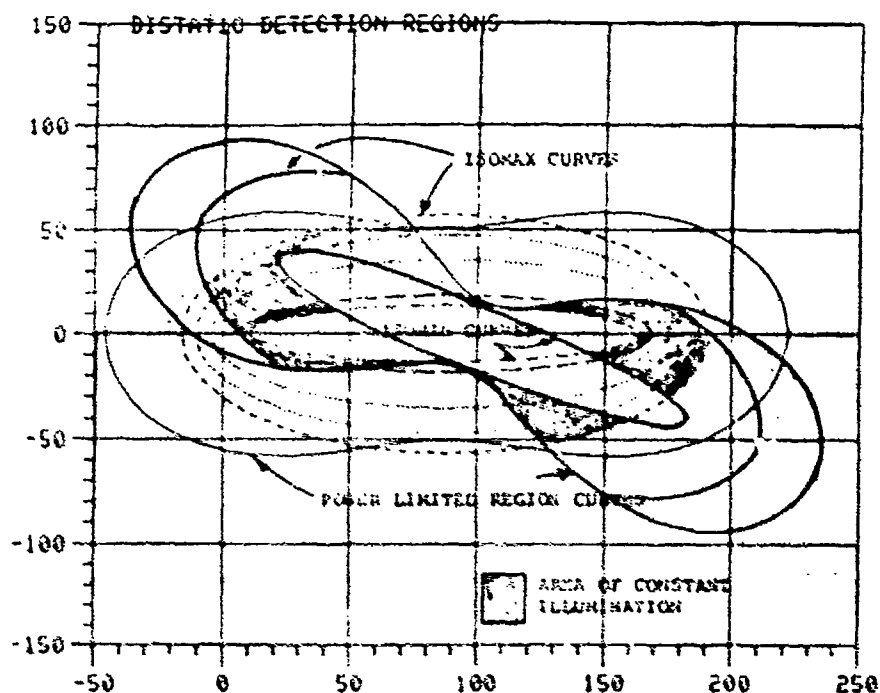


Figure 55 Change in Bistatic Detection Regions

Just as the detection regions change, the doppler spread of the clutter cell changes. Figure 56 shows the clutter cell doppler spread for initial acquisition at 200

kilometers. Figure 57 shows the change in the doppler spread as the transmitter receiver pair approach their minimum separation, while Figure 58 shows the doppler spread during the moment when the pair are orthogonal. Figure 59 shows the doppler spread as the transmitter and receiver platforms separate. Note in particular the doppler shift for the various angles of beam elevation and the shift in the magnitude of the beam spread.

1
DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

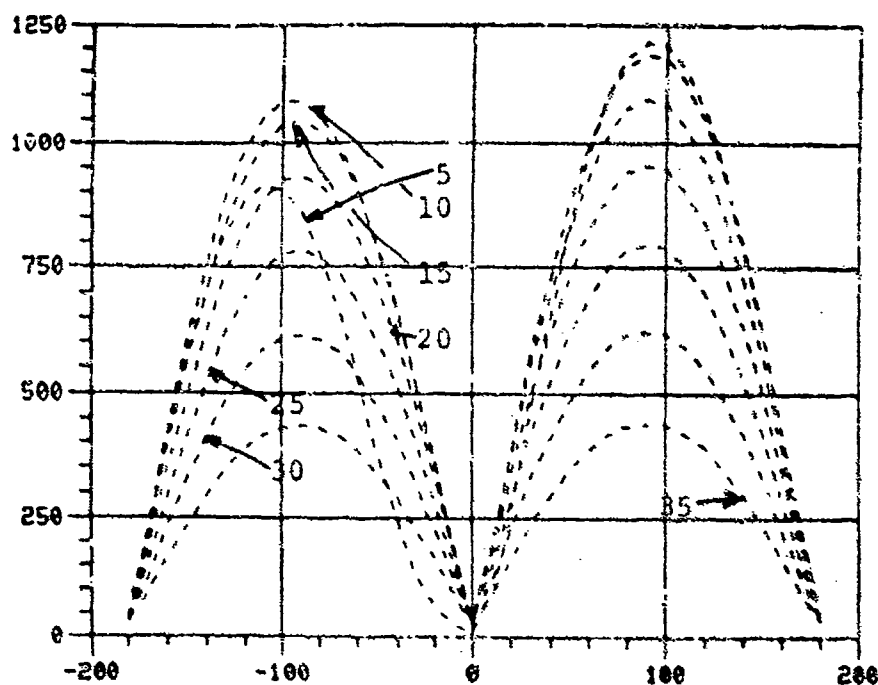


Figure 56 Doppler Spread, Closing
(Separation = 200 KM)

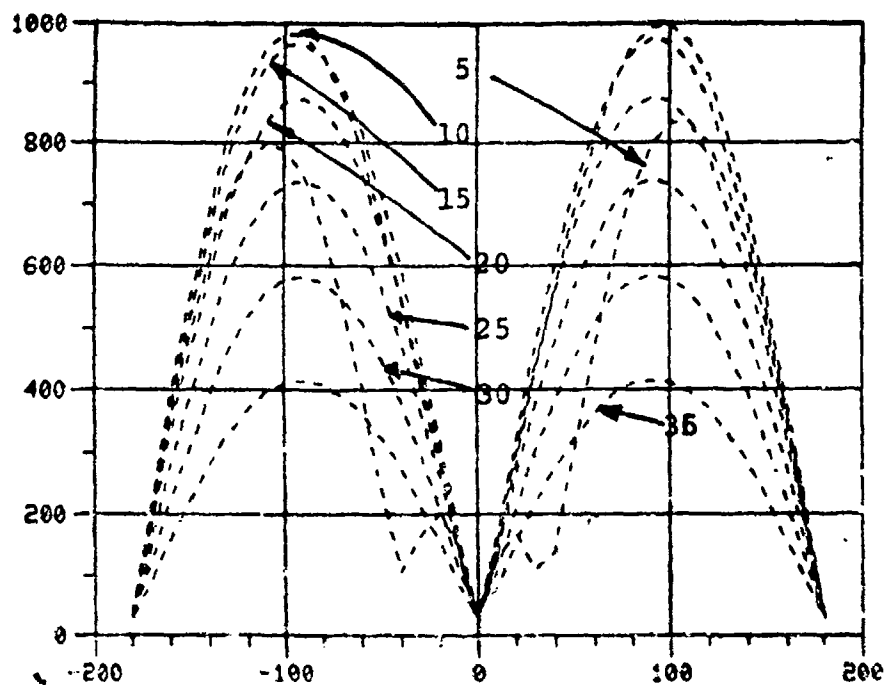


Figure 57 Doppler Spread, Closing
(Separation = 175.3 KM)

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

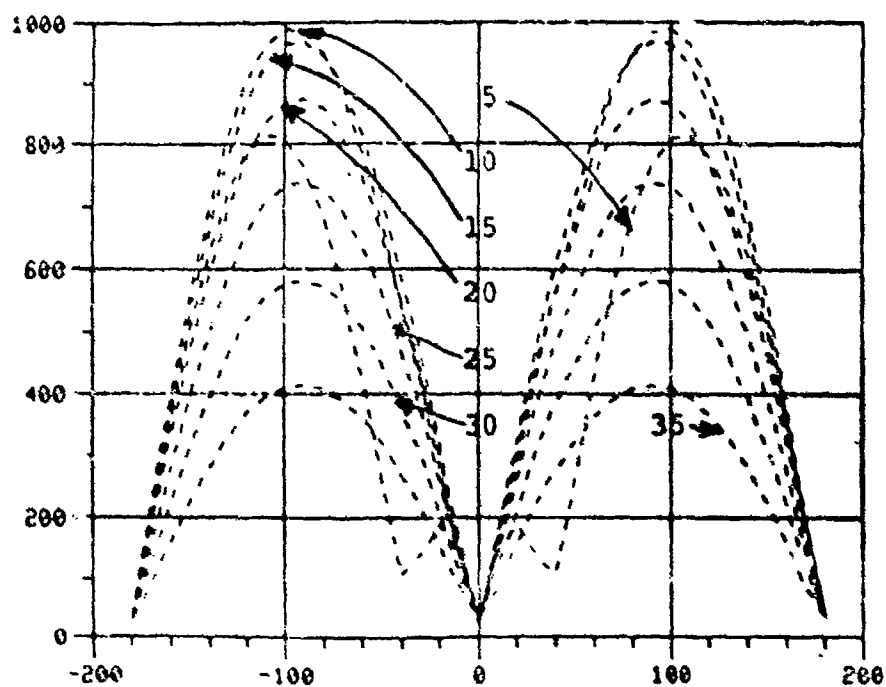


Figure 58 Doppler Spread, Receding
(Separation = 175.0 KM)

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

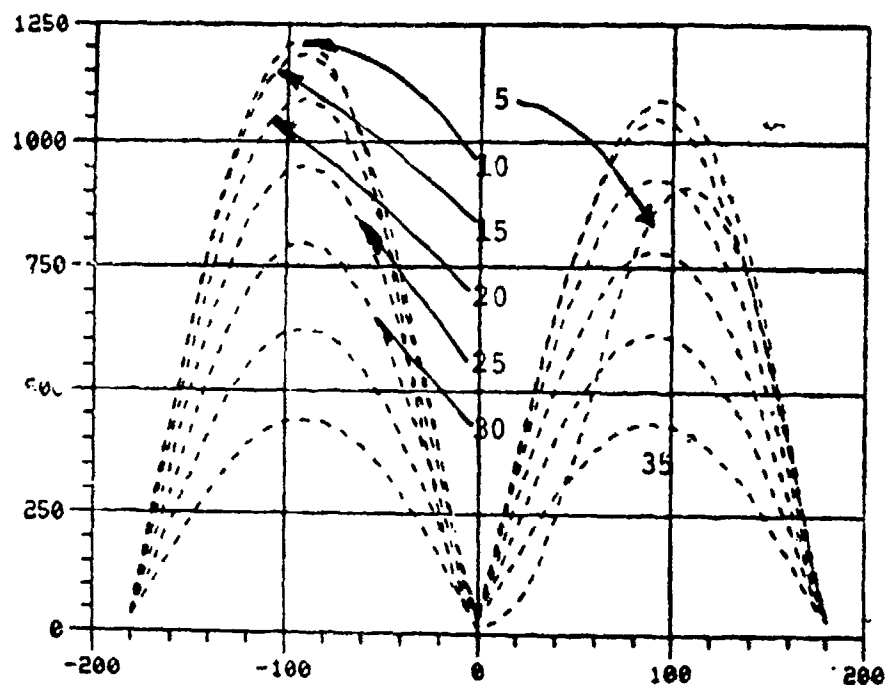


Figure 59 Doppler Spread, Receding
(Separation = 200 KM)

The sample scenario shows the shift in the detection regions and the shift in the doppler spread of the clutter cell. A passive receiver must be capable of dynamically adjusting parameters in order to maximize the possible information available at its antenna.

V. Summary, Conclusions and Recommendations

Summary

The bistatic radar problem is composed of many variables. The model developed demonstrates the need for understanding the effects of these variables on the detection regions. The model demonstrates the ability to predict the signal to clutter ratios and doppler effect for particular beam shapes and system configurations. The system and its viewing area is more complex and limited when compared to a monostatic radar system. The bistatic system is faced with a blind zone which is controlled by the waveform parameters. Chapter IV examples demonstrated the effects of varying the parameters such as pulse duration and pulse repetition frequency. Varying other system parameters such as the antenna gain and beam shape have similar effects on the Ovals of Cassini.

The figures of merit for clutter and doppler spread of the beam are predictable, and therefore usable in real time processing. The doppler spread and SCR functions are well behaved and will allow a surveillance receiver to continually update the waveform processing portion of the receiver. Continuous updates would allow for improved performance and sub-clutter visibility by having a dynamically varying clutter notch filter.

The means for exploiting a bistatic radar system are apparent. This system is most vulnerable along the

transmitter receiver baseline. The blind zone is limited by waveform and doppler spread. Additionally, the system needs to be able to have rapid synchronization and acquisition of the transmitter waveform. Changing the waveform will disrupt the receiver surveillance until the system can be resynchronized. Any parameter which maximizes the viewing area of the receiver platform is a prime candidate for change if the transmitter wishes to deny or decrease the viewing area of the receiver. Specifically, increasing the pulse width or the prf and decreasing the prf multiple will cause a drastic change in the receivers viewing area. In fact, these changes could effectively blind the receiver.

Conclusions

Choice of a good host receiver pair waveform is essential in maximizing the bistatic viewing area. For example, it was shown in Chapter IV that a low prf, multiple prf, short pulse duration waveform provides much greater viewing area. Examination of the equations of interest lead to the conclusion that to maximize the viewing area, the system must strive to maximize: power, gain of the antennas and the bistatic radar cross section of the target. The system should also minimize: the receiver bandwidth, the transmitted wave length (maximize transmitter frequency), system losses, and receiver front end temperature.

The choice of maximizing or minimizing a particular parameter may not be within the capability of the receiver

if the transmitter is non-cooperative. Likewise, the receiver can do nothing to change the radar cross section of a target. The practical step is to maximize those parameters which are within the control of the receiver. If the transmitter and receiver are cooperative, the transmitter must generate a waveform which is beneficial to the receiver. If the transmitter is non-cooperative, the receiver should look to acquire only those waveforms which provide adequate coverage. In the event of an inadequate transmitter receiver pair waveform, the receiver would have to generate its own waveform and become a monostatic platform, or be prepared to cancel its surveillance activities.

Recommendations

1. The Bistatic Model should be extended to include:
 - The Curved Earth Model
 - Varying Terrain Backgrounds
 - Sky Clutter
 - Varying Beam Shapes
 - Side Lobe Detection Regions
 - Side Lobe Clutter
 - Doppler Range Gate Limitations on Clutter
 - Varying Clutter for Different Frequencies
2. A bistatic radar cross section model should be included in the model. The cross section model should be a function of look elevation angle and azimuth angle. The

radar cross section of such a model would provide more insight into subclutter visibility of potential targets.

3. Develop the computer code for mapping of the doppler contours.

Appendix A: Fortran Program Listing

```

C *****
C
C                               BISTATIC RADAR PROGRAM
C
C *****
1  DIMENSION TABLE(300,250),SPD(10,37),BASE(302),ALT(252),
C  BASE1(38),ALT2(38),I1(30),I2(63),I3(62),Iyy(37),YY(37)
C
C  THE DATA statements set up the plot10 labels
C
C      data I1/9,9,9,9,66,73,83,84,65,84,73,67,9,68,69,84,69,
C67,84,73,79,78,9,82,69,71,73,79,78,83/
C      data I2/9,9,9,9,9,83,73,71,78,65,76,9,84,79,9,67,76,85,
C84,84,69,82,9,82,65,84,73,79,9,40,65,90,73,77,85,84,72,
C9,65,78,71,76,69,9,86,83,9,69,76,69,86,65,84,73,79,78,
C9,65,78,71,76,69,41/
C      data I3/9,9,9,9,9,68,79,80,80,76,69,82,9,83,80,82,69,65,
C68,9,79,70,9,66,69,65,77,9,40,65,90,73,77,85,84,72,
C9,65,78,71,76,69,9,86,83,9,69,76,69,86,65,84,73,79,78,
C9,65,78,71,76,69,41 /
2  REAL ISOR,ISOMIN,ISOMAX,LA,LN,LOSS
3  INTEGER NPRF,PRF
C
C  Initialize the free variables to default values
C
C      P=0.01
C      GT=10
6  GR=40
7  SNR=6.5
8  RCS=1.75
9  BW=1
10 LOSS=6.5
15 TEMP=300
25 XWAZ=1.5
30 RWAZ=1.5
31 RWEL=6
32 XWEL=6
33 FQ=3
34 Z=0
35 VX=600
36 XAZ=0
37 XEL=0
38 VT=600
39 TAZ=0
40 TEL=0
41 TFULSE=5

```

```

42 PRF=25000
43 NPRF=3
44 XALT=9
   RALT=9
45 SEP=200
46 C=3E5
c
C dummy4 is a parameter that the user sets to allow the program
C to set itself up for graphics or Crt mode
c dummy4 = 1 sends plot10 codes to the tektronix terminal
c
50 PRINT*, 'ENTER 1 IF YOU ARE ON A GRAPHIC TERMINAL, ANY OTHER
C NUMBER FOR A CRT'
52 READ*, DUMMY4
   call welcom(dummy4)
   if (dummy4.eq.1) then
c *****
C set up for plot10 graphs
c *****
53 ALT(252)=125
   ALT(2)=-125
   BASE(1)=301
   ALT(1)=251
   ALT2(1)=37
   BASE1(1)=37
   DO 54 I=2,38
   BASE1(I)=-200+I*10
54 CONTINUE
   DO 55 I=2,302
   BASE(I)=I-52
55 CONTINUE
56 DO 57 I=3,251
   ALT(I)=0
57 CONTINUE
   end if
C *****
C
C The user selects the option for the program to execute
C
c *****
60 PRINT*, 'DO YOU WANT: 1 ISORANGES'
61 print*, ' 2 DOPPLER MAP'
63 PRINT*, ' 3 SIGNAL TO CLUTTER CALCULATIONS'
   print*, ' 4 DOPPLER SPREAD OF BEAM'
64 READ*, DUMMY3
65 IF (DUMMY3.GT.4) THEN
70 CALL ERROR
73 GO TO 64
75 ELSE IF (DUMMY3.LT.1) THEN
80 CALL ERROR
82 GO TO 64
85 END IF

```

```

200  if (dummy4.eq.1) then
      call wipe
    end if
C*****
C
C  The program prints out the current parameter values before any
C  execution. This allows the operator to change any value or
C  set of values.
C
C  *****
201  PRINT*, 'CURRENT VALUES ARE DEFINED AS:'
202  PRINT*, '          TARGET          TRANSMITTER
      C          RECEIVER'
208  PRINT 1110, VT, VX, TEMP
210  PRINT 1112, TAZ, XAZ, SNR
214  PRINT 1114, TEL, XEL
216  PRINT 1116, RCS, P, LOSS
220  PRINT 1120, Z, XALT, SEP
230  PRINT 1130, GT, GR
240  PRINT 1140, FO, BW
245  PRINT 1150, XWAZ, RWAZ
247  PRINT 1118, XWEL, RWEL
249  PRINT 1119, PRF, RALT
      PRINT 1121, TPULSE
      PRINT 1122, NPRF
250  PRINT*, 'ENTER OPTION NUMBER [1-26] TO CHANGE VALUE'
260  PRINT*, 'OR 27 TO CONTINUE'
270  PRINT*, 'OR 28 TO ABORT'
C *****
C
C  Dummy directs the program to an execute mode, a change parameter
C  mode or a quit mode
C
C  *****
300  READ*, DUMMY
310  IF (DUMMY .EQ. 28) THEN
320    GO TO 7777
330  ELSE IF (DUMMY .EQ. 27) THEN
340    GO TO 595
350  ELSE IF (DUMMY .GT. 28) THEN
355    CALL ERROR
360    GO TO 250
370  ELSE IF (DUMMY .LT. 1) THEN
380    CALL ERROR
390    GO TO 250
400  END IF
C
C  subroutine call to change parameters
C
500  CALL CHANGE (DUMMY, VT, TAZ, TEL, VX, XAZ, XEL, TPULSE, PRF, NPRF,
      CFO, SEP, Z, XALT, P, GT, GR, SNR, RCS, BW, LOSS, TEMP, RWEL, RWAZ,
      CXWEL, XWAZ, RALT)

```

```

c
c  recycle to print out of cuurent value table
c
505  GO TO 200
c    TEST DUMMY3 TO FIND PROGRAM TO RUN
595  IF (DUMMY4.EQ.1) THEN
      CALL INITT(1200)
      CALL BINITT
      end if
c  *****
c
c    vector to program selection based on dummy3
c
c  *****
597  go to (600,640,744,744) Dummy3
c
c    subroutine call to calculation power equation limitation
c    value, R4
c
600  CALL RANGE(P,GT,GR,SNR,RCS,F0,LOSS,BW,TEMP,R4)
c
c    subroutine call to determine the time domain limitations
c    of the minimum and maximum isoranges
c
610  CALL MINMAX(TPULSE,C,SEP,NPRF,PRF,ISOMIN,ISOMAX,I,XALT,RALT)
c
c  if not on a 40XX, print values for isomin and isomax on screen
c
611  if (dummy4.ne.1) then
      print 1160,isomax
      print 1161,isomin
      go to 990
      end if
c
c  if on a 40XX, draw the power equation limitation regions
c  ( the Ovals of Cassini)
c
612  call check(base,alt)
      call dsplay(base,alt)
      call hlabel(30,i1)
615  CALL POWER(Z,XALT,SEP,R4,BASE,RALT)
c
c    subroutine call to draw the isorange ellipsiods
c
620  CALL ISOR(ISOMIN,ISOMAX,I,SEP,Z,XALT,BASE,RALT)
c
c    a check to see if all the intermediate ellipsiods are drawn
c    if not, the program will recycle through the isor routine
c    until the minimum, maximum and intermediate ellipses have
c    been drawn
c
627  IF (I.NE.0) THEN

```

```

630      GO TO 620
635      END IF
636      go to 990
640      IF (DUMMY4.EQ.1)THEN
           call wipe
        END IF

C
C      subroutine call to calculate the doppler values for the region
C      defined in the model.
C
645      CALL DOPMAP(VX,XEL,XAZ,VT,TEL,TAZ,FO,C,SEP,XALT,
CZ,TABLE,RALT)

C
C      a subroutine call to print the doppler values for the plane of
C      interest.  if a graphical plot package is added at a later date,
C      it should be added here.
C
646      CALL DOPPLT(TABLE)
647      GO TO 990
C
C      THE SCR ROUTINE.  This routine calculates the SCR for seven look
C      down angles (5,10,15,20,25,30,35).  The scr is a function of the
C      Azimuthal scan angle as well.
C
744      RCSDB=10*LOG10(RCS)
           IF (Z.GE.RALT) THEN
               PRINT*, ' MODEL HAS NO CAPABILITY TO FIGURE "SKY" CLUTTER'
               GO TO 990
           END IF
           DO 900 I=1,7
745               RSEL=I*5
                   TABLE(I,38)=RSEL
750               DO 800 J=1,37
755                   RSAZ=(J-1)*10-180
                       Iyy(J)=INT(RSAZ)

C
C      The subroutine call to calculate the doppler spread of the
C      common beam area.
C
775      CALL DOPSD(SEP,Z,XALT,RSAZ,RSEL,RMAZ,RMEL,XMAZ,XMEL,
C VX,VT,FO,C,DOPSR,XSEL,XRAZ,PHIEDU,XEL,XAZ,TAZ,TEL,PHI,RALT)
           SPD(I,J)=DOPSR

C
C      subroutine call to calculate the per unit density of the
C      common beam area
C
780      CALL DENT(PHI,PHIEDU,DEN)

C
C      subroutine call to calculate the common beam area
C
785      CALL AREA(SEP,Z,RSEL,RSAZ,RW,XMAZ,RMAZ,C,ACDB,RALT,XALT)
790      TABLE(I,J)=RCSDB-DEN-ACDB

```

```

800     CONTINUE
900     CONTINUE
C
C   This section sets up the plot10 call for drawing the SCR graph
C
901     IF (DUMMY4.EQ.1) THEN
           if (dummy3.eq.3) then
           DO 902 I=1,37
               ALT2(I+1)=table(1,I)
902     CONTINUE
           CALL CHECK(BASE1,ALT2)
           CALL DSPLAY(BASE1,ALT2)
           call hlabel(63,i2)
           do 904 j=2,7
               do 903 i=1,37
                   alt2(I+1)=TABLE(J,i)
903     continue
               call cplot(base1,alt2)
               n=int(j/2)
               call line(n)
904     continue
               go to 990
               end if
           DO 905 I=1,37
               ALT2(I+1)=spd(1,I)
905     CONTINUE
           call hlabel(62,i3)
           CALL LINE(34)
           CALL CHECK(BASE1,ALT2)
           CALL DSPLAY(BASE1,ALT2)
           DO 907 I=2,7
               DO 906 J=1,37
                   ALT2(J+1)=spd(I,J)
906     CONTINUE
               CALL CPLOT(BASE1,ALT2)
907     CONTINUE
               go to 990
               end if
C
C   If not on a 40xx, the program will Print a table of SCR
C   values and doppler values on the CRT screen.
C
910     PRINT*,('                SIGNAL TO CLUTTER RATIO AND DOPPLER
C SPREAD')
           PRINT 1162,(Iyy(I),i=1,37,3)
915     DO 955 I=1,7
920     PRINT 1000,(TABLE(I,J),J=1,37,3),TABLE(I,38)
925     PRINT 1001,(SPD(I,J),J=1,37,3)
955     CONTINUE
990     if (dummy4.eq.1) then
           call tinput(y)
           call finitt(0,700)

```

```

      end if
      PRINT*, 'DO YOU WISH TO CHANGE PARAMETERS AND TRY AGAIN
C      (ENTER 1)'
995  READ*, DUMMY
996  IF (DUMMY.EQ.1) THEN
997    GO TO 60
998  END IF
1000 FORMAT(' SCR dB '14F5.0)
1001 FORMAT(' SPREAD ',13F5.0)
1110 FORMAT(' 1 VELOCITY = ',F7.2,' 6 VELOCITY = ',
CF7.2,' 18 TEMP = ',F6.2)
1112 FORMAT(' 2 AZ ANGLE = ',F7.2,' 7 AZ ANGLE = ',
CF7.2,' 19 SNR = ',F6.2)
1114 FORMAT(' 3 EL ANGLE = ',F7.2,' 8 EL ANGLE = ',
CF7.2)
1116 FORMAT(' 4 RCS = ',F7.2,' 9 POWER = ',
CF7.4,' 20 LOSS = ',F7.2)
1120 FORMAT(' 5 Z PLANE = ',F7.2,' 10 ALTITUDE = ',
CF7.2,' 21 SEP = ',F7.2)
1130 FORMAT(' 11 GAIN = ',
CF7.2,' 2 GAIN = ',F7.2)
1140 FORMAT(' 12 CARRIEK = ',
CF7.2,' 23 BW = ',F7.2)
1150 FORMAT(' 13 BEAM WD = ',
CF7.2,' 24 BEAM WD = ',F7.2)
1118 FORMAT(' 14 BEAM HT = ',
CF7.2,' 25 BEAM HT = ',F7.2)
1119 FORMAT(' 15 PRF = ',
CI7,' 26 ALT = ',F7.2)
1121 FORMAT(' 16 PULSE WD = ',
CF7.2)
1122 FORMAT(' 17 # PRF = ',
CI7)
1160 format(' Maximum Isorange = ',f6.2)
1161 format(' Minimum Isorange = ',f6.2)
1162 format(' Az ',13I5,' El ')
7777 PRINT*, 'THANK YOU AND COME AGAIN'
      STOP
      END

```

```

C
C  a short routine to send an error message to the operator
C  if an out of bounds parameter is specified.
C

```

```

1  SUBROUTINE ERROR
5  PRINT*, 'ERROR IN DATA ENTRY, TRY AGAIN'
10 RETURN
15 END

```

```

C  a short welcome
C

```

```

1  SUBROUTINE WELCOM(dummy4)
      PRINT*, ' '

```

```

PRINT*, ' '
PRINT*, '      Welcome to the World of Bistatic Radar'
PRINT*, ' '
PRINT*, ' '
PRINT*, 'The purpose of this program is to assist the study'
PRINT*, 'of Bistatic Radar. This program allows for varying'
PRINT*, 'parameters to develop isodoppler and isorange maps,'
PRINT*, 'as well as Signal to Clutter Ratio values and the ,'
PRINT*, 'doppler frequency spread of the clutter cell.'
PRINT*, 'The maps can be displayed on a Tektronix 40XX graphics'
PRINT*, 'terminal and/or generated in hardcopy. The program'
PRINT*, 'will ask you to input data. Enter the data required:'
PRINT*, 'All distance measures are in Kilometers. All angles'
PRINT*, 'in Degrees. All Velocities in Kilometers per Second.'
PRINT*, ' '
PRINT*, 'The Bistatic Radar system modeled by this system always'
PRINT*, 'assumes the receiver and transmitter form the baseline.'
PRINT*, 'All angles are measured with reference to the base line'
PRINT*, ' '
PRINT*, '      //'
PRINT*, '      / Angle Theta (positive)'
PRINT*, '      //'
PRINT*, ' *****'
PRINT*, 'Receiver                                     Transmitter'
PRINT*, ' '
PRINT*, 'STRIKE ANY NUMBER AND CARRIAGE RETURN KEY TO CONTINUE'
READ *, DUMMY
if (dummy4.eq.1) then
    call wipe
end if
PRINT*, ' '
PRINT*, ' '
PRINT*, 'Remember:'
PRINT*, ' '
PRINT*, 'The relationship of kilometers to nautical miles is:'
PRINT*, '1 Nautical Mile = 1.852 Kilometers'
PRINT*, 'The relationship of kilometers to statute miles is:'
PRINT*, '1 Statute Mile = 1.613 Kilometers'
PRINT*, 'The relationship of meters per second to nautical miles'
PRINT*, 'per hour is: 1 NM/Hr = 0.514 M/SEC'
PRINT*, 'The relationship of meters per second to statute miles'
PRINT*, 'per hour is: 1 M/Hr = 0.448 M/SEC'
PRINT*, ' '
PRINT*, ' '
RETURN
END

```

50
55
C
C
C
1
5
30

```

THIS SUBROUTINE CALCULATES THE DENSITY OF THE CLUTTER CELL

SUBROUTINE DENT(PHI,PHIEQU,DEN)
    X=PHI
    IF (X.GT.90) THEN

```

```

35     DEN=SQRT((X-90)*3.2111)-32
40     ELSE
45     DEN=SQRT((90-X)*10)-32
50     END IF
55     IF (PHIEQU.GT.30) THEN
56     PRINT*, 'MODEL ILL DEFINED AT THIS POINT'
57     CORR=0
58     ELSE IF (PHIEQU.LT.1.5) THEN
59     CORR=(PHI/180)*(-8)
60     ELSE
61     CORR=(PHI/180)*(9.2*LOG10(PHIEQU)-9.2)
62     END IF
63     DEN = DEN + CORR
64     RETURN
65     END

```

C THIS SUBROUTINE CALCULATES THE Area of the clutter cell
c which is dependent upon the beam geometry and the
c look down and azimuthal angles

```

1     SUBROUTINE AREA(SEP,Z,RSEL,RS AZ,BW,XWAZ,RWAZ,C,ACDB,RALT,XALT)
5     R2=(RALT-Z)/(SIND(RSEL))
10    Y=R2*COSD(RSEL)*SIND(RSAZ)
15    X=R2*COSD(RSEL)*COSD(RSAZ)
20    R1=SQRT((SEP-X)**2+Y**2+(XALT-Z)**2)
22    rwaz1=rwaz*0.0174533
23    xwaz1=xwaz*0.0174533
25    R3=SQRT((SEP-X)**2+(XALT-RALT)**2)
30    SEC2BI=4*R1*R2/(2*R1*R2+R2**2+R1**2-R3**2)
35    TEST = R2*RWAZ1/R1
40    IF (TEST.GE.XWAZ1) THEN
45    AC=R1*XWAZ1*C*SEC2BI/(2*BW)
50    ELSE
55    AC=R2*RWAZ1*C*SEC2BI/(2*BW)
60    END IF
100   ACDB=10*LOG10(AC)
105   RETURN
110   END

```

C Compute The Doppler Spread, and the Transmitter
C Elevation and Azimuth Angles

```

1     SUBROUTINE DOPSD(SEP,Z,XALT,RS AZ,RSEL,RWAZ,RWEL,XWAZ,XWEL,
2     CVX,VT,FO,C,DOPBR,XSEL,XRAZ,PHIEQU,XEL,XAZ,TAZ,YEL,PHI,RALT)
3     DIMENSION GATE(8,4)
5     REAL LA, LN
25    RWEL2=RWEL*0.5
30    RWAZ2=RWAZ*0.5
35    XWAZ2=XWAZ*0.5
40    XWEL2=XWEL*0.5
45    TEMP=(RALT-Z)/TAND(RSEL)
50    X=TEMP*COSD(RSAZ)
55    Y=TEMP*SIND(RSAZ)
60    TEMP2=SQRT(Y**2+(SEP-X)**2)

```

```

65  XSAZ=ATAND(Y/(SEP-X))
C   THE AZIMUTHAL ANGLE IS NOW DETERMINED
66  IF (RSAZ.GT.180) THEN
      RSAZ=360-RSAZ
      END IF
67  PHI=ABS(XSAZ)+ABS(RSAZ)
70  XSEL=ATAND((XALT-Z)/TEMP2)
C   THE EQUIVALENT ANGLE CAN NOW BE DETERMINED
72  PHIEQU=(RSEL+XSEL)/2
75  GATE(1,1)=TEMP*COSD(RSAZ-RWAZ2)
80  GATE(2,1)=TEMP*COSD(RSAZ+RWAZ2)
85  GATE(3,1)=(RALT-Z)*COSD(RSAZ)*TAND(RSEL+RWEL2)
90  GATE(4,1)=(RALT-Z)*COSD(RSAZ)*TAND(RSEL-RWEL2)
95  GATE(1,2)=TEMP*SIND(RSAZ-RWAZ2)
100 GATE(2,2)=TEMP*SIND(RSAZ+RWAZ2)
105 GATE(3,2)=(RALT-Z)*SIND(RSAZ)*TAND(RSEL+RWEL2)
110 GATE(4,2)=(RALT-Z)*SIND(RSAZ)*TAND(RSEL-RWEL2)
115 GATE(5,1)=SEP-TEMP2*COSD(XSAZ-XWAZ2)
120 GATE(6,1)=SEP-TEMP2*COSD(XSAZ+XWAZ2)
125 GATE(7,1)=SEP-(XALT-Z)*TAND(XSEL-XWEL2)*COSD(XSAZ)
130 GATE(8,1)=SEP-(XALT-Z)*TAND(XSEL+XWEL2)*COSD(XSAZ)
135 GATE(5,2)=TEMP2*SIND(XSAZ-XWAZ2)
140 GATE(6,2)=TEMP2*SIND(XSAZ+XWAZ2)
145 GATE(7,2)=(XALT-Z)*TAND(XSEL-XWEL2)*SIND(XWAZ2)
150 GATE(8,2)=(XALT-Z)*TAND(XSEL+XWEL2)*SIND(XWAZ2)
155 DO 160 I=1,8
160   GATE(I,3)=(X-GATE(I,1))*#2+(Y-GATE(I,2))*#2
165 CONTINUE
C
C   NOW THE PROGRAM LOOKS FOR THE SMALLEST FOUR DISTANCES AND
C   PLACES THE COORDINATES IN THE TOP FOUR RUNGS OF GATE
170 DO 230 N=1,7
175   L=N
180   JJ=N+1
185   DO 210 I=JJ,8
190     IF(GATE(L,3).LT.GATE(I,3)) THEN
195       GO TO 230
200     END IF
205     L=I
210   CONTINUE
215   T=GATE(L,3)
216   T2=GATE(L,2)
217   T3=GATE(L,1)
220   GATE(L,3)=GATE(N,3)
221   GATE(L,2)=GATE(N,2)
222   GATE(L,1)=GATE(N,1)
225   GATE(N,3)=T
226   GATE(N,2)=T2
227   GATE(N,1)=T3
230 CONTINUE
C   NOW FIND THE DOPPLER OF THE FOUR POINTS
235 VXZ = (VX*SIND(XEL))/3600

```

```

240 VXY = (VX*(COSD(XEL))*SIND(XAZ))/3600
245 VXX = (VX*(COSD(XEL))*COSD(XAZ))/3600
250 VTZ = (VT*SIND(TEL))/3600
255 VTY = (VT*(COSD(TEL))*SIND(TAZ))/3600
260 VTX = (VT*(COSD(TEL))*COSD(TAZ))/3600
265 LA=C/(F0*1E9)
270 DO 295 I=1,4
275   X=GATE(I,1)
276   Y=GATE(I,2)
277   AP = SQRT(X*X + Y*Y + (Z-RALT)*(Z-RALT))
278   BP = SQRT ((SEP-X)*(SEP-X) + Y*Y + (XALT-Z)*(XALT-Z))
279   FD1=((SEP-X)*(VTX-VXX)+Y*(VXY-VTY)+(XALT-Z)*(VTZ-VXZ))
280   FD1= FD1/(BP*LA)
281   LN=C/(F0*1E9+FD1)
282   FD2 =-1*(VTX*X + VTY*Y + VTZ*(Z-RALT)) / (AP*LN)
290   GATE(I,4)=FD1 + FD2
295 CONTINUE
300 FDMAX=MAX(GATE(1,4),GATE(2,4),GATE(3,4),GATE(4,4))
305 FDMIN=MIN(GATE(1,4),GATE(2,4),GATE(3,4),GATE(4,4))
310 DOPSR=ABS(FDMAX-FDMIN)
320 RETURN
330 END

```

c
c This routine prints out a table of values on the screen
c The values are the doppler frequency of the plane of interest.
c A doppler map is constructed by hand drawing the isodoppler
c contours.

```

c
1      SUBROUTINE DOPPLT(TABLE)
5      DIMENSION TABLE(300,250),IY(15)
10     DO 30 I=1,11
        IY(I)=-150+25*I
30     CONTINUE
35     PRINT*,'          Idodoppler Information'
40     PRINT*,'<X axis><          Y axis
c          >')
45     PRINT 100,(IY(i),i=1,11)
50     DO 70 i=1,300,5
        ii=i-51
55     PRINT 105,ii,(TABLE(I,J),J=1,11)
70     CONTINUE
100    FORMAT('          ',11I6)
105    FORMAT(18,11F6.0)
110    RETURN
115    END

```

c
c The routine for interactively changing the variables of interest.

```

1      SUBROUTINE CHANGE(DUMMY,VI,TAZ,TEL,VX,XAZ,XEL,IPULSE,PRF,NPRF,
cF0,SEP,Z,XALT,P,GT,GR,SNR,RCS,BW,LOSS,TEMP,RWEL,RWAZ,XWEL,
CXWAZ,RALT)
        INTEGER PRF,NPRF,D

```

```

REAL LOSS
11  D=INT(DUMMY)
22  GO TO(600,700,800,1600,500,100,200,300,1400,900,1500,1300,
    C 2500,2400,1000,1200,1100,2100,1800,2000,400,1700,1900,2300,
    C 2200,2600) D
100 PRINT*, 'INPUT TRANSMITTER VELOCITY (0-1200)'
140 READ*, VX
150 IF (VX .LT. 0) THEN
155     CALL ERROR
160     GO TO 100
170 ELSE IF (VX .GT. 1200) THEN
175     CALL ERROR
177     GO TO 100
180 END IF
190 GO TO 2700
200 PRINT*, 'INPUT TRANSMITTER AZIMUTH ANGLE (0-360 DEGREES)'
240 READ*, XAZ
250 IF (XAZ .LT. 0) THEN
255     CALL ERROR
260     GO TO 200
270 ELSE IF (XAZ .GT. 360) THEN
275     CALL ERROR
277     GO TO 200
280 END IF
290 GO TO 2700
300 PRINT*, 'INPUT TRANSMITTER ELEVATION ANGLE (-10 TO +10 DEGREES)'
340 READ*, XEL
350 IF (XEL+10 .LT. 0) THEN
355     CALL ERROR
360     GO TO 300
370 ELSE IF (XEL .GT. 10) THEN
375     CALL ERROR
377     GO TO 300
380 END IF
390 GO TO 2700
400 PRINT*, 'INPUT TRANSMITTER RECEIVER SEPARATION (10-200 KM)'
440 READ*, SEP
450 IF (SEP .LT. 10 ) THEN
455     CALL ERROR
460     GO TO 400
470 ELSE IF (SEP .GT. 200) THEN
475     CALL ERROR
477     GO TO 400
480 END IF
490 GO TO 2700
500 PRINT*, 'INPUT ALTITUDE PLANE OF INTEREST (0-30 KM)'
540 READ*, Z
550 IF (Z .LT. 0 ) THEN
555     CALL ERROR
560     GO TO 500
570 ELSE IF (Z .GT. 30) THEN
575     CALL ERROR

```

```

577      GO TO 500
580  END IF
590  GO TO 2700
600  PRINT*, 'INPUT TARGET VELOCITY (0-2500)'
640  READ*, VT
650  IF (VT .LT. 0) THEN
655      CALL ERROR
660      GO TO 600
670  ELSE IF (VT .GT. 2500) THEN
675      CALL ERROR
677      GO TO 600
680  END IF
695  GO TO 2700
700  PRINT*, 'INPUT TARGET AZIMUTH ANGLE (0-360 DEGREES)'
740  READ*, TAZ
750  IF (TAZ .LT. 0) THEN
755      CALL ERROR
760      GO TO 700
770  ELSE IF (TAZ .GT. 360) THEN
775      CALL ERROR
777      GO TO 700
780  END IF
795  GO TO 2700
800  PRINT*, 'INPUT TARGET ELEVATION ANGLE (-10 TO +10 DEGREES)'
840  READ*, TEL
850  IF (TEL+10 .LT. 0) THEN
855      CALL ERROR
860      GO TO 800
870  ELSE IF (TEL .GT. 10) THEN
875      CALL ERROR
877      GO TO 800
880  END IF
890  GO TO 2700
900  PRINT*, 'INPUT TRANSMITTER ALTITUDE (0.01-30 KM)'
940  READ*, XALT
950  IF (XALT .LT. 0.01 ) THEN
955      CALL ERROR
960      GO TO 900
970  ELSE IF (XALT .GT. 30) THEN
975      CALL ERROR
977      GO TO 900
980  END IF
990  GO TO 2700
1000 PRINT*, 'INPUT PULSE REPETITION FREQUENCY (1-50000)'
1040 READ*, PRF
1050 IF (PRF .LT. 1) THEN
1055     CALL ERROR
1060     GO TO 1000
1070 ELSE IF (PRF .GT. 50000) THEN
1075     CALL ERROR
1077     GO TO 1000
1080 END IF

```

```

1090 GO TO 2700
1100 PRINT*, 'INPUT NUMBER OF PRF FREQUENCIES (1-10)'
1140 READ*, NPRF
1150 IF (NPRF .LT. 1) THEN
1155     CALL ERROR
1160     GO TO 1100
1170 ELSE IF (NPRF .GT. 10) THEN
1175     CALL ERROR
1177     GO TO 1100
1180 END IF
1190 GO TO 2700
1200 PRINT*, 'INPUT PULSE WIDTH (0.1 TO 30 MICROSECONDS)'
1240 READ*, TPULSE
1250 IF (TPULSE .LT. 0.1) THEN
1255     CALL ERROR
1260     GO TO 1200
1270 ELSE IF (TPULSE .GT. 30) THEN
1275     CALL ERROR
1277     GO TO 1200
1280 END IF
1290 GO TO 2700
1300 PRINT*, 'INPUT CARRIER FREQUENCY (S BAND 2-4 GHZ)'
1340 READ*, FO
1350 IF (FO .LT. 2) THEN
1355     CALL ERROR
1360     GO TO 1300
1370 ELSE IF (FO .GT. 4) THEN
1375     CALL ERROR
1377     GO TO 1300
1380 END IF
1390 GO TO 2700
1400 PRINT*, 'INPUT TRANSMITTER POWER (0.00050-2.0 MEGAWATTS)'
1440 READ*, P
1450 IF (P .LT. 0.00050) THEN
1455     CALL ERROR
1460     GO TO 1400
1470 ELSE IF (P .GT. 2.0) THEN
1475     CALL ERROR
1477     GO TO 1400
1480 END IF
1490 GO TO 2700
1500 PRINT*, 'INPUT TRANSMITTER GAIN (0-45 dB)'
1540 READ*, GT
1550 IF (GT .LT. 0) THEN
1555     CALL ERROR
1560     GO TO 1500
1570 ELSE IF (GT .GT. 45) THEN
1575     CALL ERROR
1577     GO TO 1500
1580 END IF
1590 GO TO 2700
1600 PRINT*, 'INPUT MINIMUM TARGET CROSS SECTION (0.1-100 Sq M)'

```

```

1640 READ*,RCS
1650 IF (RCS .LT. 0.1) THEN
1655     CALL ERROR
1660     GO TO 1600
1670 ELSE IF (RCS .GT. 100) THEN
1675     CALL ERROR
1677     GO TO 1600
1680 END IF
1695 GO TO 2700
1700 PRINT*, 'INPUT RECEIVER ANTENNA GAIN (0-45 dB)'
1740 READ*,GR
1750 IF (GR .LT. 0) THEN
1755     CALL ERROR
1760     GO TO 1700
1770 ELSE IF (GR .GT. 45) THEN
1775     CALL ERROR
1777     GO TO 1700
1780 END IF
1795 GO TO 2700
1800 PRINT*, 'INPUT RECEIVER MINIMUM DETECTION SNR (1-20 dB)'
1840 READ*,SNR
1850 IF (SNR .LT. 1) THEN
1855     CALL ERROR
1860     GO TO 1800
1870 ELSE IF (SNR .GT. 20) THEN
1875     CALL ERROR
1877     GO TO 1800
1880 END IF
1890 GO TO 2700
1900 PRINT*, 'INPUT RECEIVER BANDWIDTH (0.5-2.0 MEGAHERTZ)'
1940 READ*,BW
1950 IF (BW .LT. 0.5 ) THEN
1955     CALL ERROR
1960     GO TO 1900
1970 ELSE IF (BW .GT. 2.0) THEN
1975     CALL ERROR
1977     GO TO 1900
1980 END IF
1990 GO TO 2700
2000 PRINT*, 'INPUT ESTIMATE OF SYSTEM LOSSES (1-25 dB)'
2040 READ*,LOSS
2050 IF (LOSS .LT. 1) THEN
2055     CALL ERROR
2060     GO TO 2000
2070 ELSE IF (LOSS .GT. 25) THEN
2075     CALL ERROR
2077     GO TO 2000
2080 END IF
2090 GO TO 2700
2100 PRINT*, 'INPUT RECEIVER FRONTEND TEMPERATURE (290-500
CDEGREES K)'
2140 READ*,TEMP

```

```

2150 IF (TEMP .LT. 290) THEN
2155     CALL ERROR
2160     GO TO 2100
2170 ELSE IF (TEMP .GT. 500) THEN
2175     CALL ERROR
2177     GO TO 2100
2180 END IF
2190 GO TO 2700
2200 PRINT*, 'INPUT RECEIVER ANTENNA BEAM HEIGHT (1-8 DEG)'
2240 READ*, RWEL
2250 IF (RWEL .LT. 1) THEN
2255     CALL ERROR
2260     GO TO 2200
2270 ELSE IF (RWEL .GT. 8) THEN
2275     CALL ERROR
2277     GO TO 2200
2280 END IF
2295 GO TO 2700
2300 PRINT*, 'INPUT RECEIVER ANTENNA BEAM WIDTH (1-5 DEG)'
2340 READ*, RWAZ
2350 IF (RWAZ .LT. 1) THEN
2355     CALL ERROR
2360     GO TO 2300
2370 ELSE IF (RWAZ .GT. 5) THEN
2375     CALL ERROR
2377     GO TO 2300
2380 END IF
2395 GO TO 2700
2400 PRINT*, 'INPUT TRANSMITTER ANTENNA BEAM HEIGHT (1-8 DEG)'
2440 READ*, XWEL
2450 IF (XWEL .LT. 1) THEN
2455     CALL ERROR
2460     GO TO 2400
2470 ELSE IF (XWEL .GT. 8) THEN
2475     CALL ERROR
2477     GO TO 2400
2480 END IF
2495 GO TO 2700
2500 PRINT*, 'INPUT TRANSMITTER ANTENNA BEAM WIDTH (1-5 DEG)'
2540 READ*, XWAZ
2550 IF (XWAZ .LT. 1) THEN
2555     CALL ERROR
2560     GO TO 2500
2570 ELSE IF (XWAZ .GT. 5) THEN
2575     CALL ERROR
2577     GO TO 2500
2580 END IF
2595 GO TO 2700
2600 PRINT*, 'INPUT RECEIVER ALTITUDE (0.01 - 30 KILOMETERS)'
2605 READ*, RALT
2610 IF (RALT .LT. 0.01) THEN
2615     CALL ERROR

```

```

2620      GO TO 2600
2625  ELSE IF (RALT.GT.30) THEN
2630      CALL ERROR
2635      GO TO 2600
2640  END IF
2700  RETURN
2210  END

```

```

c
c   the routine to calculate the range constant for the power
c   limiting equation region
c

```

```

1      SUBROUTINE RANGE(P,GT,GR,SNR,RCS,FO,LOSS,BW,TEMP,RANGE4)
10     REAL C2,LOSS,TEMP,GT,GR,P,RCS,FO,BW,RANGE4
15     C2=(GR+GT-LOSS-SNR)/10
20     C2=10**C2
25     C3=3.2865E6
30     RANGE4=P*RCS*C2*C3/(BW*TEMP*FO*FO)
35     RETURN
40     END

```

```

c
c   the routine to calculate the doppler frequencies for the plane
c   of interest
c

```

```

1      SUBROUTINE DOFMAP(VX,XEL,XAZ,VT,TEL,TAZ,FO,C,SEP,XALT,
CZ,TABLE,RALT)
5      DIMENSION TABLE(300,250)
10     REAL LA,LN
600    VXZ = VX*SIND(XEL)/3600
605    VXY = VX*COSD(XEL)*SIND(XAZ)/3600
610    VXX = VX*COSD(XEL)*COSD(XAZ)/3600
615    VTZ = VT*SIND(TEL)/3600
620    VTY = VT*COSD(TEL)*SIND(TAZ)/3600
625    VTX = VT*COSD(TEL)*COSD(TAZ)/3600
630    LA=C/(FO*1E9)
635    DO 710 I=1,300,5
640      X=I-51
645      DO 705 J=1,11
650        Y=-150+J*25
655        AP = SQRT(X*X + Y*Y + (Z-RALT)*(Z-RALT))
660        BP = SQRT ((SEP-X)*(SEP-X) + Y*Y + (XALT-Z)*(XALT-Z))
674        FD1=((SEP-X)*(VTX-VXX)+Y*(VXY-VTY)+(XALT-Z)*(VXZ-VXZ))
675        FD1=FD1/(BP*LA)
677        LN=C/(FO*1E9+FD1)
680        FD2 =-1*(VTX*X + VTY*Y + VTZ*(Z-RALT)) / (AP*LN)
700        TABLE(I,J)=FD1 + FD2
705      CONTINUE
710    CONTINUE
735    RETURN
740    END

```

```

c
c   The routine that calculates the minimum and maximum values
c   for the isorange ellipses

```

```

C
1  SUBROUTINE MINMAX(TPULSE,C,SEP,NPRF,PRF,ISOMIN,ISOMAX,I,
C  XALT,RALT)
5  REAL ISOMIN,ISOMAX
7  integer PRF
8  R3 = SQRT(SEP*SEP + (XALT-RALT)**2)
10 ISOMIN=2*TPULSE*1E-6*C+R3
15 ISOMAX=(NPRF*C/PRF)+R3-(TPULSE*1E-6*C)
20 I=INT((ISOMAX-ISOMIN)/10)+2
25 RETURN
30 END

```

```

C
C  This routine plots the ovals of Cassini
C
1  SUBROUTINE POWER(Z,XALT,SEP,R4,BASE,RALT)
5  DIMENSION UPPER(302),DOWNER(302),BASE(302)
6  UPPER(1)=301
7  DOWNER(1)=301
11 C4=SEP*(-2)
DO 135 I=-50,250
    X=I
31  C1=(Z-RALT)**2
72  C2=(Z-XALT)**2
73  C3=C2+C1+SEP**2
741 C5=C4*C1
742 C6=C1*SEP**2+C1*C2-R4
122 B4=X**2+C3/2-X*SEP
123 CC=X**4+C4*X**3+C3*X**2+C5*X+C6
    B5=B4**2-CC
    IF(CC.GT.0) THEN
        UPPER(I+52)=0
        GO TO 130
    end if
124 UPPER(I+52)=SQRT(-B4+SQRT(B5))
130 DOWNER(I+52)=-UPPER(I+52)
135 CONTINUE
232 CALL CPLOT(BASE,UPPER)
233 CALL CPLOT(BASE,DOWNER)
235 RETURN
240 END

```

```

C
C  This routine plots the isorange ellipsoids and keeps track
C  of whether or not the last required ellipsoid has been drawn
C
1  SUBROUTINE ISOR(ISOMIN,ISOMAX,I,SEP,Z,XALT,BASE,RALT)
5  DIMENSION UPPER(302),DOWNER(302),BASE(302)
6  REAL ISOMIN,ISOMAX
7  UPPER(1)=301
8  DOWNER(1)=301
10 SEP2=SEP/2
    GO TO(100,200,300,300,300,300,300,300,300,300,300,300,
C300,300,300,300,300,300,300,300,300,300,300,300,300,

```

```

C300,300,300,300,300,300,300) I
100  CURVE=ISOMIN
      GO TO 400
200  CURVE=ISOMAX
      GO TO 400
300  CURVE=10*(I-2+INT(ISOMIN/10))
400  I=I-1
20   A=CURVE/2
23   A2=A*A
      B2=A2-SEP2*SEP2
      C12=B2/A2
24   STHETA=(XALT-RALT)/SEP
25   CTHETA=COS(ASIN(THETA))
26   C1C=Z*CTHETA-RALT*CTHETA
27   C11=Z*STHETA-RALT*STHETA+SEP/2
45   DO 65 J=-50,250
46     X=J
50     Y=(B2-(X*STHETA+C10)**2-C12*(X*CTHETA-C11)**2)
      IF (Y.LT.0) THEN
        UPPER(J+52)=0
        GO TO 55
      END IF
      UPPER(J+52)=SQRT(Y)
      DOWNER(J+52)=-UPPER(J+52)
55   CONTINUE
66   CALL LINE(I+2)
67   CALL CPLOT(BASE,UPPER)
68   CALL CFLOT(BASE,DOWNER)
70   RETURN
75   END

C
C   This routine clears the 40XX screen when in the 40XX mode.
C
1   SUBROUTINE WIPE
5   CALL INITT(1200)
10  CALL BINITT
15  CALL FINITT(0,700)
20  RETURN
25  END

```

Bibliography

1. Bonanno, J., N. Powell, and G. Malleen. "Bistatic SAR Self-Synchronization Concept Development Program," Aeronautical Systems Division, Air Force Systems Command, Contract F33615-82-C-1856 with Westinghouse Defense and Electronic Systems Center. Wright-Patterson AFB OH, April 1983.
2. "ESM Augmented Active Surveillance Evaluation," Vol II. Electronic Systems Division, Air Force Systems Command. Contract F30602-82-C-0084 with Westinghouse Defense and Electronic Systems Center. Rome Air Development Center, Griffiss AFB NY. March 1984.
3. Farina, A. and E. Hanle. "Position Accuracy in Netted Monostatic and Bistatic Radar," IEEE Transactions on Aerospace and Electronics Systems VOL. AES-19, NO. 4, 513-520 (July 1983).
4. Lorti, D. "Airborne Bistatic Radar Operation With Non-Cooperative Transmitters," Aeronautical Systems Division, Air Force Systems Command. Contract F33657-83-C-0048 with XonTech, Inc. Wright-Patterson AFB OH. March 1983.
5. ----- and C. Moreno. "Bistatic Sea and Terrain Scattering Models," Aeronautical Systems Division, Air Force Systems Command, Contract F33657-83-C-0048 with XonTech, Inc.
6. Medgyesi-Mitschang, L. N. "RCS Prediction Techniques for Dielectrically Coated Bodies. Vol I. Final Technical Report. Ballistic Missile Defense Advanced Technology Center. Contract DASG60-82-C-0014 with McDonnell Douglas Research Labs. Huntsville AL. July 1982.
7. Moreno, C. and D. Lorti. "Tactical Bistatic Radar Demonstration (TBIRD) Program," Aeronautical Systems Division, Air Force Systems Command. Contract F33615-79-C-1745 with XonTech, Inc. Wright-Patterson AFB OH. February 1982.
8. Papa, Robert J., K. V. N. Rao, John F. Lennon and James W. Coffey. "A Survey of Terrain Scattering Theory and Measurements for Air Force Systems," Electronic Systems Division, Air Force Systems Command. In-House Report RADC-TR-84-78. Rome Air Development Center, Griffiss AFB NY, April 1984.

9. "Passive Multistatic Radar: R&D Activity Summary," Company Report ATC:82:234, ITT-Gilfillan, ITT, Van Nuys CA, November 1982.
10. Peebles, P. "Bistatic Radar Cross Sections of Chaff," Electronic Systems Division, Air Force Systems Command. Contract DAAK21-82-C-0107 with The University of Florida Gainesville Electronic Communication Lab. Rome Air Development Center, Griffiss AFB NY, June 1983.
11. Skolnik, M. Introduction to Radar Systems. New York: McGraw-Hill Book Company, 1980.
12. -----. Radar Handbook. New York: McGraw-Hill Book Company, 1970.
13. Spiegel, M. R. Mathematical Handbook of Formulas and Tables. New York: McGraw-Hill Book Company, 1968.
14. Stimson, George W. Introduction to Airborne Radar. El Segundo: Hughes Aircraft Company, 1983.
15. Weiner, M. "Multistatic Radar Phenomenology, VOL-I Terrain and Sea Scatter," Electronic Systems Division, Air Force Systems Command. Contract F19628-80-C-0001 with The MITRE Corporation. Rome Air Development Center, Griffiss AFB NY, September 1980.
16. Wylie, C. R. Advanced Engineering Mathematics. New York: McGraw-Hill Book Company, 1975.

VITA

Captain William P. Thomson was born on 20 July 1948 in Phoenix, Arizona. He completed his first degree (Bachelor of Arts in Economics) while serving an enlistment in the USAF. He was selected for Officer Training School while performing duty in the Republic of Korea. During a tour of duty as a Missile Maintenance Officer, he was nominated to the Air Force Institute of Technology for the Undergraduate Engineer Conversion Program. He graduated from AFIT with a Bachelor of Science in Electrical Engineering in March 1981. He served as the Strategic Air Command Missile Facility Electrical Engineer until reentering the School of Engineering to pursue graduate studies 24 May 1984.

Permanent address: Box 3

Morman Lake, Arizona 85121

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A163941

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			5. MONITORING ORGANIZATION REPORT NUMBER(S)			
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GE/ENG/85D-49			7a. NAME OF MONITORING ORGANIZATION			
6a. NAME OF PERFORMING ORGANIZATION School of Engineering		6b. OFFICE SYMBOL (If applicable) AFIT/ENG		7b. ADDRESS (City, State and ZIP Code)		
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433			9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Rome Air Development Center		8b. OFFICE SYMBOL (If applicable) OCDE		10. SOURCE OF FUNDING NOS.		
8c. ADDRESS (City, State and ZIP Code) Griffiss AFB, NY 13441-5700		PROGRAM ELEMENT NO.		PROJECT NO.		TASK NO.
11. TITLE (Include Security Classification) See Box 19		10. SOURCE OF FUNDING NOS.		PROJECT NO.		TASK NO.
12. PERSONAL AUTHOR(S) William P. Thomson, B.S., Capt, USAF		10. SOURCE OF FUNDING NOS.		PROJECT NO.		TASK NO.
13a. TYPE OF REPORT MS Thesis		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Yr., Mo., Day) 1985 December		15. PAGE COUNT 123
16. SUPPLEMENTARY NOTATION						
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)			
FIELD	GROUP	SUB. GR.	Bistatic clutter			
17	09		Isorange			
			Isodoppler			
19. ABSTRACT (Continue on reverse if necessary and identify by block number)						
Title: AIRBORNE BISTATIC RADAR LIMITATIONS AND SAMPLE CALCULATIONS Thesis Chairman: Major Kenneth G. Castor Approved for public release 14W APR 1986 JON E. WOLAVER 16 JAN 86 Done for Research and Technological Development Air Force Institute of Technology (AFIT) Wright-Patterson AFB OH 45433						
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED			
22a. NAME OF RESPONSIBLE INDIVIDUAL Major Kenneth G. Castor			22b. TELEPHONE NUMBER (Include Area Code) 613-255-5533		22c. OFFICE SYMBOL AFIT/ENG	



This thesis examined the effects of system configuration and transmitted waveform as applied to an airborne bistatic radar. The study concentrates on the limiting effects of the transmitted signal parameters, the signal to clutter ratio, and the doppler spread of the receiver beam.

The analysis was performed by constructing a computer model to graphically display the results of the applicable equations. The equations developed in this study are: The power limited region equation, the isorange equation, the isodoppler equation, and the signal to clutter ratio. These equations and those of ellipsoidal geometry were used to develop the bistatic radar model.

