ORDER

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PRIMARY/SECONDARY EN ROUTE RADAR SITING HANDBOOK

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

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FOREWORD

This order establishes procedures and responsibility for assuring the optimum selection of sites for new FAA en route air traffic control radar facilities. In the interests of completeness and to minimize the need for reference to other material, the order also contains background explanatory information covering the current en route radar equipment and all applicable siting criteria.

The material contained in this order is organized into four chapters: (1) general introduction, (2) equipment considerations, (3) ARSR and ATCRBS siting criteria, and (4) siting procedures. Several explanatory and/or supplementary appendices are also included.

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CHAPTER 1. GENERAL INTRODUCTION

1. PURPOSE. This handbook establishes specific procedures which are to be observed in selection of sites for Air Route Surveillance Radar/Air Traffic Control Radar Beacon Interrogator (ARSR/ATCBI) en route facilities. These procedures are necessary to assure uniform and objective comparison of candidate radar sites and to permit selection of an optimum site.

2. DISTRIBUTION. This directive is distributed to branch level in the Program Engineering and Maintenance, Systems Engineering, and Air Traffic Services and the Office of Flight Operations in Washington headquarters; to branch level in the regional Airway Facilities, Air Traffic, and Flight Standards divisions; and to the Engineering and Production Branch and the Airway Engineering Support Division at the Aeronautical Center.

3. CANCELLATIONS. FAA Order 6340.7, Long Range Radar ARSR Facility Siting Procedure Handbook, is canceled.

4. BACKGROUND. This handbook was prepared to meet the need for a clear and concise statement of the procedures to be followed in selection of sites for new en route ARSR/ATCBI installations. Observance of these procedures will allow superior future site selection at a lower net long-term cost to the FAA. The material was prepared by IIT Research Institute under contract to FAA, after a careful review of regional site selection practices.

5. RESPONSIBILITY AND AUTHORITY. In order to assure that selected sites meet the needs of the agency,maximumattention shall be given to the selection of a radar site. A group shall be established in the Program Engineering and Maintenance Service (APM) to be the focal point for siting data. The Service will chair a group composed of regional, AAT, and APM personnel to review, analyze, and recommend site locations. The Director, APM, shall be the final approving authority for radar surveys. Development of the operational requirements shall basically be a regional responsibility. AAT shall be the focal point for operational requirements and shall establish a group consisting of regional and headquarters personnel to review and recommend the final operational requirements. The procedures for establishing the groups to coordinate operational requirements and site selection are specified in the latest edition of Order 6300.5, Enroute Radar And Beacon Siting Procedures, Responsibilities, And Approvals. The Director of the Air Traffic Service shall be the final approving authority for operational requirements.

6. RELATED DOCUMENTS. The information contained in this handbook was obtained from previous FAA en route and terminal radar siting documents, FAA headquarters-and regional engineering personnel, FAA technical specifications and manuals, and other more general sources. Specific document references are made in the text, with a complete reference index at the end of the handbook.

7. APPLICATION. The information presented in this handbook is intended primarily for the siting of new FAA en route radar facilities, but may also be applied to facilities modification/relocation and to the correction of siting problems.

8. SCOPE.

a. Equipment. This handbook covers site selection and report preparation for the ARSR-3 and the ATCBI-5 equipments. With comparatively minor modifications, however, it should also be applicable to bther FAA long range radar equipment.

b. Limitations. Because of the simplifying assumptions used in order to reduce the equations and charts contained in this document to readily usable form, the user should be aware that coverage predicted by the techniques described herein will necessarily be only a close approximation to the actual coverage obtainable from a given installation. The principal value of the selection techniques presented is as a realistic yardstick for comparison of the various sites under consideration.

9. HANDBOOK ORGANIZATION.

a. Chapter 2 of this handbook summarizes the operational performance achievable with the ARSR-3 and other en route radars and with the accompanying ATCBI-4, 5 radar beacon equipments in idealized, free-space situations. It also discusses the significance of equipment characteristics as related to site selection.

b. Chapter 3 presents a fairly detailed discussion of ARSR and ATCRBS siting criteria including coverage and facility requirements, coverage capabilities, operational limitations, and site requirements and limitations.

c. Chapter 4 provides a step-by-step radar siting procedure including preliminary data acquisition, preliminary site selection, site survey, and detailed site analysis.

10. REVISION OF MATERIAL. Revision of the material in this handbook will be made periodically as required. Forward any recommendations for changes to this directive through normal channels to the Communications and Surveillance Mvision, APM-300, Program Engineering and Maintenance Service.

CHAPTER 2. EQUIPMENT CONSIDERATIONS

SECTION 1. INTRODUCTION

11. INTRODUCTION. This chapter of the ARSR/ATCBI siting handbook constitutes a short review of the operation of air traffic control equipment commonly installed at en route radar sites. Topics to be covered include a brief description of system functions together with a discussion of those system characteristics and parameters which are important to site selection or siting data analysis. It should be noted, however, that this chapter is not intended as a comprehensive general treatment of radar and beacon system operation, but rather as a brief highlighting of those ARSR and ATCBI features important to site selection. For more detailed textbook treatment the reader is referred to references 1 and 2.

SECTION 2. AIR ROUTE SURVEILLANCE RADAR

12. FUNCTION.

a. General. A surveillance radar consists basically of an antenna, a transmitter, a receiver, an automated data processor, and a display. The transmitter generates short pulses of radio energy which are radiated into space by the antenna. A small portion of this energy is returned to the radar after striking reflecting objects. Echo energy picked up by the antenna is sent to the radar receiver and automated processor for amplification, detection, and special data processing. It is then displayed visually for operational purposes, as well as perhaps being processed in other ways. Since radar energy travels at the speed of light, distance to the reflecting object can be determined on the basis of time required for the radar pulse to travel to and from the object. The bearing of the target is determined by the direction in which the antenna beam is pointed when the reflected pulse is received.

b. Air Route Surveillance Radar (ARSR). The Air Route Surveillance Radar (ARSR), as its name implies, is a surveillance radar system designed to detect the presence and location of en route aircraft. The aircraft reflected signals received by the radar are transmitted to an Air Route Traffic Control Center (ARTCC), where they are displayed on an indicator for the use of air traffic control personnel, The signals are also automatically supplied to a computer which maintains a record of the present locationsof allaircraft in the region and predicts future locations of the aircraft. The computer uses this data to determine any major deviations from the aircraft's flight plan and, most importantly, to detect any potentially unsafe situation due to insufficient separation of aircraft. Use of ARSR equipment, therefore, is extremely important to the safe, expeditious movement of air traffic.

c. Primary/Secondary Radar Systems. In order to provide increased strength of the aircraft signal for improved detection as well as to transmit additional data such as aircraft identification and aircraft altitude, many aircraft are equipped with radar beacons, However, since not all aircraft are beacon equipped, reliance must be placed on the surveillance radar, and therefore the ARSR is designed as the PRIMARY RADAR to distinguish its functions from other en route radar equipment. The radar beacon system is often referred to as the SECONDARY RADAR, While this latter designation may be subject to alteration as more sophisticated radar beacons assume a larger role in air traffic control, the nature of ARSR equipment is such that it will probably always be required. A surveillance radar is the only type of system capable of providing information on the presence and location of non-beacon equipped aircraft in the controlled airspace.

13. EQUIPMENT PARAMETERS. Currently, the FAA utilizes Air Route Surveillance Radars designated as ARSR-1, ARSR-2, ARSR-3, MERF (Mobile Enroute Radar Facility), AN/FPS-20, and AN/FPS-60. The ARSR-1/2 and the AN/FPS-20/60 are older equipments which are gradually being replaced, and no further siting of these radars is anticipated. They are not covered in this handbook, nor is MERF equipment. The latter system is used for temporary or emergency ATC purposes, but is not a subject for permanent site establishment. The handbook, therefore, is intended for siting the ARSR-3 or subsequent new radar equipment. The important parameters of the ARSR-3 are tabulated below in table 2-l.

14. AREA COVERAGE. The ARSR is capable of detecting aircraft which are within its line-of-sight as the antenna rotates azimuthally through 360 degrees. The precise region of area coverage provided by an ARSR is dependent upon (a) the parameters of the particular radar, (b) the target being detected, and (c) the nature of the radar site.

15. VERTICAL COVERAGE. Each ARSR is used for detection and tracking of aircraft overflying its control area as well as aircraft whose flights originate and/or terminate within the control area. It is'important, therefore, that the ARSR provide coverage throughout a wide range of altitudes. A typical vertical coverage chart for the ARSR-3 for idealized conditions is given in figure 2-l. This includes the effect of atmospheric attenuation, but not the effect of precipitation nor the effect of ground reflection. More detailed coverage charts are presented in chapter 3.

16. CHARACTERISTICS PERTINENT TO SITE SELECTION.

a. Antenna Coverage. The function of the ARSR antenna system is to radiate the transmitter output energy into a directional beam, and receive the returning echo energy, passing it on to the receiver with a minimum of loss. An electronic switching technique is used to switch the antenna from transmitter to receiver, thereby facilitating operation and providing protection against receiver overload during the time of pulse transmission (nominally 0.06 percent of the pulse repetition period).

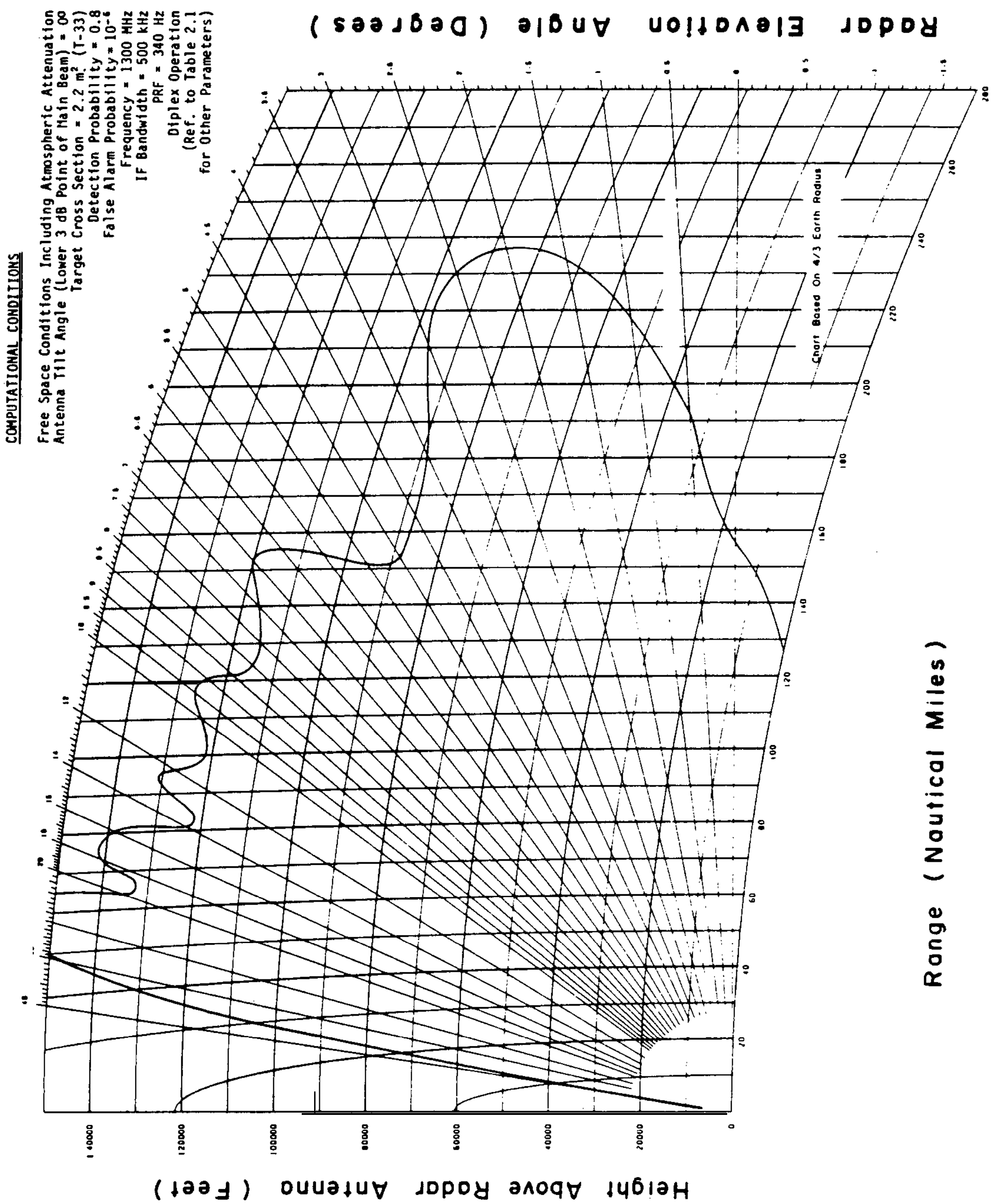
Table 2-1

ARSR-3 PARAMETERS

Nominal PPI Range		20' nmi
Accuracy		
Azimuth		± 0.180
Range		± 1/8 nmi, .005 R
Resolution		
Azimuth		2°
Range		.25 nmi
Antenna		
Main (low beam)		
Pattern Shape		mod $\csc^2\theta$
Beamwidth		
Azimuth		1.1° min
Elevation		3.6° min
Max. Gain	dBir	34.5
Scan Rate		5 rpm
Polarization		LP/CP
Passive (high beam)		
Pattern Shape		mod $\csc^2\theta$
Beamwidth		
Azimuth		0.9° - 1.1°
Elevation		3.6° min
Max. Gain	dBir	33.5
Polarization		LP/CP
RF Frequency	MHz	1250-1350
PRF	pps	310-365 1/
Peak Power Output	MW	5
Pulse Duration	μs	2
Receiver Noise Figure (dB)		4.0
Sensitivity (dBm)		
Log (Log/CFAR/AntiLog)		-115
MTI (I and Q, Log/CFAR/AntiLog)		-112
MTI (I or Q, Log/CFAR/AntiLog)		-112
WEA (Log)		-113
WEA (MIT/Log/AntiLog)		-112
Normal		-114
MTI		
Log		
MTI Improvement Factor (dB)		39
Antenna Tilt Capability		3° to + 3°

1/ Range of average PRF settings - range of instantaneous PRF with VIP is between 276 and 399 PPS.

FIGURE 2-1 FREE SPACE ARSR-3 COVERAGE OF T-33 AIRCRAFT
(Reception on Lower Beam)



(1) Antenna Pattern. Probably the most important aspect of an antenna's performance is its directive radiation pattern wherein the transmitted energy is concentrated in some particular direction(s). ARSR antennas produce a fan,beam, narrow in the horizontal or azimuthal direction to provide good azimuthal resolution of closely spaced aircraft, and relatively broad in the vertical direction to detect aircraft within a wide-range of altitudes. Figure 2-2 shows a portion of the horizontal pattern including the main lobe. Figure 2-3 shows a typical vertical pattern, which is a modified $\csc^2\theta$ pattern. These two patterns shown are free-space patterns. Due to the effects of the ground and other nearby objects, the actual radiation patterns of installed ARSR antennas will differ from the free-space patterns shown.

(2) Antenna Gain. The gain of an antenna in a given direction is a quantitative measure of the power transmitted in that direction as compared with some reference standard. Normally an isotropic radiator is used as a reference, and antenna gain is given in decibels above the isotropic level (dBir). Although antenna gain is actually angle dependent., a single number, the maximum value of the antenna's gain, is frequently used to describe antennaperformance. Maximum gain for the ARSR antennas is approximately 34.5 dBir, as indicated iii table 2-1.

(3) Beamwidth,

(a) Azimuthal Beamwidth. The antenna azimuth beamwidth is descriptive for the angular resolution of the ARSR and is measured at the -3 dB points. For Air Traffic Control (ATC) purposes, good azimuth definition is provided by a focused parabolic reflector that concentrates the radiated energy into a narrow azimuthal angle, as shown in figure 2-2. Good azimuth resolution is important in separating targets that are close to each other. All directions are covered by rotating the antenna horizontally at a constant rate.

(b) Elevation Beamwidth. A $\csc^2\theta$ vertical pattern is often chosen for the antenna's upper elevation coverage in order that the radar signal power from a given size target flying at a constant altitude be independent of range. However, a radar with a requirement for low-angle coverage will also receive a substantial amount of close-in clutter signal from ground reflections. While much of this clutter energy can be eliminated by means of moving target indicator (mti) and other techniques, additional clutter reduction at short ranges can be provided by reducing the receiver sensitivity for the very short ranges, and then gradually increasing the sensitivity during the early portion of each pulse repetition time period. This sensitivity time control (stc), while reducing the clutter, will also reduce the detectability of high-altitude, close-in aircraft unless the antenna's high-angle vertical pattern is modified to compensate for the stc. The ARSR antenna vertical pattern follows the $\csc^2\theta$ variation at low angles, but it is modified appropriately at the high angles to compensate for the receiver stc. Accordingly, the vertical pattern is considered to be modified $\csc^2\theta$. This modification is evidenced by the plateau region in figure 2-3.

Fig. 2-2 TYPICAL ARSR-3 AND MERF FREE-SPACE ANTENNA AZIMUTH PATTERN

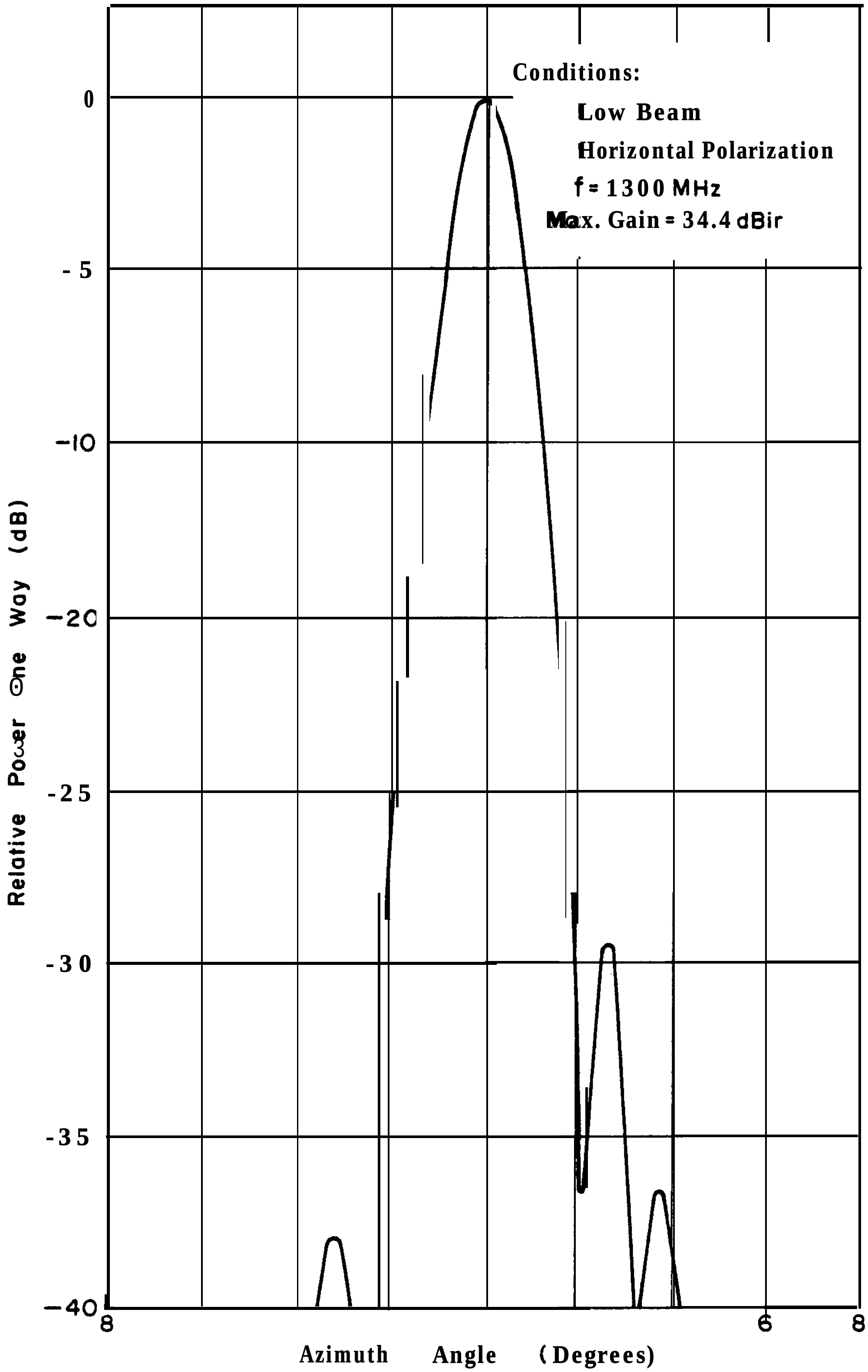
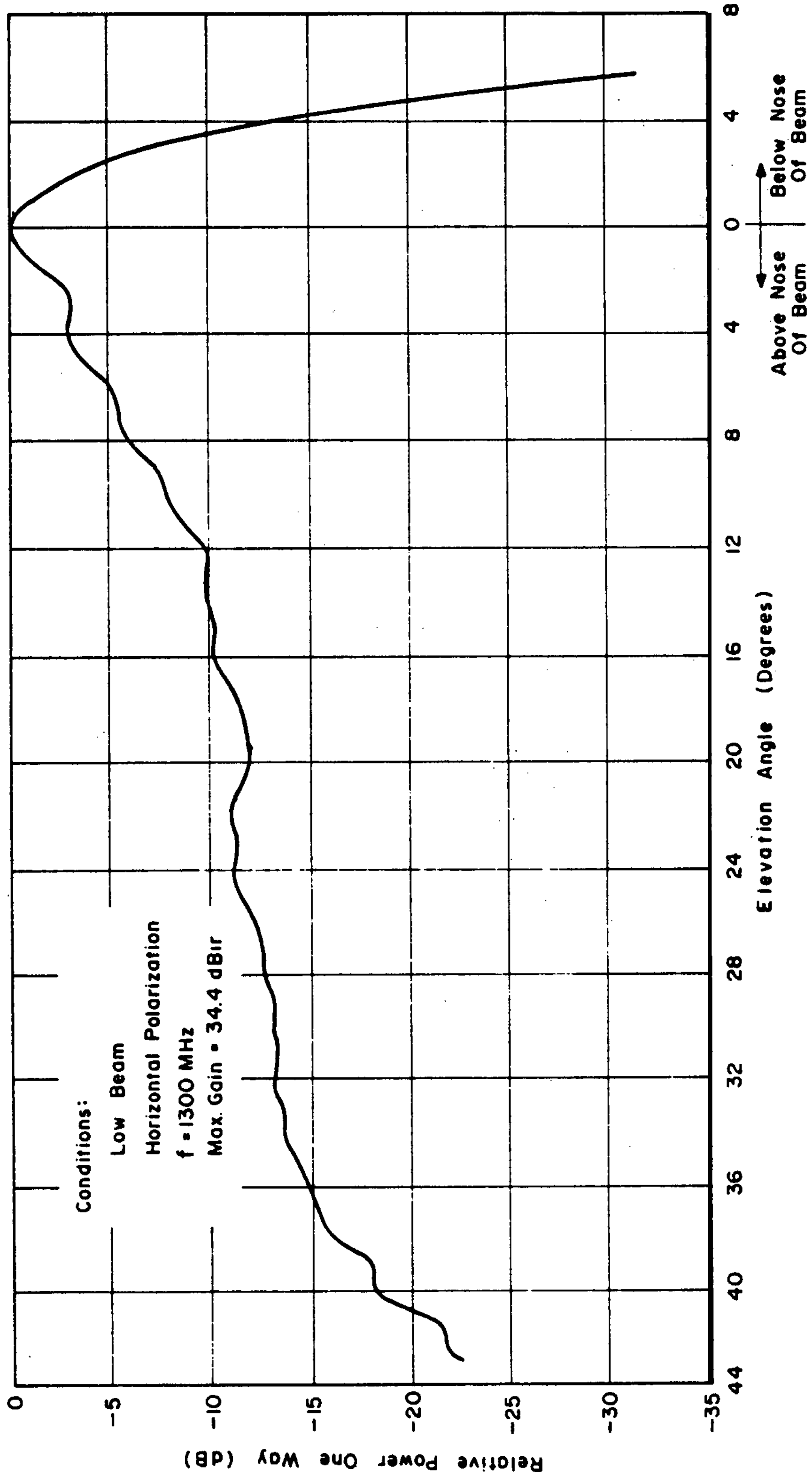


Fig. 2-3 TYPICAL ARSR-3 AND MERF FREE- SPACE ANTENNA ELEVATION PATTERN



(4) Polarization,

(a) Definitions, The direction of polarization of an antenna is defined as the direction traced in a plane by the tip of the radiated electric field vector, Most radars are linearly polarized;-that is, the direction of the electric field vector is constant as a function of time. The polarization may also be elliptical or circular. Elliptical polarization may be considered as the combination of two linearly polarized waves of the same frequency, traveling in the same direction, which are perpendicular to each other in space. The relative amplitudes of the two waves and their phase relationship can assume any values. If the wave amplitudes are equal, and if they are 90 degrees out of (time) phase, the polarization is circular. Circular and linear polarizations are special cases of elliptical polarization. More details on polarization can be found in references 3 and 4.

(b) Performance Characteristics. Linear polarization normally produces greater signal return due to higher values for the product of antenna gain and target cross section in this polarization. Circular polarization is used at times, however, to reduce clutter produced by rain, fog, or other weather disturbances.. The impact of reduced radar range coverage during operation with circular polarization and of its effect on tangential course problems should be considered when establishing a radar site. In the absence of conclusive experimental data indicative of the degree of CP coverage reduction for a given aircraft, the detection range with circular polarization may be assumed to be approximately 75 percent of the range with linear polarization. This is based upon an interpolation of data from p. 147 of reference 2.

(c) ARSR Polarization. ARSR equipment is arranged to operate using vertical, horizontal, or circular polarization. The ARSR-3 has two radar channels-- each with its own transmitter and receiver, but with the antenna shared using two separate inputs to the antenna polarizer. The two channels always utilize radiation with orthogonal polarizations: when one channel uses vertical polarization, the other uses horizontal; and when the polarizer is switched to circular polarization, the two channels use radiation with the opposite sense circular polarization (right handed and left handed).

(5) Scan Rate. The rate at which the ARSR fan beam antenna rotates on its pedestal is called the scan rate. This rate is important to radar operation since it, together with prf and beamwidth, determines the number of radar pulses which will impinge upon a target during the passage of the search beam. The'number of pulses, in turn, affects target detectability. Scan rate is equivalent to the primary radar data refresh rate supplied to the traffic controller. The scan rate for the ARSR-3 is five rotations per minute.

(6) Passive Horn.

(a) Purpose. The ARSR-3 has two similar antenna feedhorns, one mounted immediately above the other. The antenna patterns for the two feedhorns (plus the reflector) are almost identical except for a vertical displacement of approximately four degrees as shown in figure 2-4. The lower beam is used for transmission, and for reception in the detection of targets. at long range, where the elevation angle is small. The upper beam is used for reception in the detection of close-in targets where ground clutter returns are present. Due to its upward tilt, the high beam has a lower gain at the low angles where clutter returns arise, thus reducing the received clutter power and consequently improving the signal-to-clutter ratio.

(b) Performance. Use of the passive horn for signal reception can provide as much as 19 dB of signal-to-clutter improvement, thus enhancing the radar's capability for detecting close-in targets. Improvement for a typical case is indicated in figure 2-5, The overall radar coverage provided by the main and passive antennas are also shown in figure 2-6 for a typical case. The figures indicate that while use of the passive antenna provides improved operation in clutter, this is achieved at the expense of free space coverage of longer range targets. For this reason, ARSR-3 operations should utilize the passive antenna only for target ranges where clutter is visible to the main antenna. For longer range reception, operation should be switched to the main beam to improve detection capability.

(c) Beam Switching. After a radar pulse is transmitted on the low beam, radar returns are received simultaneously on both the low and high beams and their associated receivers. In each azimuthal sector signals from the high-beam receiver should be used for ranges out to the maximum clutter range along that azimuth, and the low-beam receiver output should be used for ranges beyond the maximum clutter range. As a typical example of an unscreened case, with an antenna height of 55 feet and 0-degree antenna tilt angle (for the lower 3 dB point of the low beam), the optimum switching point would occur at approximately 9 nmi, assuming clutter out to the radar horizon, Switching is controlled in 32 adjoining azimuth regions (each 11.25 degrees) by' the range/azimuth gate generator (rag). The available increments for range switching are 10 nmi for ranges between 10 and 100 nmi, and 20 nmi between 100 and 200 nmi. Siting of the ARSR-3 should take into consideration the clutter reduction capabilities provided by use of the passive antenna beam.

(7) Antenna Height.

(a) Effect on Coverage. The height at which ARSR antenna is installed, defined by the horizontal center line of the main horn, is important to the overall radiation characteristics insofar as these are modified by the reflecting of the terrain surface. Pattern distortion and vertical lobing effects are natural by-products of over-ground installation and cannot be wholly avoided. These effects are dependent upon the height of the antenna installation. Radar screeningangle is also important to overall ARSR operation, and this too is affected by the antenna height. The selection of an antenna

Fig. 2-4 ARSR-3 ANTENNA DESIGN PATTERN

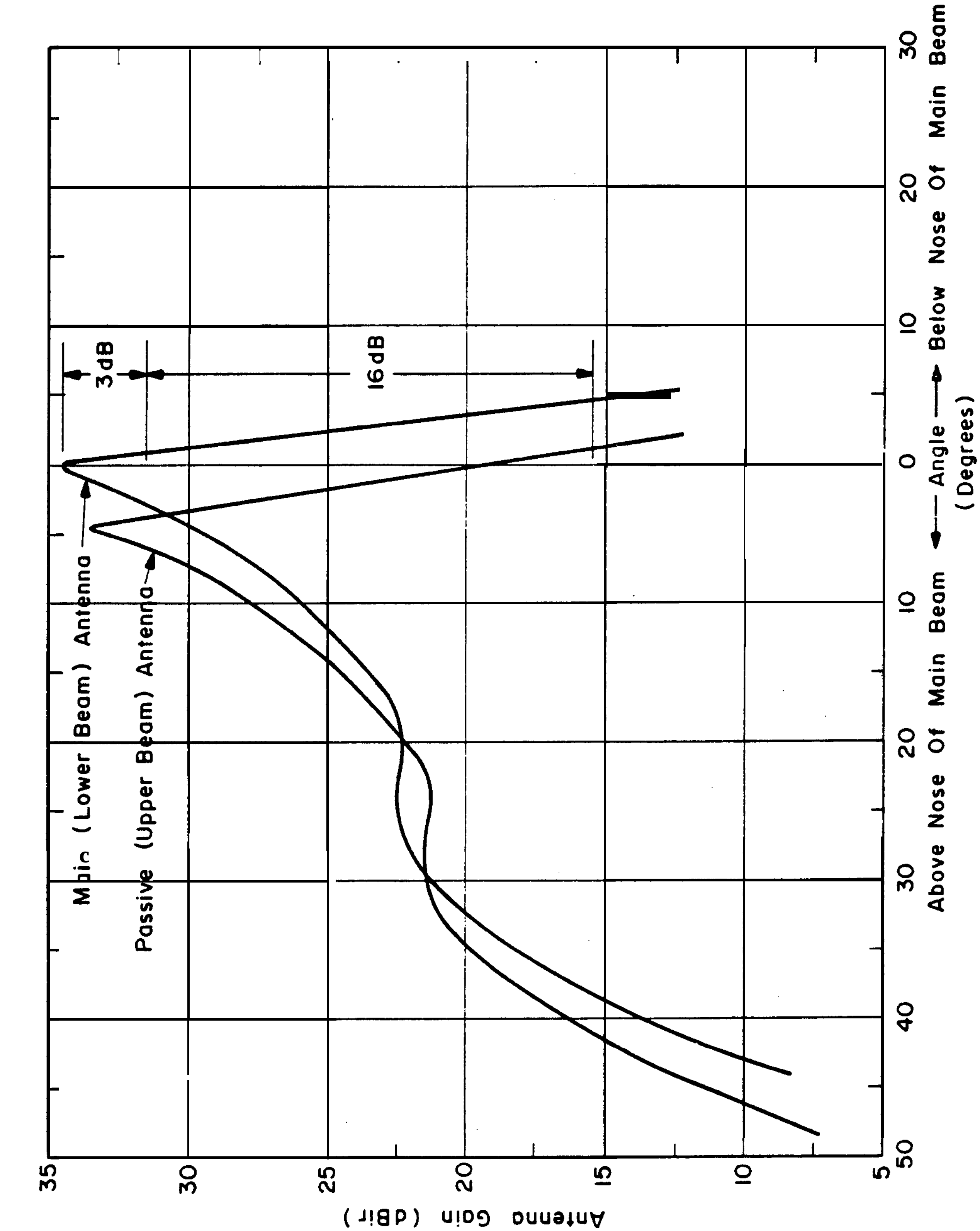


Fig. 2-5 SIGNAL - TO- CLUTTER IMPROVEMENT PROVIDED BY USE OF ARSR-3 PASSIVE ANTENNA HORN

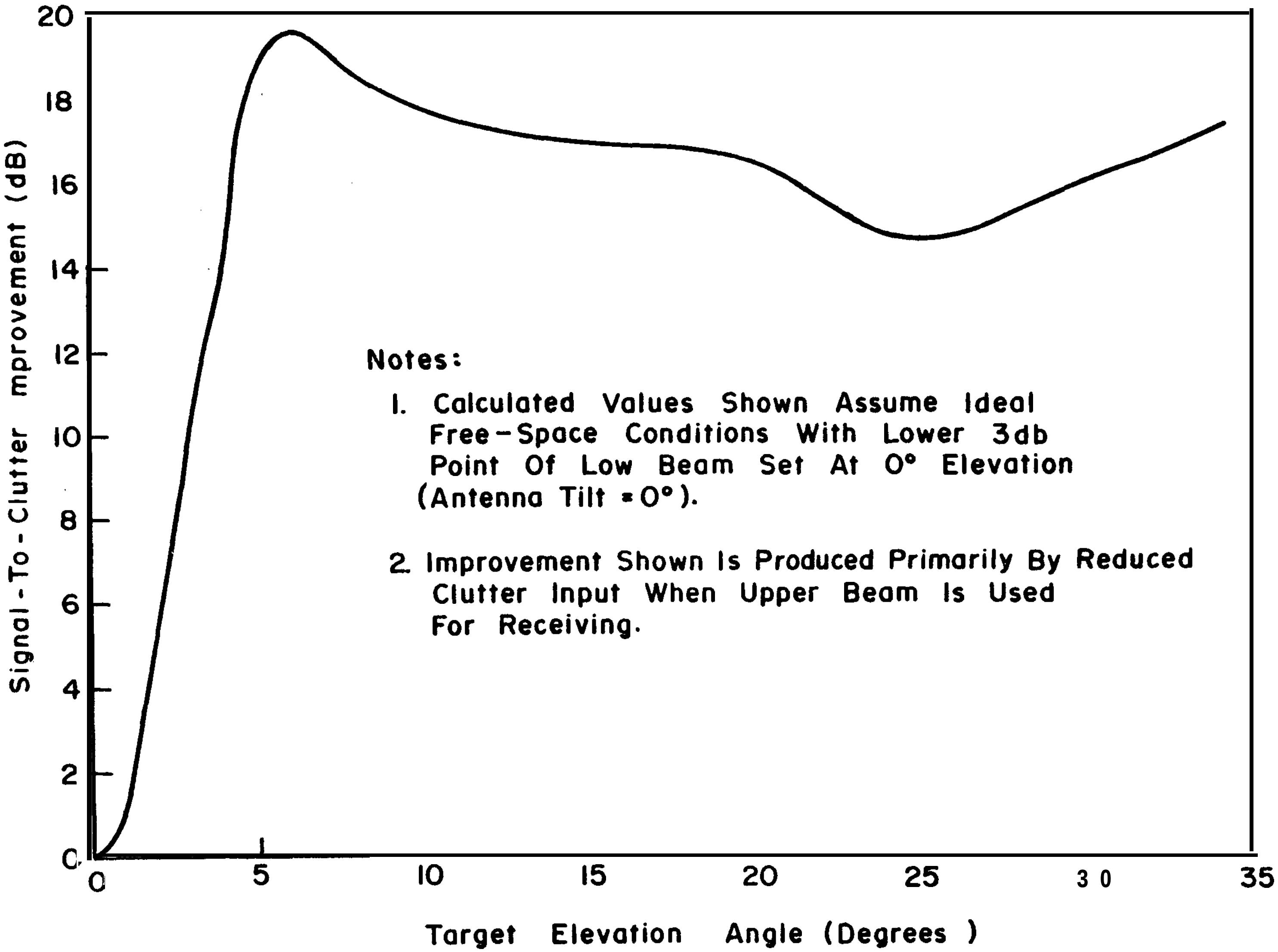
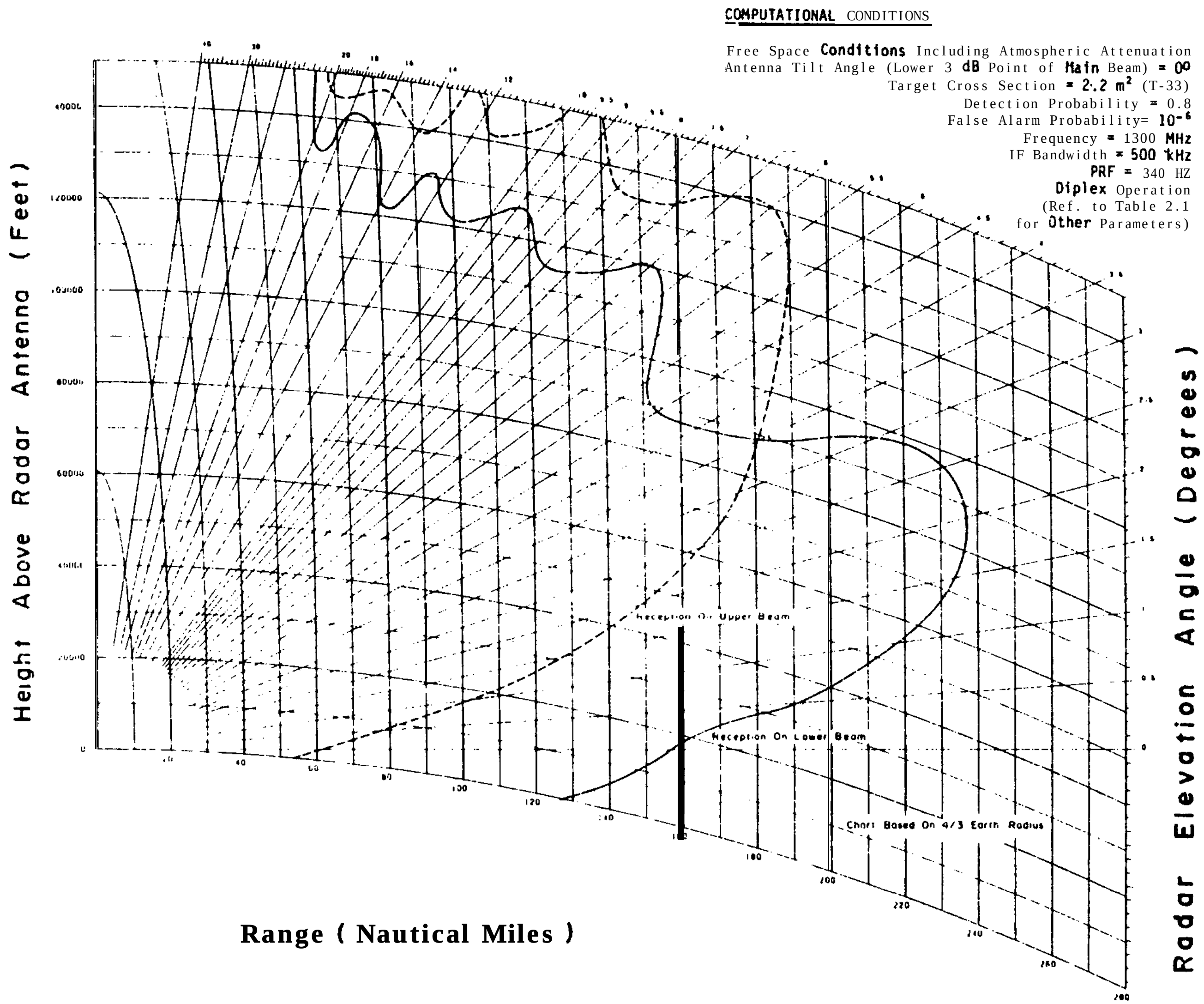


FIGURE 2-6 FREE SPACE ARSR -3 COVERAGE OF T-33 AIRCRAFT UPPER BEAM VERSUS LOWER BEAM RECEPTION



height involves a trade-off in coverage requirements. The tower should be as high as necessary to achieve the required low altitude target coverage, but should be kept low to minimize waveguide losses and to take advantage of close in screening objects.

(b) Available ARSR-3 Heights. The antenna heights available for a given installation are constrained somewhat due to the nature of standard FAA radar towers. Available tower heights are 25, 37½, 50, 62½, or 75 feet. The antenna main feedhorn is an additional 12 feet above the top of the tower. Consequently, the resultant height will be 37, 49½, 62, 74½ or 87 feet above the local surface of the ground,

(8) Antenna Tilt Angle.

(a) Purpose of Tilting. The antenna tilt angle determines the angular relationship of the elevation pattern with respect to the horizontal. This is adjusted after installation for optimum radar performance. Consideration should be given to tilt angle at the time of siting, however, since it affects the amount of clutter received by the ARSR, the range coverage pattern, and the depth of nulls in vertical lobing patterns of both ARSR and ATCBI equipment. Ordinarily, antenna tilt is set at the best compromise value between (a) the low angles required for best long range coverage of low altitude fixes, and (b) the high angles required for minimizing clutter input such that good near-in radar detection is possible. For many installations this occurs when the antenna's lower half-power point is at an elevation of about 0.25' degrees. This rule-of-thumb may be altered in the case of ARSR-3 installations where the passive horn may allow use of lower tilt angles than would otherwise be possible, due to the signal-to-clutter improvement noted above. Two types of antenna tilting are possible with the ARSR-3 as discussed below.

(b) Tilting Antenna on Pedestal. The antenna reflector can be tilted with respect to the antenna pedestal, This feature allows the beams to be tilted within a six degree interval. The tilt is continuously adjustable so that the underside -3 dB point of the low beam can be set to any angle between -3 degrees and +3 degrees above the horizontal. The underside -3 dB point on the low beam elevation pattern is the tilt reference point. This tilt mechanism provides the same beam tilt angle at all azimuths as the antenna rotates.

(c) Tilting of Pedestal. The mounting pedestal, which supports the reflector, polarizers, and feedhorns is capable of operatingin anunleveled position sufficient to tilt the antenna beam ± 2 degrees in elevation with respect to the horizontal when the antenna is directed at any specified azimuth. The pedestal can be tilted in O.l-degree vertical increments over the full ± 2 degree range. By tilting the antenna pedestal some amount, for example,1 degree above normal in any direction, the antenna will mechanically scan sinusoidally in elevation ± 1 degree as the antenna rotates through its 360-degree scan. For some radar sites this type of capability could provide improved low angle coverage over clutter which is concentrated in one azimuthal sector.

(9) Radome. All ARSR-3 installations employ a radome to protect the antenna from severe weather conditions. The radome attenuates the radar signals by 0.6 dB in each direction. These losses have been includedintheradar coveragecharts includedinthishandbook. The MERF antennadoes not use aradome.

b. Signal Characteristics.

(1) Frequency. The rf operating frequency of the ARSR-3 and the MERF is adjustable within the band 1250 MHz to 1350 MHz. While the MERF is a single channel radar, the ARSR-3 is a dual-channel frequency diversity radar, having duplicate transmitter and receiver systems with the two channels operating at different frequencies. Simultaneous operation at two frequencies separated by at least 25 MHz (avoiding transmit frequencies separated by the STALO frequency 31.07 MHz, i.e., channel numbers n and n+12) and using orthogonal polarizations substantially improves the probability of detecting a slowly scintillating target. Selection of the operating frequencies for a given ARSR installation should be made at the time of siting based on interference considerations. This can be done by collecting information on the operating frequencies of all nearby radar and/or communications equipment and selecting a compatible ARSR operating frequency. Selection should consider the harmonic content of signals as well as their fundamental frequencies. ARSR frequency selection is made by regional Frequency Management Division personnel. Reference 15 provides information useful in determining compatible operating frequencies for ARSR siting.

(2) Pulse Duration. The duration of the transmitted pulse establishes the range resolution capability of the radar, the range dimension of each illuminated ground clutter patch, the required receiver bandwidth, and the minimum range of the radar. Pulse duration is fixed at 2 microseconds for the ARSR-3 and MERF radars, as indicated in table 2-1.

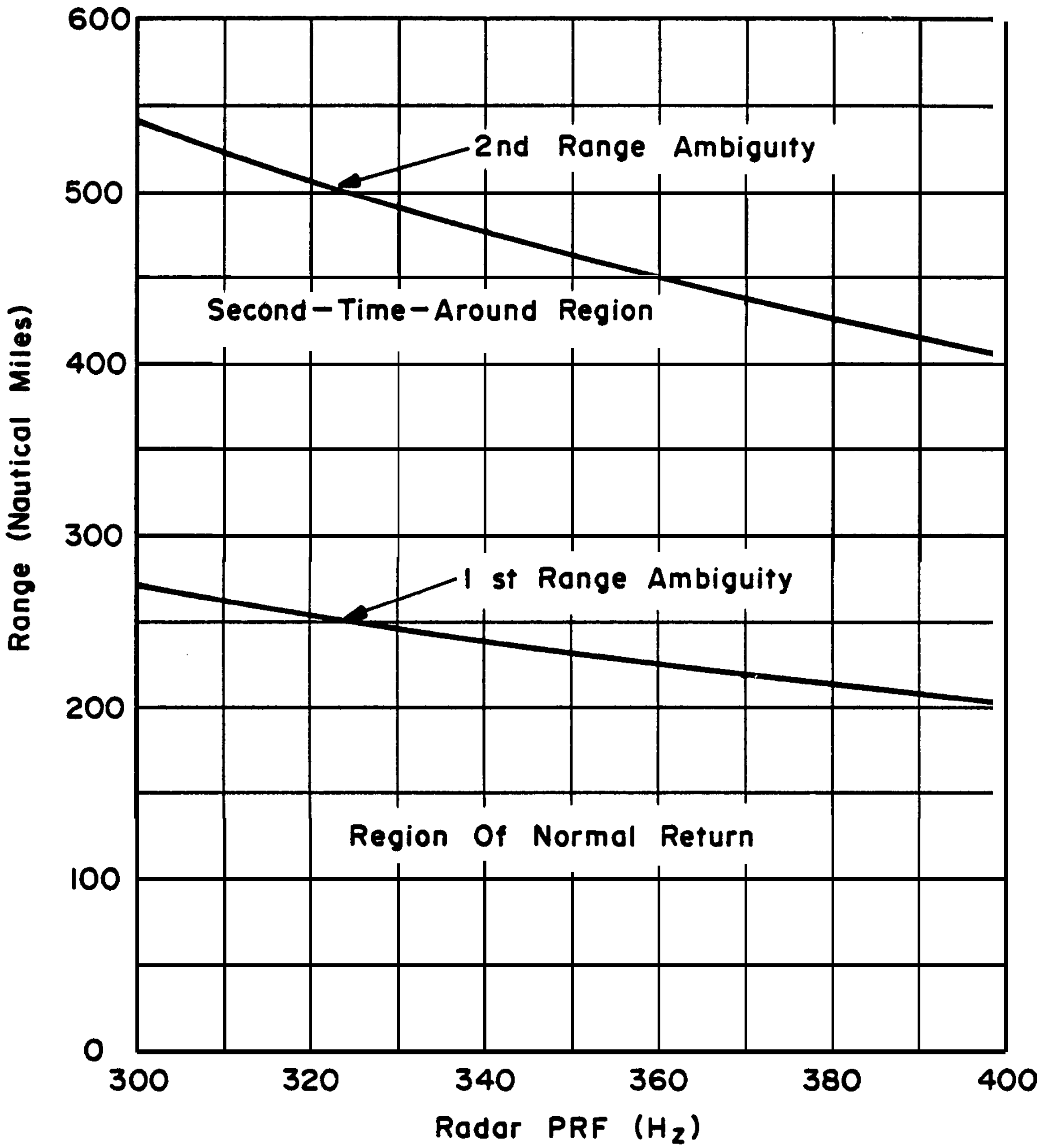
(3) Pulse Repetition Frequency (PRF).

(aj Unambiguous Radar Range. The number of radar pulses transmitted per second is known as the pulse repetition frequency. PRF determines the maximum unamoiguous range of the radar, beyond which second-time-around echoes can appear as close-in targets. The regions of normal returns and of second-time-around echoes are shown In figure 2-7. Surveillance radars are designed with prf's which ordinarily avoid the occurrenceof rangeambiguities within the area of desired coverage. However, conditions of anomalous propagation or an exceptionally strong source of reflection at a very distant location may produce an ambiguous return.

(b) Target Detectability in Receiver Noise.

1 Fonnulation. The prf affects target detectability in several ways. First, the prf, along with the antenna's azimuth beamwidth and angular scan rate, determines the number of pulses, M, impinging on the target and integrated during each antenna scan. This number is important in determining the detectability of a weak target in the presence of receiver noise; it is found from the following relationship:

Fig. 2-7 RANGE AMBIGUITY POINTS



$$M = \frac{\theta_a f_r}{6\, w_r} \quad (2\text{-}1)$$

where

θ_a = antenna azimuth beamwidth (degrees)

f_r = radar prf (Hz)

w_r = scan rate (rpm).

2 Application. This equation applies directly to the MERF, which has one radar channel. However, for the ARSR-3, which has dual channel capability, M is twice as large when both channels are used. In both the ARSR-3 and the MERF, $\theta_a = 1.1^\circ$, and w_r = 5 rpm. Figure 2-8 shows the variation of M, as a function of prf, for both single-channel and dual-channel operation.

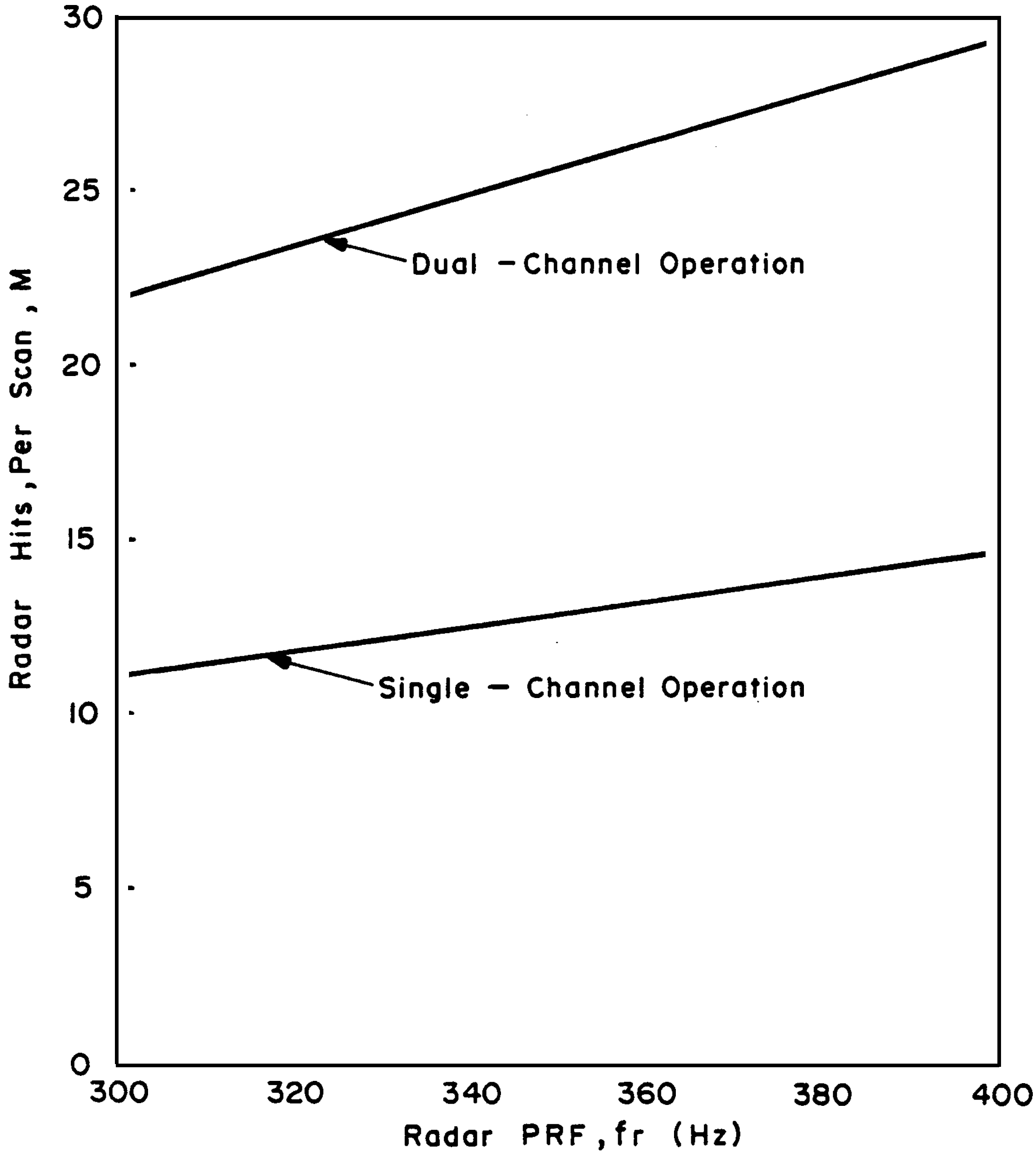
(c) PRF Effects on Moving Target Indicator (mti) Performance. In order that the mti system provide good clutter suppression as well as good target detectability at all radial velocities, staggered prf's are used. Incremental adjustment of the prf allows an average prf between 310 and 364.5. Any one of three prf stagger programs can be selected, depending on the average prf desired. If second-time-around clutter returns are received and are to be cancelled, the transmission must be changed to a fixed interpulse period instead of the usual variable interpulse period. This feature can be programmed for one sector using the range-azimuth generator (rag).

(d) Interference/PRF Assignment. With suitable rf frequency assignment, it is unlikely that interference will occur between the ARSR and another radar, especially if the ARSR is geographically separated from the other radar by a substantial distance, for example, several tens of miles. However, if interference does occur, it is possible that adjustment of the prf can reduce or eliminate any operational difficulty. FAA frequency management personnel are responsible for the final prf assignment as well as for the rf frequency assignment. See reference 15.

c. Receiver Characteristics. Only a small portionof theenergy radiated from the antenna strikes a distant target in spite of the beam shaping produced by a narrow beam antenna. The target reflections are, in turn, widely scattered, producing a received echo signal which is very small. The radar receiver, therefore, must be capable of detecting and amplifying these weak signals despite competing noise and clutter inputs.

(1) Sensitivity. The effective range of a surveillance radar for a given size target, in most cases, is directly dependent upon the sensitivity of its receiver; that is, the ability of the receiver to detect and utilize weak echo pulses. Generally, the weaker the signal which can be detected the greater the effective range of the radar. The fundamental limitation on weak

Fig. 2-8 HITS/SCAN VS PRF FOR ARSR-3 EQUIPMENT



signal detection is the noise generated in the receiver input circuits. To achieve a satisfactory probability of detection along with an acceptable false alarm rate, the received signal, after processing in the receiver, must be of sufficiently greater amplitude than the inherent receiver noise. Where ground clutter effects are observed, effective surveillance range is dependent upon the ability of the receiver and processor to raise the ratio of input signal to clutter-plus-noise to a level sufficient for detection.

(2) Sensitivity Time Control.

(a) Purpose. Sensitivity Time Control (stc) is incorporated into ARSR systems to reduce the risk of receiver saturation due to clutter returns, which can be especially strong at short range. If the receiver is saturated by clutter, it will not respond to the additional signal input from a target, and thus signal detectability is impaired. In order to reduce the likelihood of receiver saturation on these clutter returns, receiver gain is intentionally reduced at short range, and gradually increased up to its maximum value at some greater range where clutter is not likely to cause saturation. The reduced sensitivity at short range may also reduce the visibility of certain second-time-around echoes from strong, very distant reflectors and undesired moving targets such as birds and automobiles.

(b) STC Implementation. A digitally generated stc control waveform is used for controlling a PIN diode attenuator ahead of the receiver's rf amplifier. Four individually programmable stc waveforms are available, two for the upper beam and two for the lower beam. For each beam, the range/azimuth gate generator (rag) can be used for selecting which of the stc waveforms is used-- one with strong stc action in azimuth sectors with high levels of clutter, or one with less stc in sectors with little or no clutter.

(3) Logarithmic Receiver Channel. A surveillance radar, especially one which is utilized in an automated atc system, should have a known, constant false alarm rate in order to avoid frequently overloading the tracking channel with spurious detections. Furthermore, the receiver must be capable of handling incoming signals over a wide dynamic range without limiting or saturating. Otherwise, a target signal, received simultaneously with strong clutter, will not be detected. To provide the required performance, the receiver is designed to have a logarithmic characteristic with over 60 dB dynamic range. As an additional feature to reduce the chance of experiencing false alarms on the leading edges of clutter, the ARSR-3 receiver employs a special output filter. The receiver provides a virtually constant falsealarm rate (CFAR), and is termed a log-CFAR receiver.

(4) MTI Capability.

(a) Purpose. To improve the ability of a radar to reject ground clutter, a (mti) moving target indicator receiver is often employed. With such a system, clutter rejection is achieved by signal processing techniques which distinguish between moving and stationary targets. In many older surveillance radars this was done through the use of delay-line feedback networks which provide destructive cancellation of the video return signals whose phase and amplitude are unchanged from pulse to pulse. The phase of the signal produced by a moving target is not constant from pulse to pulse and so yields an uncancelled residue which can be detected. In new ARSR equipments, such as the ARSR-3, the video signal is sampled, and the samples are stored as digital numbers. Consequently, in a digital mti of this type the signals can be stored, delayed, weighted, and added with the convenience, accuracy, and stability associated with digital computation.

(b) ARSR-3 Techniques. The ARSR-3 employs several techniques to yield improved mti performance relative to earlier radars. It uses two detector channels,anin-phase channel(I), and a 90-degree or quadrature channel (Q), to avoid the blind-phase problem which can be encountered in receivers using only one synchronous detector. The ARSR-3 uses a three-pulse canceller with staggered prf to provide a relatively smooth mti velocity response with no blind speeds to over 2000 knots. Also, the range/azimuth generator (rag) provides thirty windows where either mti video or log video can be used. MTI should be used to improve aircraft detection only wherethere is ground clutter. To avoid possible signal losses, such as those from aircraft on tangential courses, do not use mti when not needed for reduction of ground clutter, Although the ARSR-3 incorporates numerous features to control false alarms, extreme ground clutter at some locations may not be completely cancelled. To help prevent alarms in such cases, a Dynamic Threshold Generator is incorporated in the radar. It senses and stores information on clutter amplitude prior to'the mti canceller. When the clutter amplitude exceeds the cancellation capability of the mti, the video quantizer threshold is raised by a small amount. The dynamicthreshold isapplied only to themti sectorsunder ragcontrol.

(c) Performance. The most important figure of merit for an mti system is the improvement factor,defined as the ratio of signal-to-clutter out of the canceller to signal-to-clutter into the canceller. For the ARSR-3, which uses a 3-pulse canceller, the mti improvement factor is 39 dB. As will be shown in chapter 3, signal detectability in the presence of clutter can be determined using this value for the signal-to-clutter improvement due to receiver processing, in conjunction with estimates of received signal power, received clutter power, and signal-to-clutter improvement provided by use of the ARSR-3 passive antenna horn (figure 2-5). Another important aspect of mti performance is the behavior at various radial velocities. Figure 2-9 shows the signal response for the ARSR-3 mti channel relative to the response using the ARSR-3 normal receiver (log CFAR). There are no blind velocities to over 2000 knots. At 75 knots radial velocity, relative response is down by approximately 8 dB. It then increases, and it is at least equal to response of the normal receiver down to the radial velocities of 20 knots.

(5) Pulse Integration. Pulse integration is employedin surveillance radars for the purpose of enhancing signal detectability. For the ARSR-3,each of the two displaced transmitters illuminates the target approximately 12.5 times as the beam scans past the target. Thus, for dual-channel operation, 25-pulse echoes are received. Pulse integration is the process of adding together the target returns from these successive pulses, thus yielding a

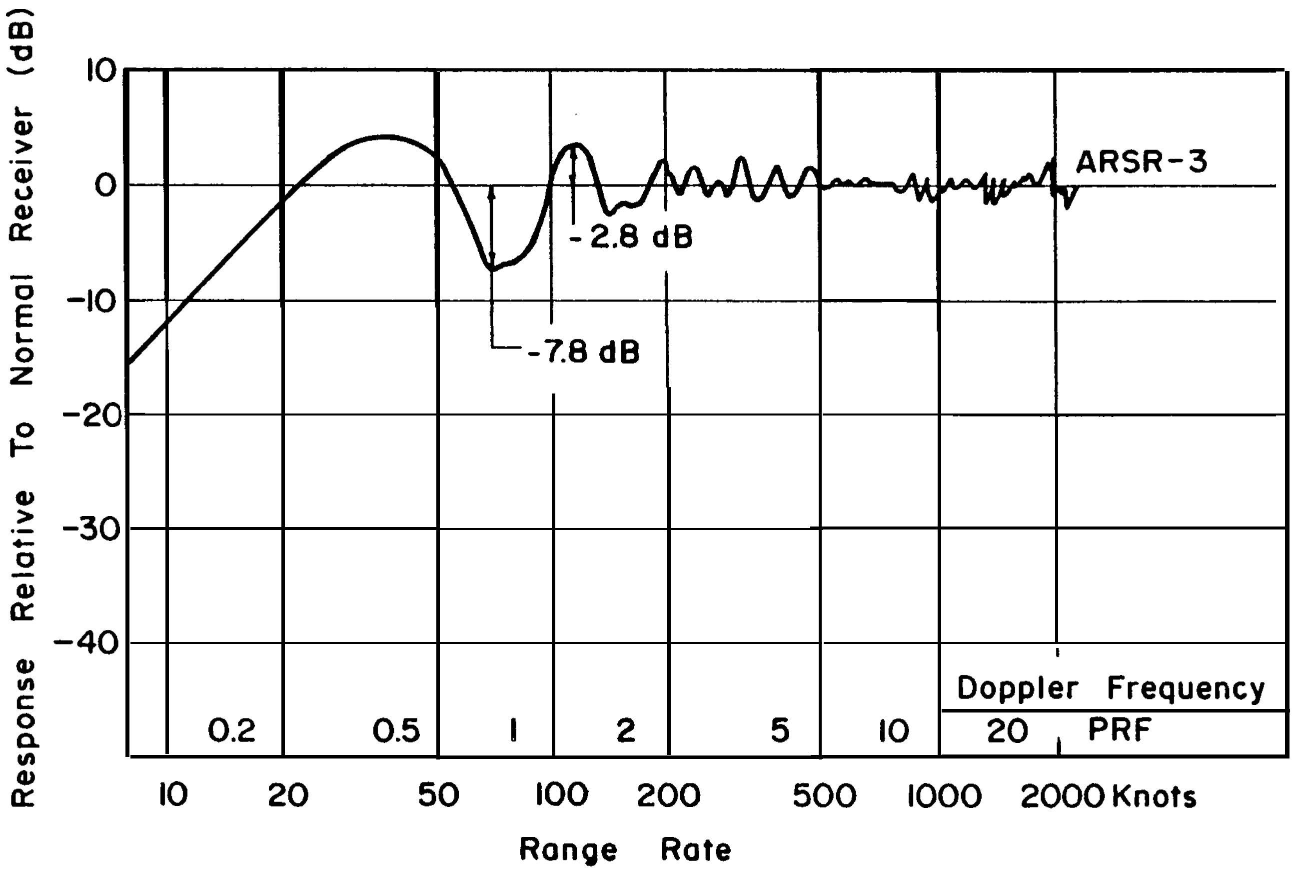


Fig. 2-9 RESPONSE OF ARSR-3 MTI RECEIVER RELATIVE TO NORMAL (LOG CFAR) RECEIVER

higher net signal-to-noise ratio, and consequently a higher probability of detection (Pd) for a given false alarm rate. Alternatively, for a specified required value of P_d, integration allows the use of a lower input signal-to-noise ratio, and thereby increases the range to which a target is detectable. The two'radar channels operate at an rf frequency separation of at least 25 MHz so that the signal fading in the two channels is uncorrelated. The statistics of the signal fading tend to follow the theoretical model of the Swerling Class III target. The effective signal-to-noise improvement due to integration depends on the probability of false alarm (P_{fa}), the probability of detection (Pd), and the number of pulses integrated (M). For $P_{fa} = 10^{-6}$, $P_d = 0.8$, and M = 25, this integration gain is approximately 9.9 dB. Pulse integration is employed in both the normal receiver and the mti receiver.

(6) Range/Azimuth Gating (rag). New ARSR equipment such as the ARSR-3 will contain a range/azimuth gate generator which will generate a variety of programmable azimuth/range windows, azimuth gates, and rangegates. Some of these are outlined briefly below. The added radar capability which is provided by the rag should be considered at the time of siting, since it may allow an increase in the number of potentially acceptable site locations.

(a) Video Gating. The rag provides for selection of one or two video signals on range/azimuth basis. This will normally be used for gating between mti and normal video. The rag will have the capability of generating 20 range/azimuth gating windows, beginning at zero range and adjoining in azimuth. Ten additional adjustable, isolated gating windows will also be provided for this purpose.

(b) Antenna Beam Switching. As discussed above, the rag also allows switching from high to low beam antenna at selectable range in eight contiguous azimuth regions beginning at zero range, and at four additional isolated range/azimuth windows.

(c) PRF Stagger Operation. The rag provides the capability for switching from prf stagger to nonstagger operation on an azimuth basis.

(d) Receiver Gain. The rag has eight isolated windows for receiver gain control, plus provision for selectionof either of twostc curves.

(7) Digital Target Extractor. The ARSR-3, as an integral part of its design, incorporates a digital target extractor (dte) which converts the hit-by-hit wideband radar pulses and the received beacon signal into digital target centroid data along with aircraft identity and altitude information at the radar site. The radar and beacon data can thus be remoted to the Air Route Traffic Control Center over narrowband links, such as telephone lines, instead of via a wideband transmission system such as a microwave link.

(8) Moving Target Detector (MTD). Improvements are constantly being made to provide better signal detectability in the presence of clutter. The moving target detector (mtd) is presently in development and will subsequently be used in the ARSR-4 and other new air traffic control radars. It will

process digitized receiver output signals to detect moving targets, while rejecting fixed ground clutter, precipitation clutter, and pulsed interference. It will incorporate numerous sub-units including a two-pulse canceller, digital filters, clutter map, various thresholders, and a weather processor. The mti improvement factor will be approximately 48 dB (within 2 dB of that obtainable with an optimum processor). The digital processing systems incorporated into this unit will develop reconstituted video for display on standard FAA PPI displays.

17.-19. RESEWED.

SECTION 3. AIR TRAFFIC CONTROL RADAR BEACON SYSTEM

20. FUNCTION.

a. Purpose. The Air Traffic Control Radar Beacon System (ATCRBS) is designed to provide an enhanced radar detection, location, and identification capability for control of properly equipped aircraft. The system is employed at both terminal and enroute FAA radar sites and is of extreme importance to the efficient control of aircraft, especially during poor weather conditions.

b. System Components. With ATCRBS, detection of aircraft is dependent upon reception of reply signals from an airborne transponder device, a process normally much more reliable than conventional radar surveillance. The basic ATCRBS components include an interrogator, a transponder and an indicator. The Air Traffic Control Beacon Interrogator (ATCBI) transmitter/antenna radiates short coded pulses at a fixed frequency of 1030 MHz. This signal, when received and validated by an antenna/transponder unit aboard an aircraft, initiates generation of a reply pulse train at 1090 MHz.

c. Target Detection and Display. Detection occurs when the transponder reply signal is picked up by the interrogating antenna, processed, and displayed on an ARTCC indicator. Target bearing and range are determined from the antenna point angle and signal propagation time, as for a skin-track radar. The range determination takes into account the time delay introduced by the airborne transponder unit. ATCRBS and ARSR transmissions are synchronized such that the video output from each can be displayed, in proper alignment, on the same indicator. Additional information can be provided by the beacon system since the reply pulse train format is independent of the interrogation signal. The reply signal is usually coded to provide the controller with aircraft altitude and/or identification information.

d. Beacon System Designations. The Air Traffic Control Radar Beacon System (ATCRBS) has been designated as the secondary radar to distinguish its function from other FAA radar equipment. As more and more aircraft become beacon equipped, however, this designation is likely to be altered as the high density commercial terminals, ATCRBS is already the dominant factor in control operations. As such, ATCRBS should receive commensurate attention at the time of site selection. The beacon system currently being installed with the ARSR-3 surveillance radar is the ATCBI-5.

e. Future Beacon System. The FAA is developing a new aircraft surveillance and data-link system, the Discrete Address Beacon System (DABS). DABS will permit evolutionary upgrading of the civil and military air traffic control system. The central feature of DABS is the use of a discrete address code for each aircraft. Thus, each reply is identified with the proper aircraft. The discrete address function also provides a highly flexible data link supporting a wide range of advanced ATC automation services.

21. EQUIPMENT PARAMETERS. The important parameters and functions cf the ATCBI-5 equipment presently being sited with the ARSR-3 at FAA en route facilities are tabulated in table 2-2.

22. AREA COVERAGE. The ATCRBS is capable of detecting aircraft within its line-of-sight at very long range. This is due to the high power capability of the equipment and the fact that propagation losses vary as R^{-2} for each of the one-way beacon paths, rather than the R^{-4} variation experienced by the primary radar. The maximum range of the beacon system is governed by the range of the interrogation link or the range of the reply link, whichever is less. The range of the reply link is fixed and is far in excess of thenominal maximum 200-mile detection range for an ARSR facility. The range of the interrogation link can also far exceed 200 nmi if the interrogator transmitter operates at full power. However, if desired, the interrogator power output can be reduced so that the interrogation link has only the range required for the beacon coverage needed. Thus the ATCRBS coverage range will ordinarily be determined by the interrogation link. Equipment should normallybe operated at the lowest output power which will permit reliable coverage of the required airspace volume. This practice will tend to minimize local interference and overinterrogation of aircraft transponders, and will reduce the fruit produced in other ATCRBS facilities. Figure 2-10 shows the ATCRBS range coverage characteristics; these are discussed more fully in chapter 3. Since separate transmitting and reply frequencies are used, ground clutter and weather clutter do not introduce any limitations on coverage.

23. CHARACTERISTICS PERTINENT TO SITE SELECTION.

a. Antenna Coverage. The ATCBI system has two antennas: the directional main antenna and an omnidirectional antenna. The purpose of the main antenna is to efficiently radiate the interrogation pulse energy in a directional beam and to receive the transponder reply signals, sending them on to the ATCBI receiver for processing. The main ATCBI antenna consists of the ARSR-3 reflector illuminated by a separate beacon feedhorn adjacent to the radar feedhorns. An 8-foot-long vertical omnidirectional transmitting antenna, used as part of a sidelobe suppression system (sls), is mounted above the ARSR-3 reflector. The characteristics of these two beacon system antennas are described below.

(1) Directional Antenna,

(a) Antenna Pattern. The radiation pattern of the directional antenna is a fan beam narrow in azimuth and broad in elevation as shown in figures 2-11 and 2-12, respectively. The beam scans its coverage volume as the antenna is rotated at the 5 rpm rate of the.ARSR system. Figure 2-11 shows a portion of the azimuth pattern taken at O-degree elevation relative to the maximum in the elevation pattern. The strongest sidelobe is approximately 26 dB below the main lobe. Azimuthal patterns for higher elevation angles, e.g., 3 degrees, 10 degrees, 20 degrees, and 30 degrees (not shown) indicate similar levels of sidelobes relative to the mainlobe radiation at those elevation angles. The physical horizontal offset of the radar and beacon feeds results in a 4-degree azimuth beam displacement, which is compensated for in the radar's digital target extractor (dte). Since the

Table 2-2

ATCBI-5 PARAMETERS AND FEATURES

Antenna		
Directional		
Pattern Shape		Fan Beam
Beamwidth		
Azimuth		2.0°
Elevation		9°
Gain	dbir	31
Polarization		Vertical
Omnidirectional		
Gain	dbir	4 ± 1
Interrogator		
Transmitter		
RF Frequency	MHz	1030 ± 0.2
RF Pulsewidth	μs	0.8 ± 0.1
Peak Power Output		50-3160 watts
RF Pulse Pair Spacing		
Mode 1	μs	3 ± 0.1
2	μs	5 ± 0.1
3/A	μs	8 ± 0.1
B	μs	17 ± 0.1
C	μ	21 ± 0.1
D	μ	25 ± 0.1
PRF 2/		310 - 365
Mode Interlace		x
SLS Transmission		x
Improved SLS		x
Receiver		
RF Frequency	MHz	1090 ± 0.2
Noise Figure		9 dB
Tangential Sensitivity		-87 dBm min
STC		10-50 dB
Defruiting - Digital Defruiter Mx- 8757 supplied		
Remoting Cable		
Maximum Length,ft RG-11A/U or RG-13A/U		12,000
Maximum Length, ft RG-35A/U		20,000

2/ Synchronized with ARSR-3; Variable Interpulse Period (VIP) extends PRF Range - ATCBI-5 STC recovery time must be considered for some VIP modes.

Figure 2-10 ATCRBS MAXIMUM RANGE COVERAGE (ATCBI - 5)

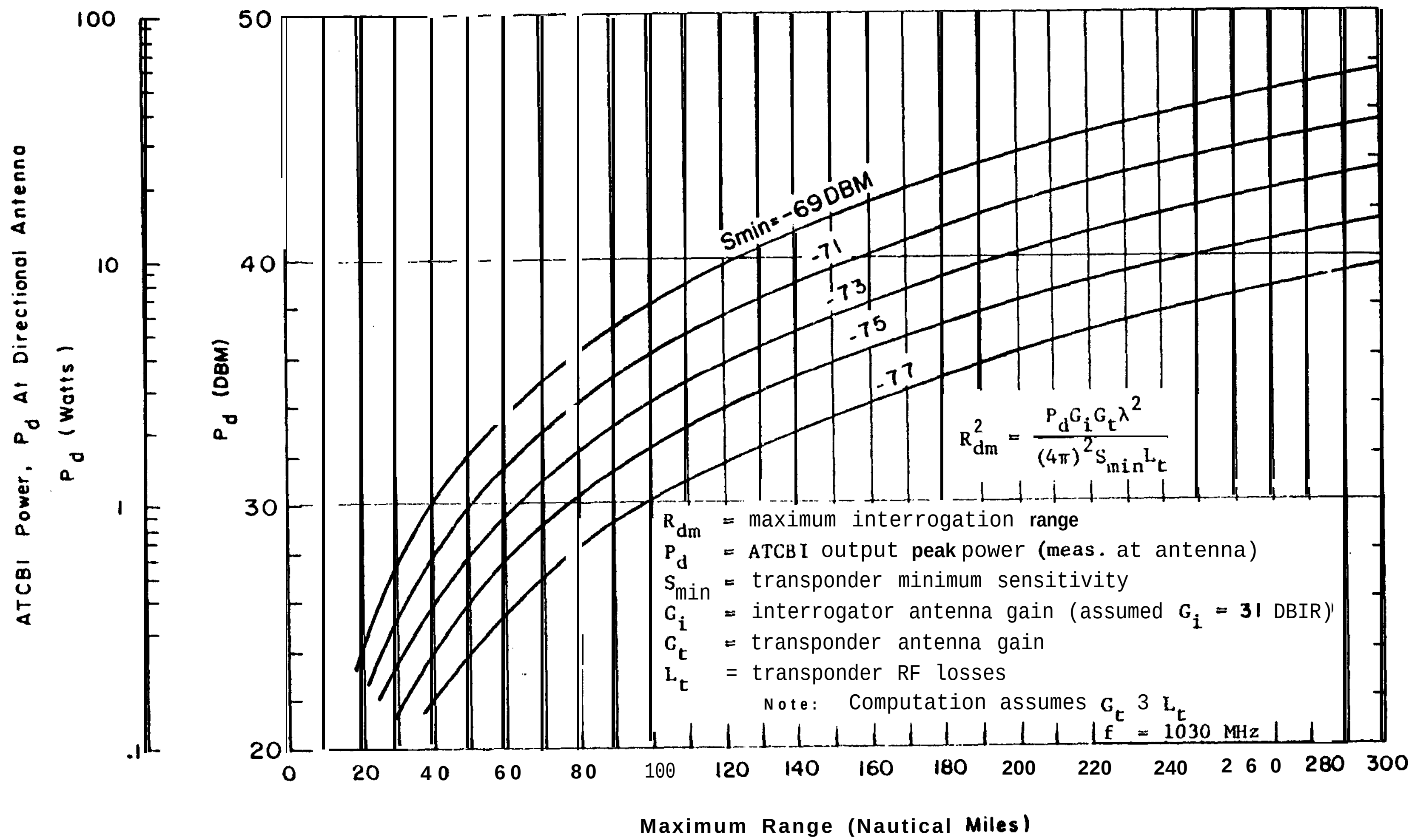


Fig. 2-11 TYPICAL FREE-SPACE AZIMUTH PATTERN FOR ATCBI DIRECTIONAL ANTENNA WITH ARSR-3 REFLECTOR

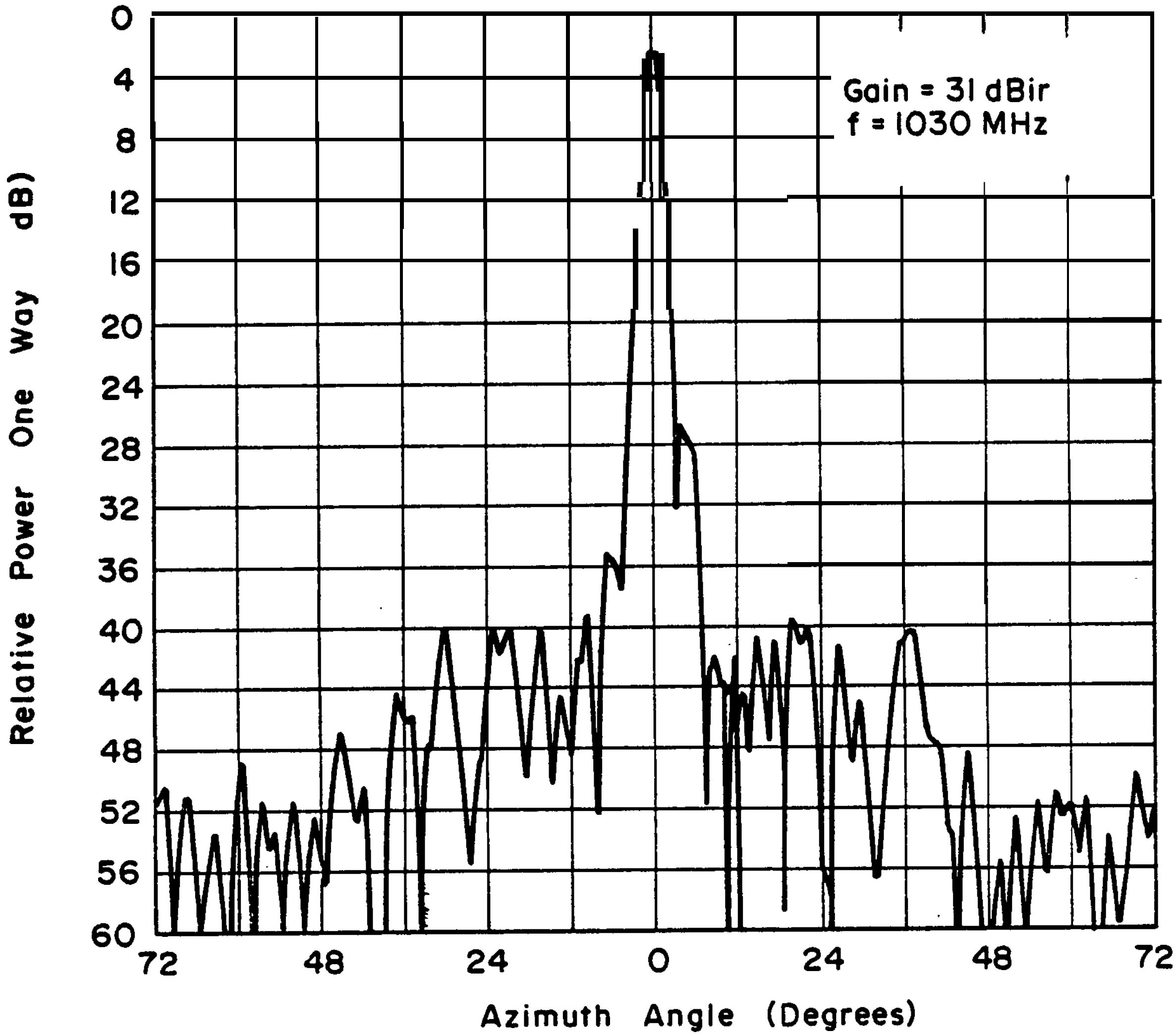
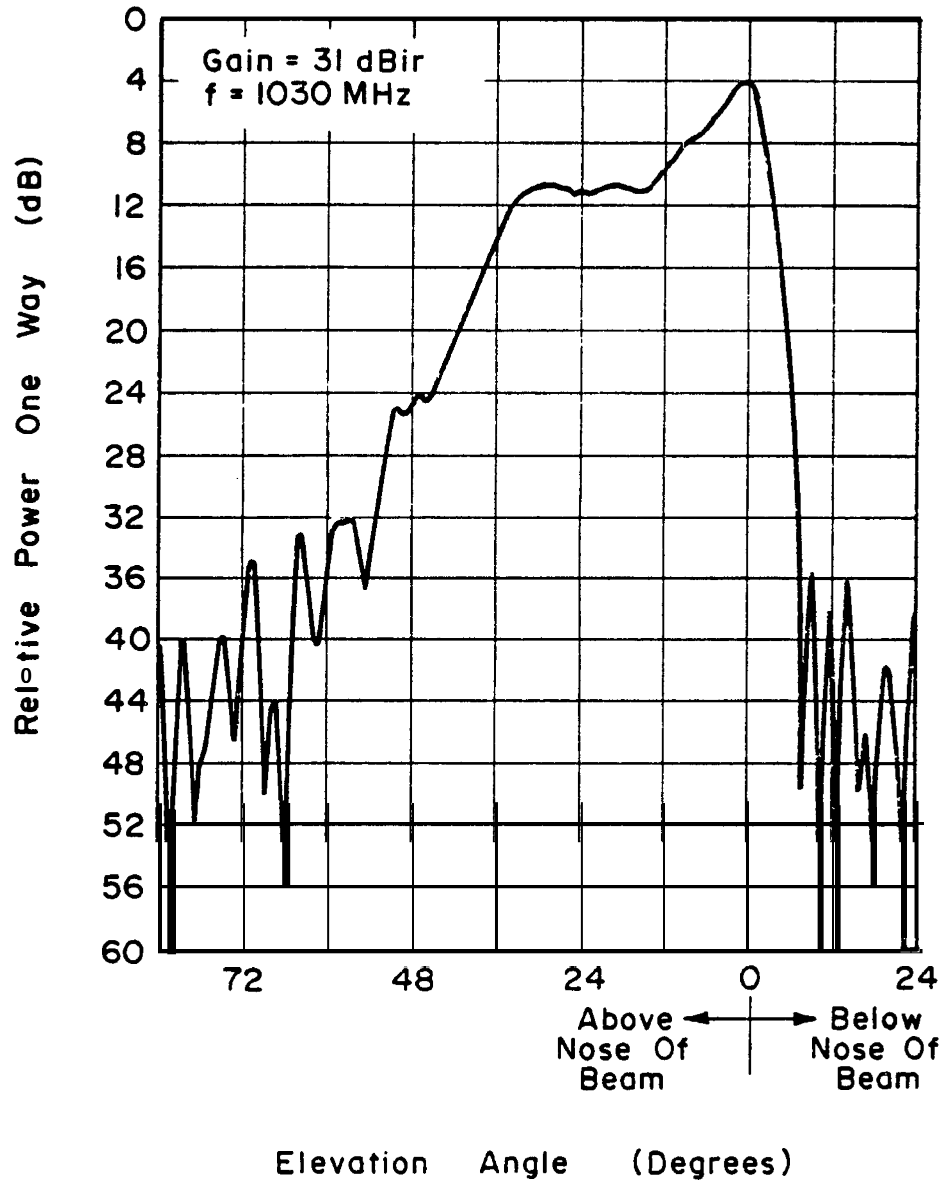


Fig. 2 -I 2 TYPICAL FREE-SPACE ELEVATION PATTERN FOR ATCBI DIRECTIONAL ANTENNA WITH ARSR-3 REFLECTOR



beacon feedhorn is separate from the radar feedhorn, it can be independently tilted to optimize usage of its sharp beam underside cutoff in controlling ground illumination and vertical lobing.

(b) Antenna Cain. As mentioned above, the gain of an antenna is a quantitative measure of the directivity compared with a reference standard (usually an isotropic radiator). Its maximum value is used as a measure of antenna performance. As noted in table 2-2, the maximum gain for the ATCBI main antenna, as part of the ARSR-3 system is 31 dBir.

(c) Beamwidth. Since ATCBI equipment must perform a function similar to that of the primary radar, antenna beamwidth requirements are also similar. The 3 dB azimuth ATCBI beamwidth is narrow (2.0 degrees) to provide good target resolution, and elevation beamwidth is broader (approximately 9 degrees) for good vertical coverage of the surveillance volume, Target altitude information is not derived from the beacon antenna elevation pattern, but directly from coded data in the beacon reply signal.

(d) Polarization. ATCRBS equipment, because of the requirement for cooperative operation of both ground and airborne equipment, operates only with vertical polarization.

(e) Scan Rate. Because the same reflector is used for both the ARSR-3 antenna and the ATCBI main antenna, the scan rate of the beacon system is the same as that of the radar, 5 rpm.

(2) Omnidirectional Antenna. In all ATCBI installations a supplementary, fixed omnidirectional antenna is employed in conjunction with the use of a Sidelobe Suppression (sls) system. SLS, which is described below, utilizes the omnidirectional antenna to suppress interrogation of properly equipped aircraft transponders via sidelobe transmission paths. In addition, use of improved sls suppresses interrogation of properly equipped aircraft transponders via reflections from nearby objects. The elevation pattern of this antenna is given in figure 2-13. The omni antenna has a sharp cutoff on the underside of its vertical pattern to minimize differences between the vertical lobing patterns of the main beacon antenna and the omni antenna. The vertical displacement of the directional and omni antennas will result in some mismatch of the lobing patterns. Maximum gain of the omni antenna is 5.5 dBir. The antenna is vertically polarized.

(3) Five-Foot Planar Array. The antenna system to be used with the en route DABS, when it is incorporated, is the five-foot, light weight-high gain array, A typical elevation pattern for this antenna is shown in figure 2-14 and an azimuth pattern in figure 2-15.

b. Signal-Characteristics.

(1) Introduction. The ATCRBS signal characteristics can most conveniently be discussed in terms of the basic interrogation signal, the reply signal, and the added features of the interrogation signal which act to suppress the unwanted interrogations caused by sidelobes of the interrogator/main antenna. These signal characteristics are discussed below.

Fig. 2-13 TYPICAL VERTICAL PATTERN OF ATCBI OMNIDIRECTIONAL ANTENNA USED WITH ARSR-3

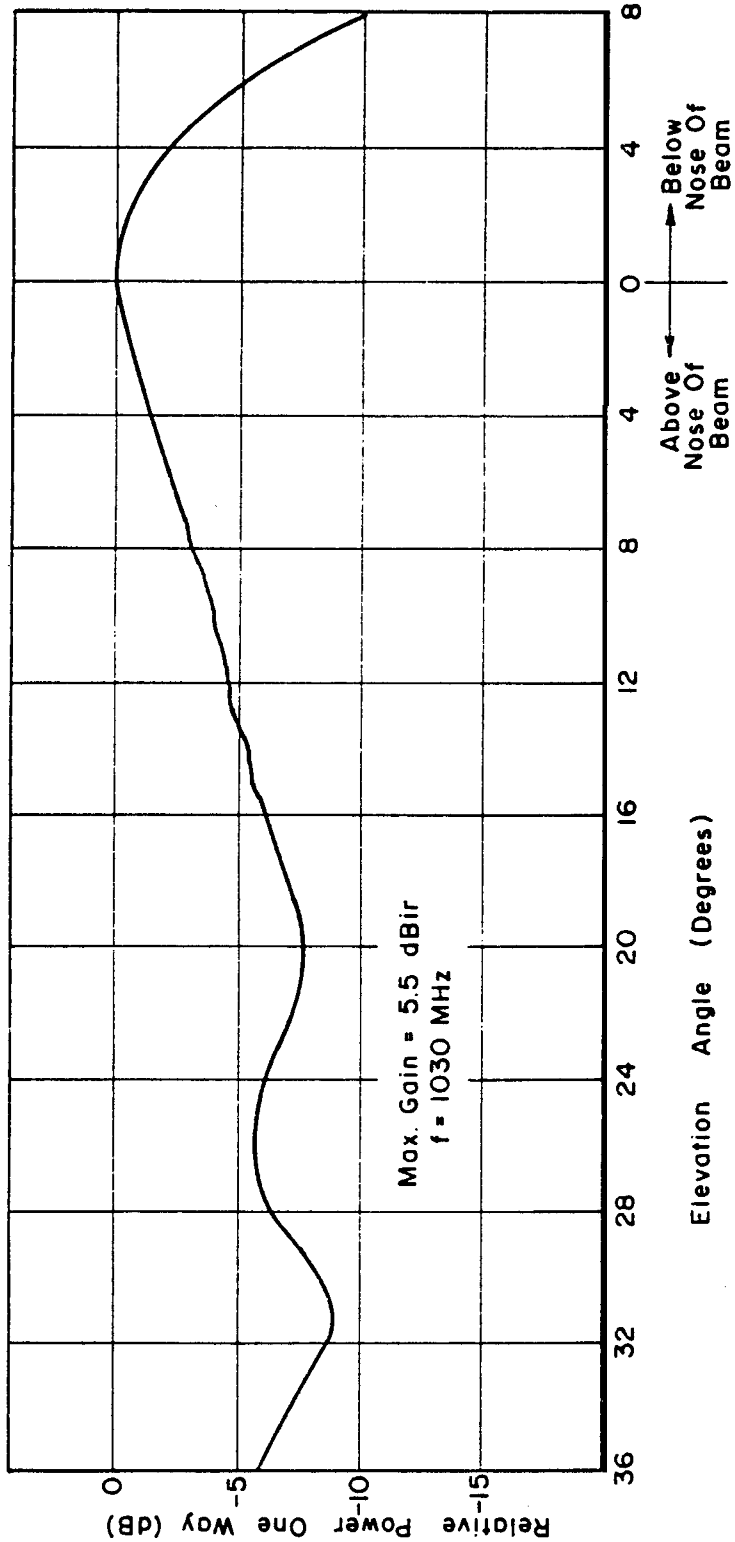


FIGURE 2-14 TYPICAL FREE SPACE ELEVATION RADIATION PATTERN FOR FIVE- FOOT LIGHT-WEIGHT HIGH GAIN ARRAY TO BE USED WITH EN ROUTE DABS

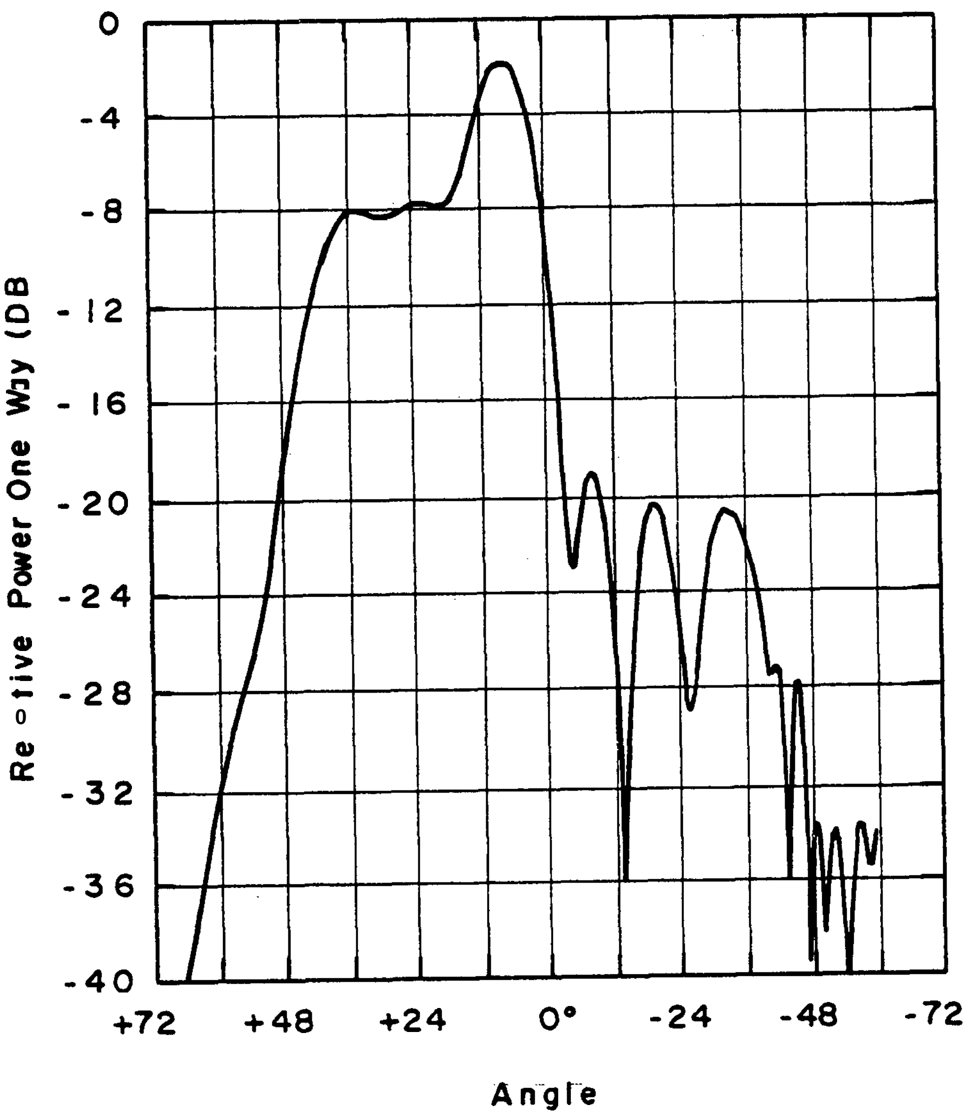
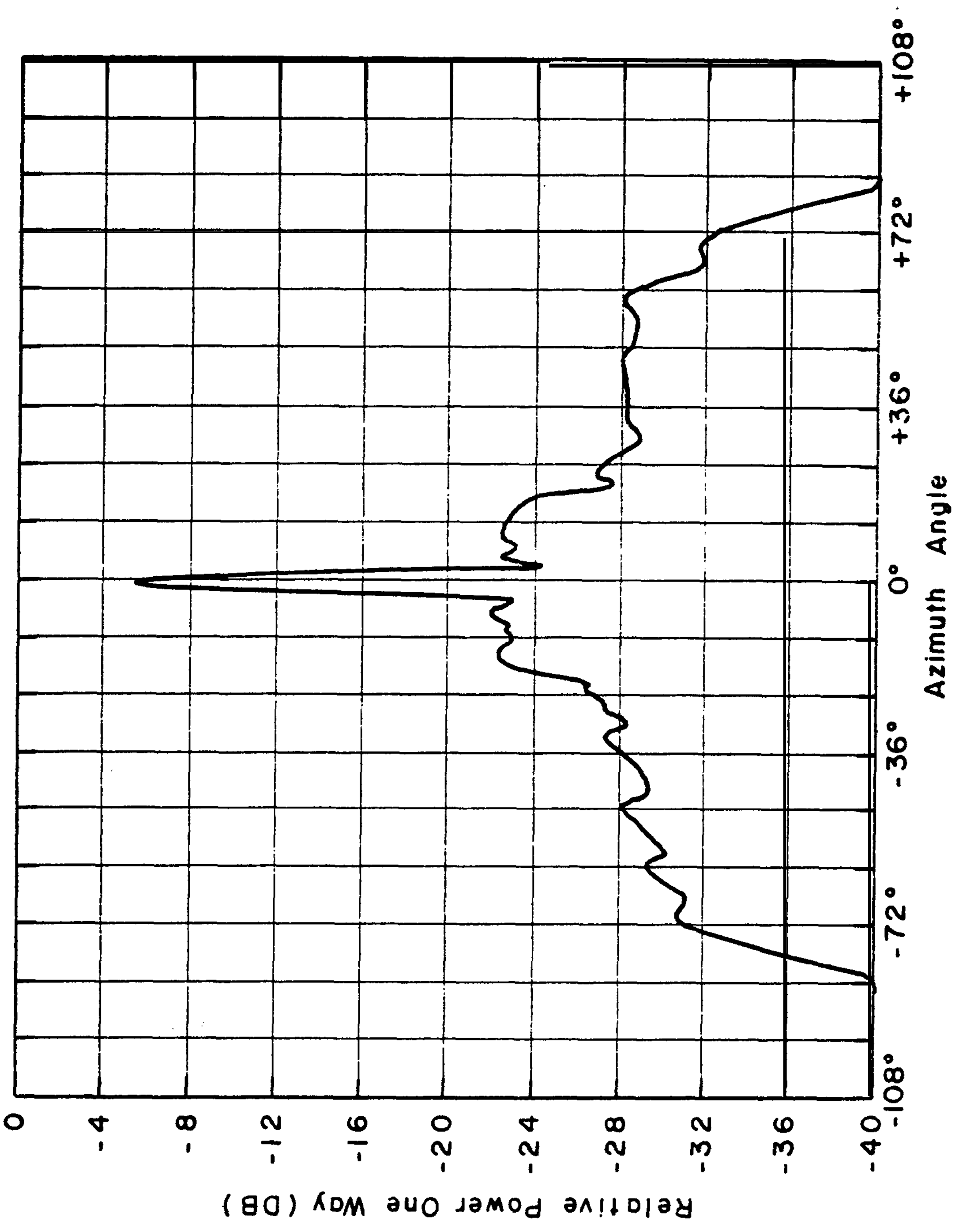


FIGURE 2-15 TYPICAL FREE SPACE AZIMUTH RADIATION PATTERN FOR FIVE-FOOT LIGHT-WEIGHT HIGH GAIN ARRAY TO BE USED WITH EN ROUTE DABS



(2) Basic Interrogation Signal.

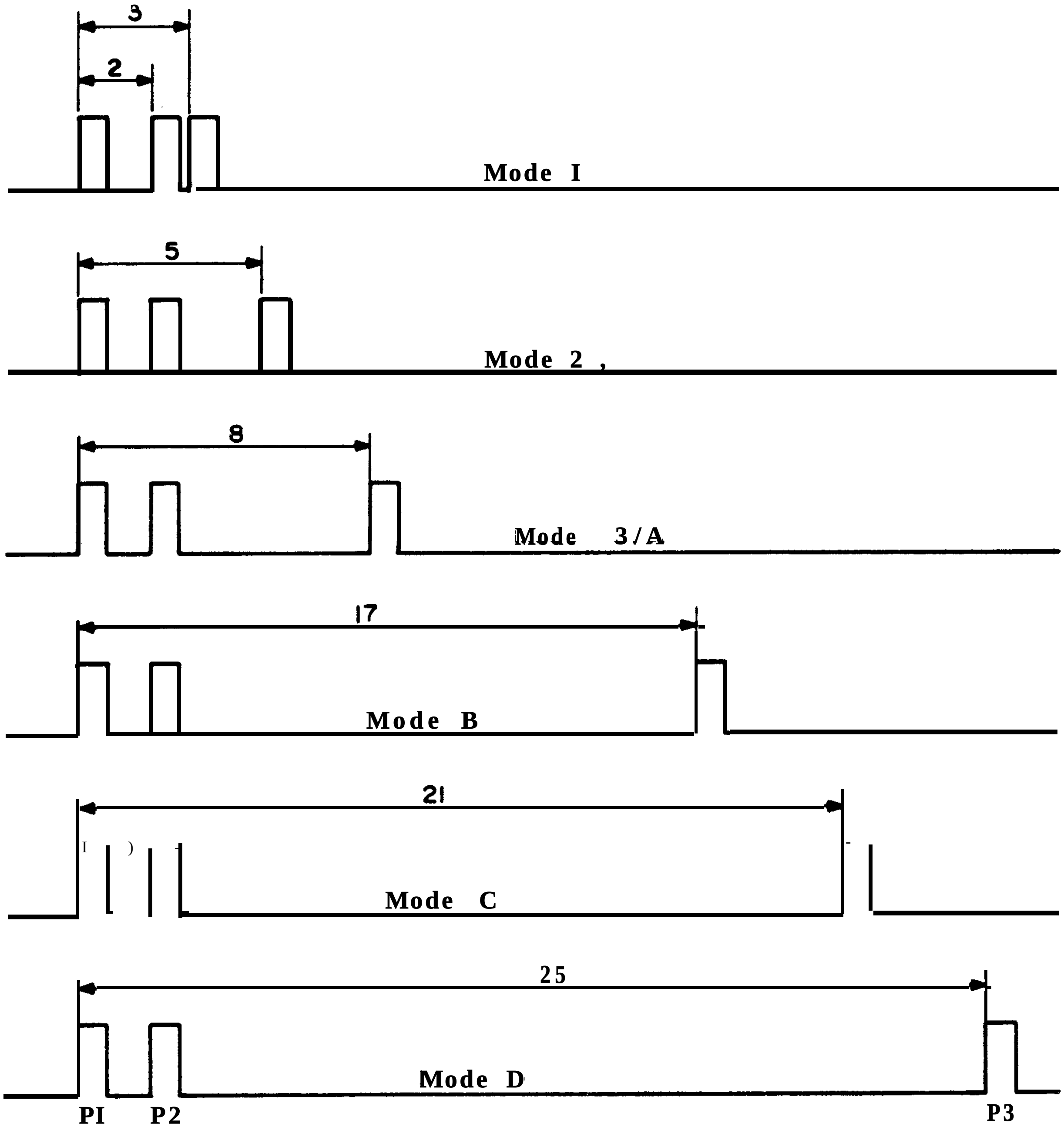
(a) Modes. ATCBI-5 interrogators transmit a sequential series of three 0.8-μs pulses at 1030 MHz as shown in figure 2-16. The first and third pulses, P1 and P3, are radiated via the ATCBI directional antenna and are the basic interrogation signal. The spacing between P1 and P3 establishes the interrogation mode as shown. (P2 is radiated via theomniantennafor side-lobe suppression 2.0 μs after P1 is radiated from the directional antenna). Six possible modes (designated mode 1, mode 2, mode 3/A, mode B, mode C, and mode D), may be used, but usually only modes 3/A (common identity)and C (common altitude) are used in air traffic control. It is common to interlace these two modes on a 1:1 or 2:1 basis to update identity and altitude data on each scan of the ground based antenna. The interrogation mode sequences available with the ATCBI-5 interrogators, some interlaced and some not, are given below. The X,Y, and Z correspond to any of the ATCRBS mode designations (i.e., mode 1, 2, 3/A, B, C, D).

XXXXX...............(no interlace)
YYYYY............... (no interlace)
ZZZZZ............... (no interlace)
XYXYXY..............
XXYXXY..............
XYZXYZ..............
XYXZXYXZ............

(b) Interrogation Repetition Frequency, The rate at which the interrogation pulse program is transmitted is termed its prf. This rate is normally adjustable between 150 and 450 Hz. The adjustment is important to equipment installation insofar as it must be kept different from other ATCBI equipment in the vicinity. Selection of a unique prf for beacon operation enhances the capability of its video defruiting equipment, thereby resulting in improved ATCBI performance. In joint ARSR/ATCBI installations, the ATCBI prf is derived directly from the basic prf of the ARSR equipment. Because of this interdependence, and the interference implications to operation of both systems, prf selection is usually the responsibility of FAA Regional Frequency Management personnel.

(3) Reply Signal. For each interrogation, the elicited transponder reply (at 1090 MHz) comprises up to 16 pulses spaced at multiples of 1.45 μs as shown in figure 2-17 and table 2-3. Two of the pulses, F1 and F2, are always present to define the pulse train. The other pulses contain the coded data (usually identity or altitude) requested by the interrogator mode selection. The specific aircraft identity code used is assigned by the airtraffic controller through voice communications, Also, one of the reply pulses can be used for special identification if the same identity code has been redundantly assigned to two or more aircraft within the surveillance volume. Special reply code provisions enable the pilot to declare an emergency or a communications failure. Some example pulse trains are illustrated in figure 2-17.

Figure 2- 16. INTERROGATION PULSE SPACINGS FOR ATCBI MODES

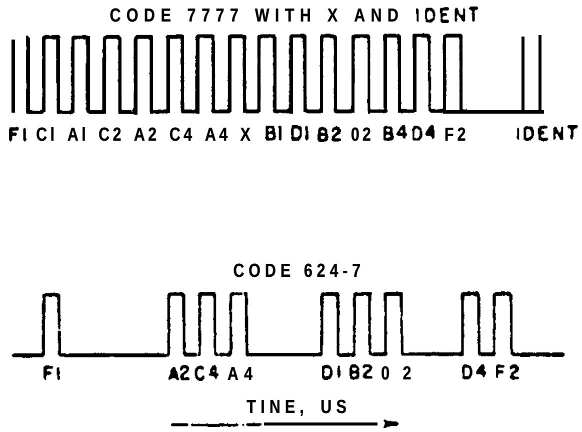


Notes : (1) All Times In Microseconds

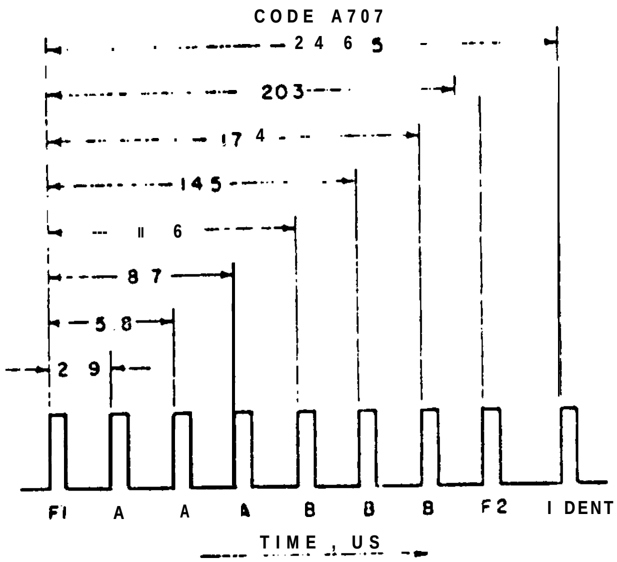
(2) All Pulses 0.8 Microsecond Wide

(3) PI 8 P3 Are Radiated By Directional Antenna; P2 Is Radiated By Omni Antenna

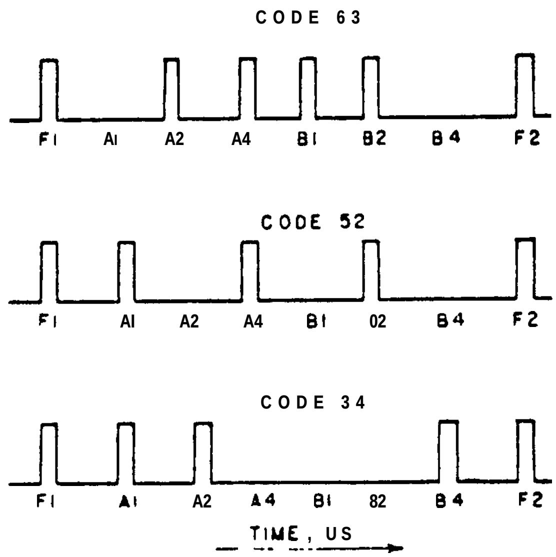
Figure 2-17 EXAMPLES OF ATCRBS REPLY PULSE CODES



(a) TWO OF THE POSSIBLE 4096 REPLY CODES USING A, B, C, AND D PULSE POSITION



(b) COMMON SYSTM REPLY CODE TRAIN CONTAINING ALL PULSES IN A AND B PULSE POSITIONS AND AN INCIDENT PULSE



(c) THREE OF THE POSSIBLE 64 COMMON SYSTEM REPLY CODE USING A AND B PULSE POSITIONS

Table 2-3

ATCRBS TRANSPONDER REPLY CODES

- Two Framing Pulses (F1, F2) .... 0.45 ± 0.10 µs
  13 possible information pulses
  between framing pulses F1, F2.
  IDENT pulse spaced 4.35 µs after F2.

- Reply Pulse Train

Pulse Width	0.45 ± 0.10 µs
Pulse Spacing	1.45 µs
Pulse C1	1.45 µs
Pulse A1	2.90 µs
Pulse C2	4.35 µs
Pulse A2	5.80 µs
Pulse C4	7.25 µs
Pulse A4	8.70 µs
Pulse X	10.15 µs
Pulse B1	11.60 µs
Pulse D1	13.05 µs
Pulse B2	14.50 µs
Pulse D2	15.95 µs
Pulse B4	17.40 µs
Pulse D4	18.85 µs

(4) Side-Lobe Suppression (SLS).

(a) Purpose, This feature is incorporated into ATCBI equipment to reduce interrogationof aircraft transponders via side-lobe radiation (nominally 24 dB below the peak of the beam) of the directional beacon antenna. Depending on the power transmitted, side-lobe ATCBI radiation can trigger replies at considerable distances from the radar , giving rise to a PPI effect known as ring-around (figure 2-18) with great deterioration of azimuth accuracy and resolution, and increased interference. Side lobe suppression techniques are incorporated into the system to allow aircraft transponders to distinguish between main and sidelobe interrogator radiation.

(b) Description. With the sls feature, normal directional radiation of Pl and P3 pulses is augmented by radiation of a control pulse, P2, from the ATCBI omnidirectional antenna. The P2 pulse, which always follows the Pl pulse by 2 µs, is compared in amplitude with Pl in transponders equipped with sls circuitry. The pulse amplitude comparison is implemented by a desensitization technique. Upon receipt of a pulse with more than 0.7 µs duration, the transponder receiver is desensitized to a level which is within 9 dB of (but not exceeding) the amplitude of the desensitizing pulse. Recovery is approximately linear over a 15 µs interval. When the Pl pulse amplitude is 9 dB (or more) greater than the P2 pulse amplitude, indicative of main beam interrogation,the P2 pulse is not detecteddue to desensitization, and a transponder reply is generated after reception of the P3 pulse, If the Pl and P2 pulse amplitudes are equal, clearly indicating a side-lobe transmission path, the P2 pulse is 'detected despite receiver desensitization and the transponder's reply capability is suppressed for a period of 35 ± 10 µs. Figure 2-19 indicates the pulse timing and amplitude relationships of the sls system.

(c) Effect of Multipath. Whereas ring-around is effectively controlled by side-lobe suppression, the technique is not as effective in removing the effects of reflections or multipath. Under this condition, false targets are generated when main beam energy from the ATCBI directional antenna successfully interrogates a transponder via a reflected signal path. When this occurs, in addition to the proper target display, a false target is displayed at the azimuth of the reflected path and at a range corresponding to the path length, including the reflection segment of the path. This is illustrated in figure 2-20.

(d) Examples of Multipath. Under the condition where the direct path sls P2 pulse and directional antenna side-lobe Pl and P3 pulses are received by the transponder, a 35 ± 10 µs suppression gate is generated which prevents some reflected path interrogations. This isillustrated in figure 2-21. Several conditions can occur, however, in which the sls system is not able to prevent successful reflected path interrogations. These include the following situations which are shown diagrammatically in figure 2-22. In each case, the reflected false targets can be generated despite the presence of sls circuitry.

1 Target ranges where direct path maln (directional antenna) side-lobe (pl pulse) energy is below the transponder sensitivity threshold.

Figure 2-18 PPI TIME EXPOSURE FOR A RADIAL FLIGHT SHOWING RING -AROUND EFFECTS

Figure 2-19 SIDE - LOBE SUPRESSION SYSTEM (SLS) AMPLITUDE RELATIONSHIPS AND ANTENNA PATTERNS

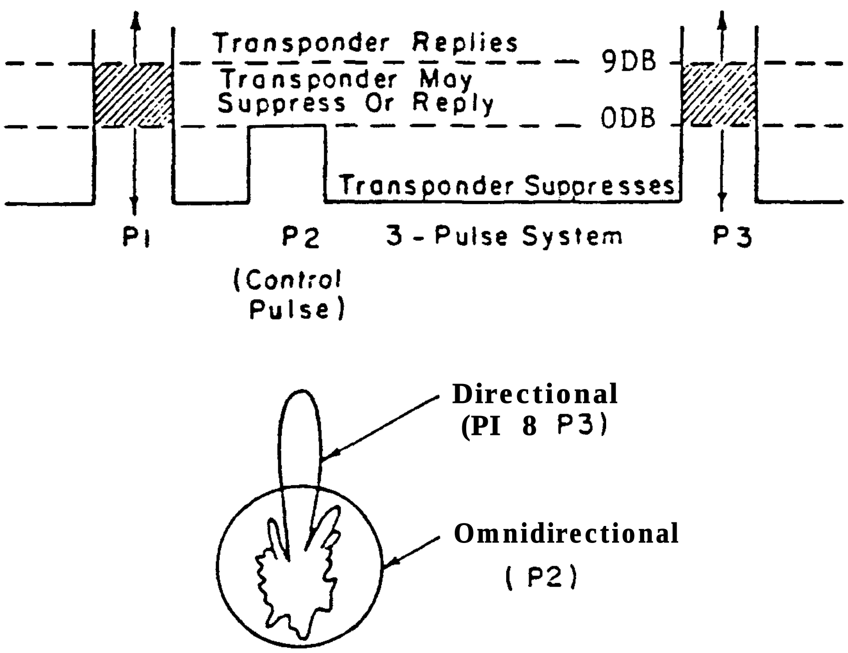
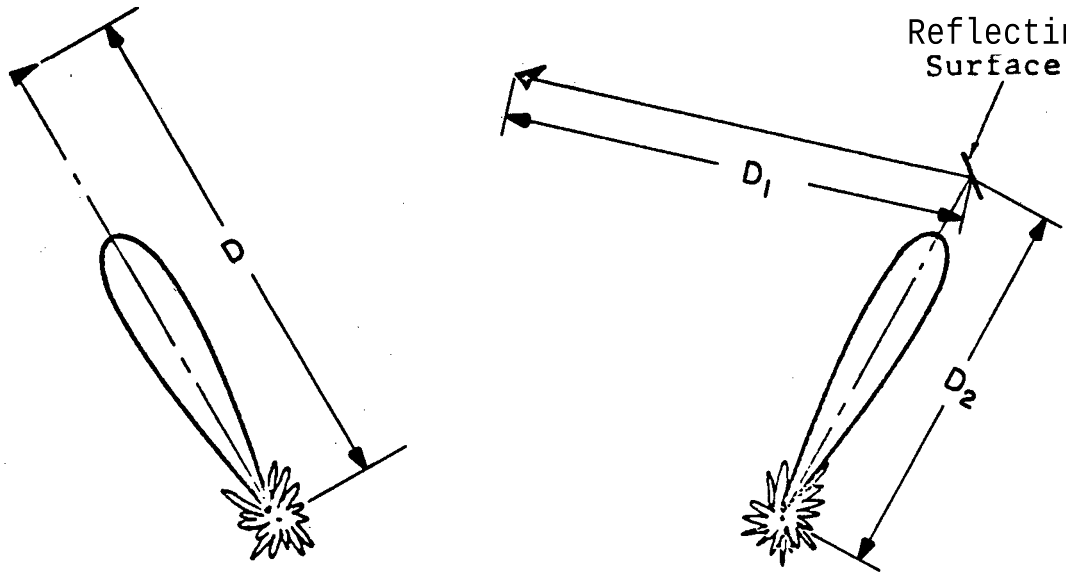
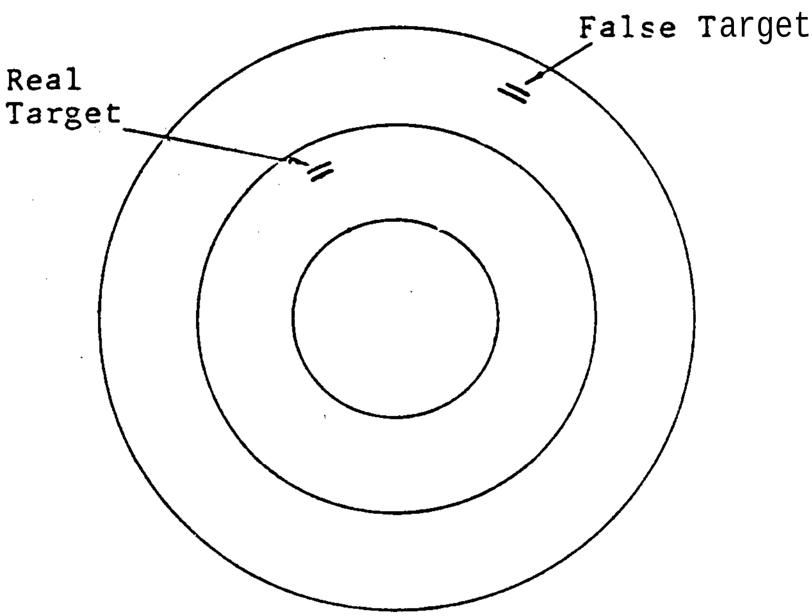


Figure 2-20 EFFECT OF REFLECTED-PATH BEACON OPERATION

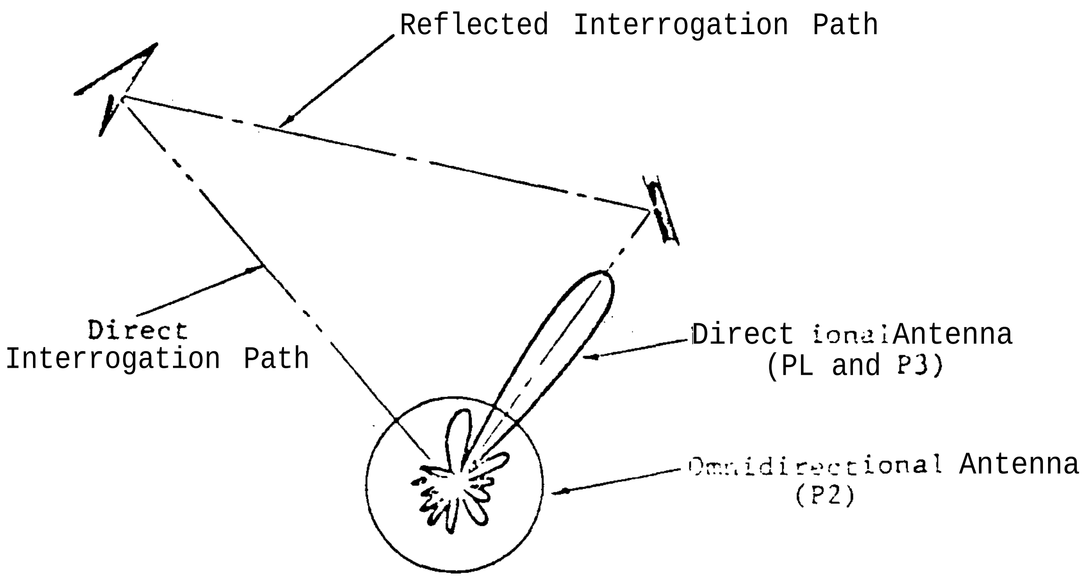


a) Normal Interrogation b) Reflected Path Interrogation

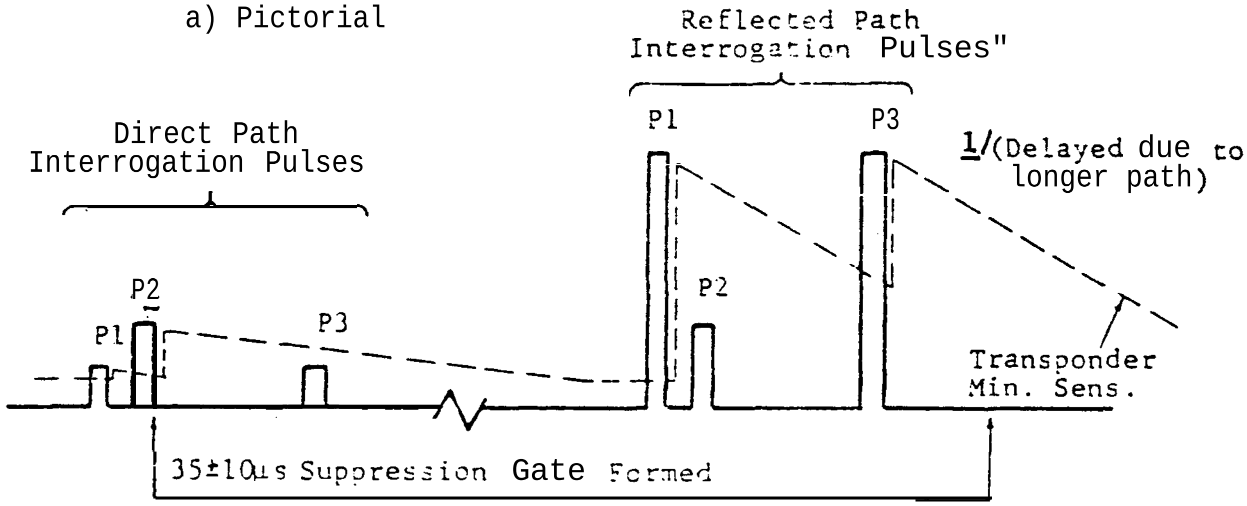


c) Resulting PPI Presentation

Figure 2-21 SUCCESSFUL SLS ACTION AGAINST REFLECTED PATH INTERROGATION

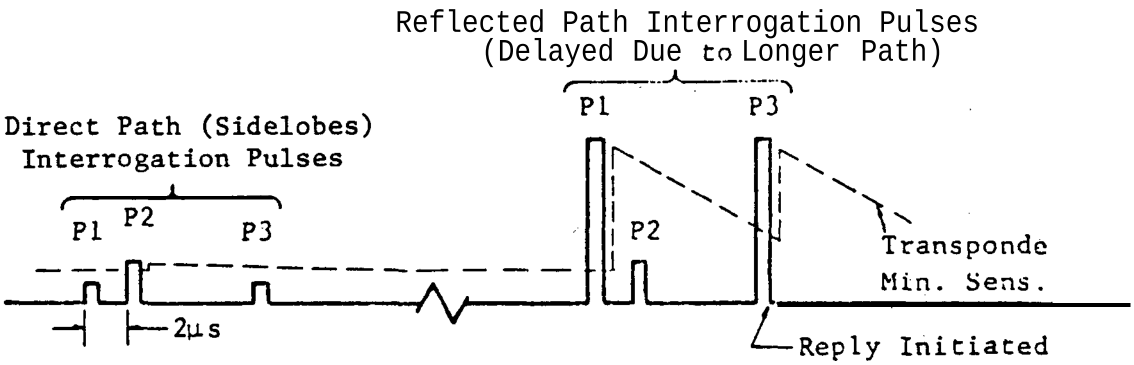


a) Pictorial

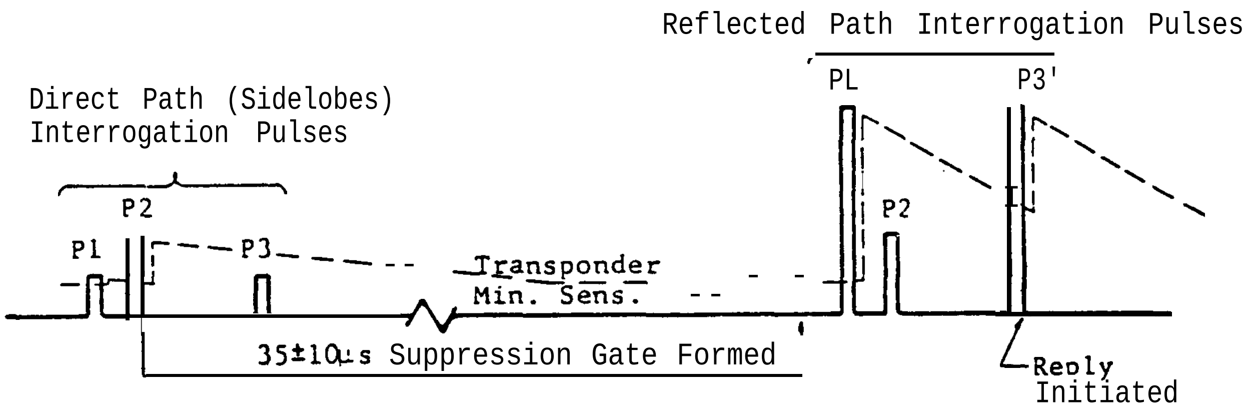


b) Transponder Input Pulse Amplitude Diagram Showing Condition of Immunity to Reflected Path Interrogation Due to Transponder Suppression - No Reply Generated

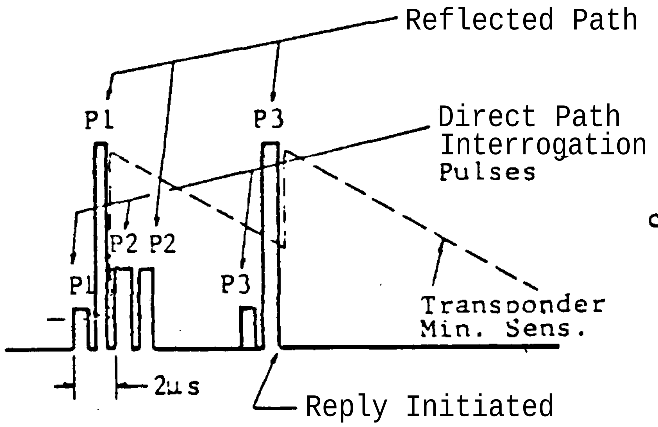
Figure 2-22 TRANSPONDER INPUT PULSE AMPLITUDE DIAGRAMS SHOWING UNSUCCESSFUL SLS ACTION AGAINST REFLECTED PATH INTERROGATION



a) Transponder Reply to Reflected Signal Path Interrogation Due to Nonrecognition of Direct Path PL (Side-lobe) Pulse



b) Transponder Reply to Reflection Path Interrogation Due to Path Delay Beyond Duration of Suppression Gate



c) Transponder Reply to Reflected Path Interrogation Due to Path Delay Less Than 2µs.

2 Path arrangements where the reflected pulses are received more than 35 ± 10 us after direct path pulses.

3 Path arrangements where the reflected pulses are received more that 2 us after direct path pulses.

(5) Improved Side-Lobe Suppression (ISLS).

(a) Introduction. Most ATCBI equipments now incorporate an isls system designed to provide additional immunity against the effects of reflected path interrogation. This is accomplished by allowing the omni-directional antenna to transmit the P1 interrogation pulse as well as the P2 control pulse, while the directional antenna transmission is unchanged.

(b) Description of Technique. In a reflected path situation, the isls provides the transponder with considerably higher direct-path P1 pulse amplitude, thus more readily allowing the establishment of a suppression gate in the airborne unit. This effect is illustrated in figure 2-23; it reduces to a considerable degree the condition of unsuccessful sls that could occur when direct path illumination is from a null in the sidelobe pattern as described in subparagraph 23b(4)(d)1 above. The time related sls deficiencies noted are unaffected by the incorporation of isls, however. It should therefore, be noted that several conditions still occur for which the (isls) system is incapable of preventing successful reflected path interrogation, and hence false targets. These include:

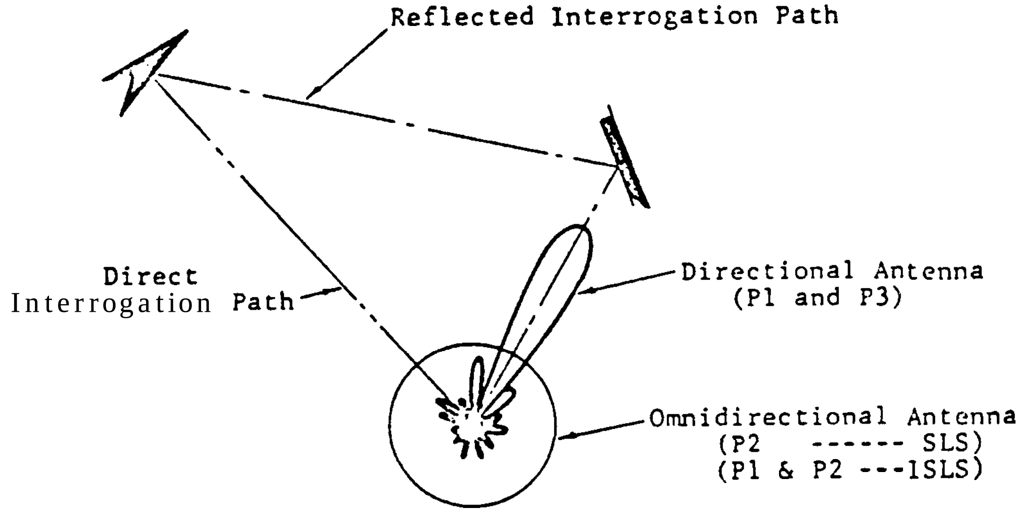
1 Target ranges where direct path omnidirectional antenna energy is below the transponder threshold. This can occur due to blockage effects in addition to range attenuation. Assuming no blockage, the maximum range at which a suppression gate can be generated can be found from figure 2-24.

2 Path arrangements where the reflected pulses are received more than 35 ± 10 us after direct path pulses (i.e., after the termination of a suppression gate). This effect may be determined from figure 2-25, which applies to both sls and isls operation.

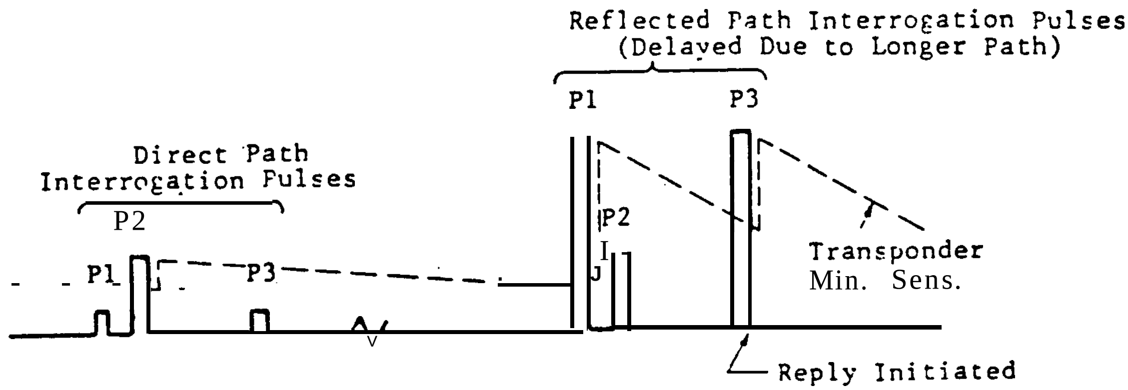
3 Path arrangements where the reflected pulses are received more than 2 us after direct path pulses (i.e., before a suppression gate can be formed). This effect may determined from figure 2-26, which applies to both sls and isls operation.

(c) Undesired Suppression of Replies. While the isls technique has utility in many applications, its use and power level should be carefully weighed since it does increase the incidence of transponder suppression. During the suppression interval, a transponder is unable to respond to any interrogation, thus affecting its ability to reply to other ATCRBS interrogators desiring a reply. As a minimum, however, simple sls should be used to prevent ring-around and fruit caused by side-lobes.

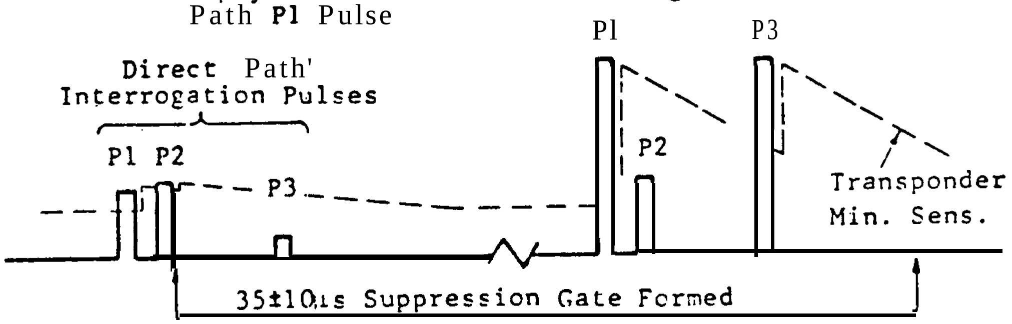
Figure 2-23 ISLS VS. SLS COMPARISON



a) Pictorial



b) Transponder Interrogator with SLS - False-Target Reply Generated Due to Nonrecognition of Direct Path P1 Pulse



c) Transponder Interrogation with ISLS - Increased Input P1 Pulse Amplitude Causes Suppression. No Reply to Reflected Interrogation

Figure 2-24 MAXIMUM ISLS EFFECTIVENESS RANGE

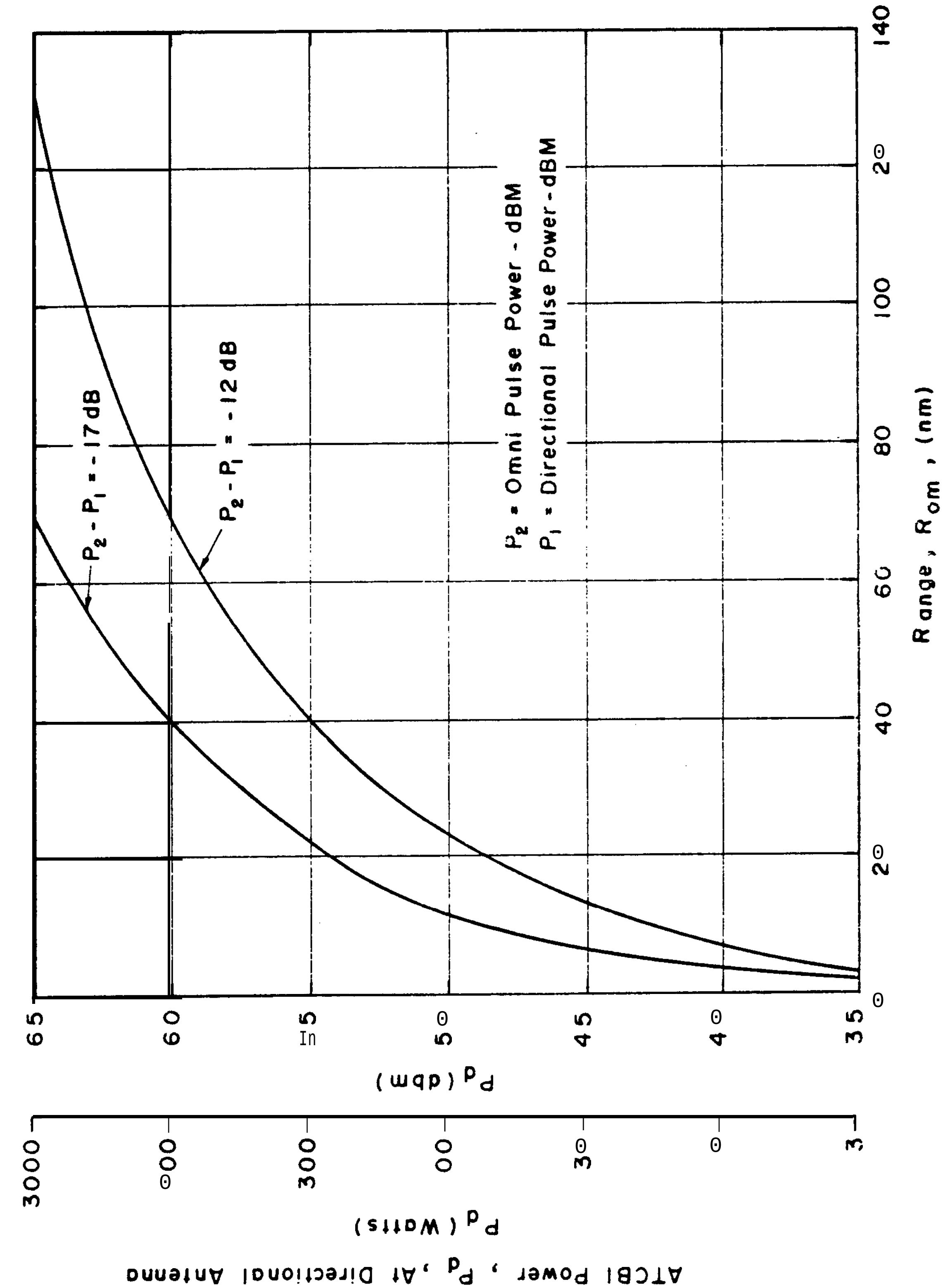


Figure 2-25 LIMITS FOR SLS/ISLS FALSE TARGET SUPPRESSION WITH REFLECTED PATH DELAY < 35 μsec

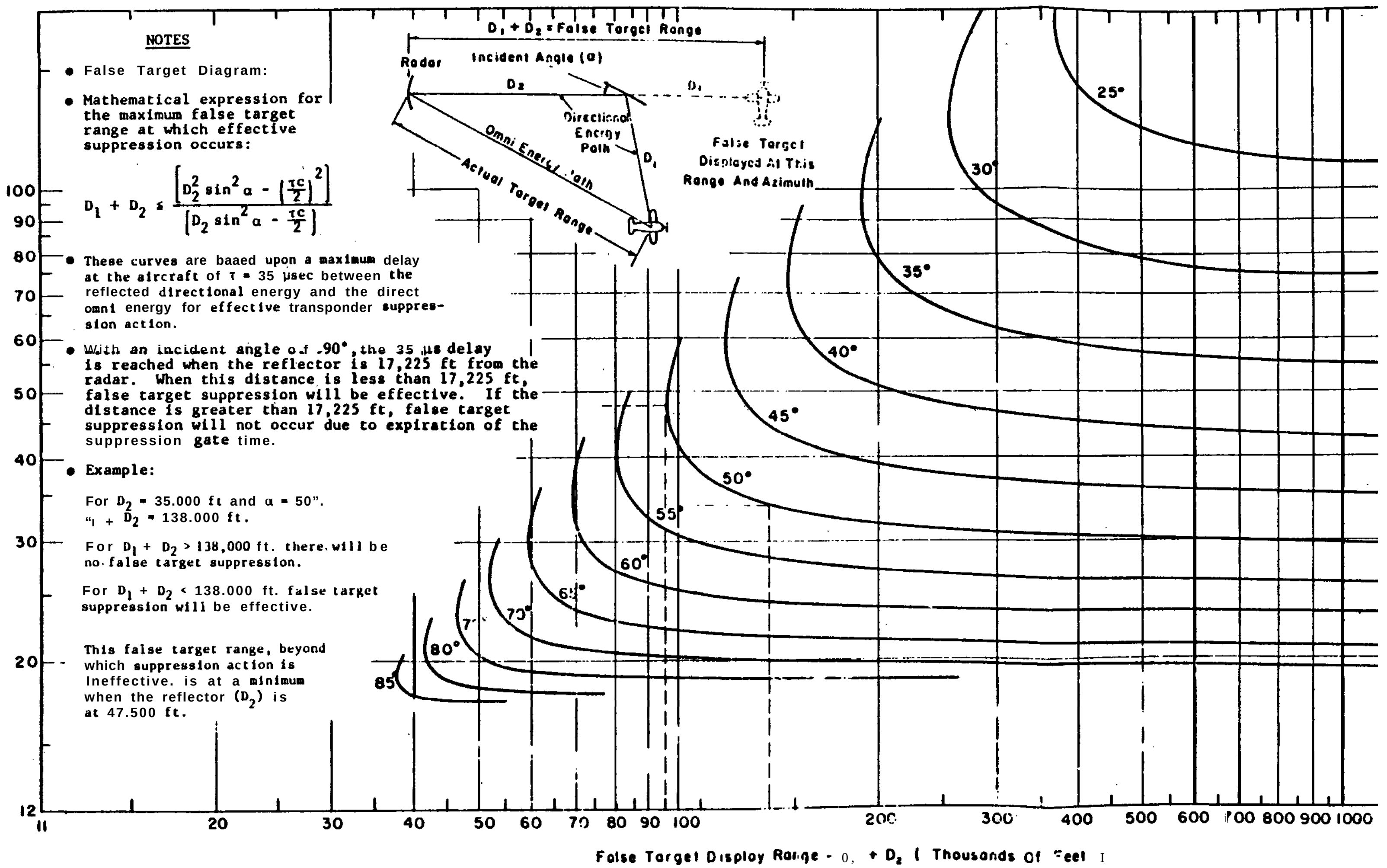
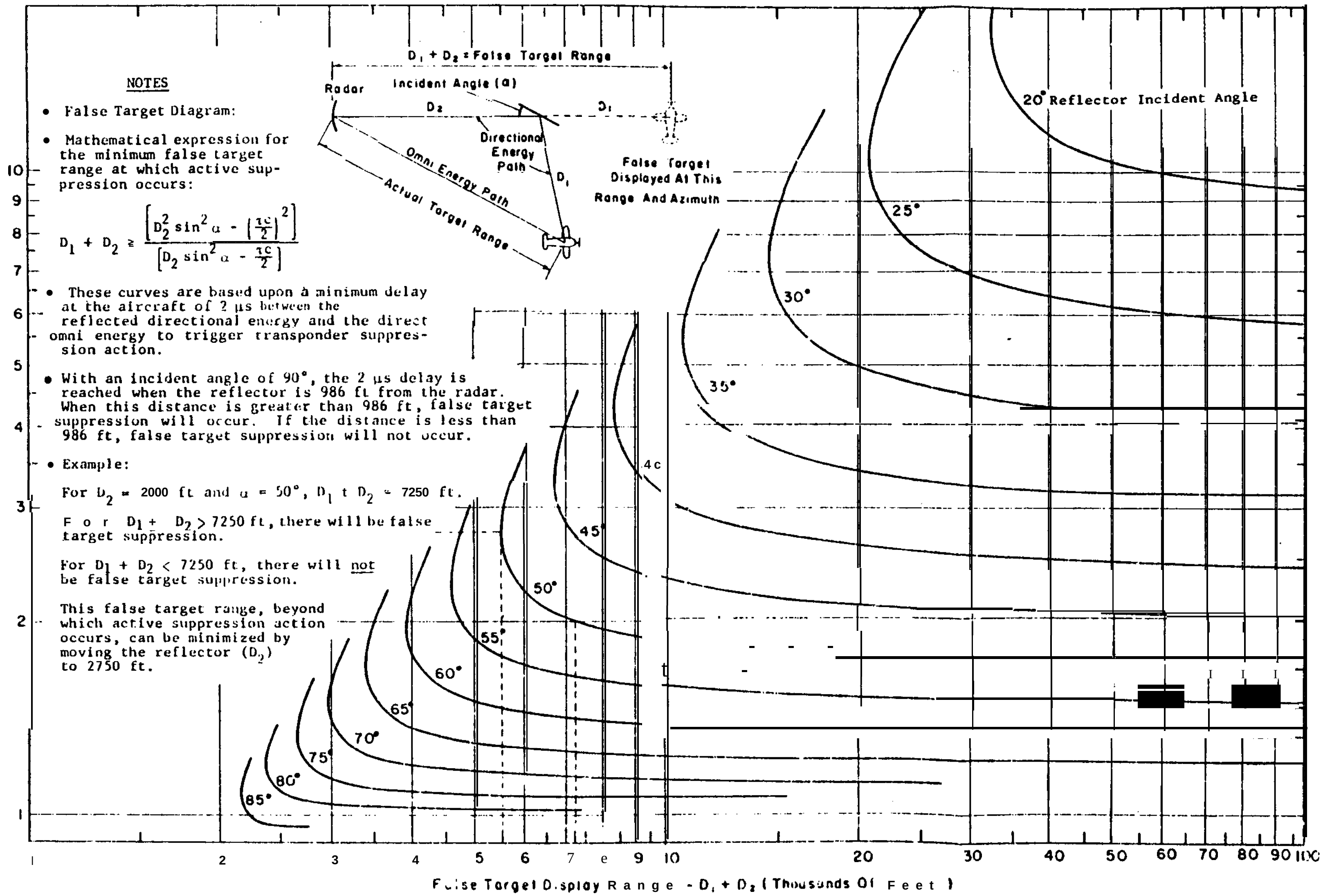


Figure 2-26 SLS / ISLS FALSE TARGET SUPPRESSION CAPABILITIES FOR PATH DELAYS ≤ 2 μSec.



(6) Reply Rate Limiting.

(a) Automatic Overload Control. The radar beacon system may suffer from the effects of **over-interrogation on the single transmission frequency.** An airborne transponder may be within line of sight of many ground stations and hence will receive many interrogations. An automatic overload control (aoc) circuit in the transponder protects the transmitter from overloading and tends to aid the system by reducing reply densities based on signal strength. AOC levels in a transponder are normally set **at 1200 replies** per second. (Transponders used in aircraft which do not operate above 15,000-foot altitude may not be capable of more than 1000 replies/second. In this case, the reply rate limited is set to maximum.) Above this level, the sensitivity is reduced to discriminate against replies from weaker sources. This also discriminates against lower level side-lobes, reflections, and more distant stations.

(b) **Deadtime** Circuit. A **deadtime** circuit is used in **the transponder** to eliminate the effect of transmitting overlapped codes in response to more than one interrogator; afterreceipt of a validmode interrogation pair, the transponder is disabled until the reply code is transmitted, A second reply cannot be initiated until the **deadtime** gate is terminated. Transponder **deadtime** includes the duration of the coded reply transmission, plus an additional period of not more than 125 µs. The probability of success, P_a, for a particular interrogator to elicit a reply is given by

$$P_a = \left[e^{(f_{sls}T_s)} + f_i T \right]^{-1}$$

where f_{sls} = **sidelobe** interrogation rate from all other stations

T_s = sls suppression gate duration (35 ± 10 µs)

f_i = interrogation rate of all other stations

T = transponder deadtime.

c. Receiver Characteristics, The ATCBI receiver detects the signals generated by a "visible" airborne transponder in response to any and all interrogatorsin thevicinity. Itemploys thespecial techniquesof sensitivity time control and video defruiting to improve operations. These are discussed below.

(1) Sensitivity Time Control (STC). The stc feature is incorporated into ATCBI equipment for somewhat the same reason as is done in an ARSR **system,** namely, control of the receiver operating **characteristic.** For beaconoperation, the received power from a given transponder will vary inversely **with the** square of transponder range. An ATCBI receiver stc characteristic, therefore, which compensates for this variation will tend to reduce the visibility of reflected

path and side-lobe replies, and of other unwanted inputs, without impairing the detectability of legitimate beacon targets. STC adjustments are made by reducing receiver gain by 10-50 dB (below maximum sensitivity) at 15.36 µs after the leading edge of pulse P3. Gain is then allowed to recover at a suitable rate, the R^{-2} rate being standard for FAA facilities.

(2) Video Defruiting. The ATCBI video defruiter greatly reduces the amount of nonsynchronous interference which can appear in an output display. This is done through filtering of the raw video pulses at the output and passing only those pulses whose prf is the same as that of the interrogator to which it is connected. Asynchronous replies resulting from interrogations by other ATCBI equipment, second-time-around echoes (with jittered prf), interference pulses, etc., are rejected by the defruiting equipment while the legitimate synchronous replies are allowed to pass on to display units unimpeded.

SECTION 4. ANCILLARY EQUIPMENT

24. TRANSMITTER/RECEIVER BUILDING. The ARSR and ATCBI transmitters and receivers will be housed in a pre-fabricated metal building assembled on site. The building will also accommodate an administration area and, for joint FAA/USAF sites, a Joint Surveillance System (JSS) annex. Figure 2-27 shows the ARSR-3 site layout. Building design details and standard site layout drawings should be available at all FAA Regional Offices. Site layout for the ARSR-3 is shown in FAA drawings.

25. RADAR TOWER. The radar and ATCBI antennas are mounted on a steel tower whose height is selected for optimum radar performance. The basic tower height is 25 feet; this can be increased by installing up to four 12½-foot sections, providing a maximum tower height of 75 feet. The ARSR-3 antenna feedhom is approximately 12 feet above the tower platform, and the ATCBI omni antenna is mounted approximately 35 feet above the platform. The antennas are enclosed in a rigid radome 57½ feet in diameter.

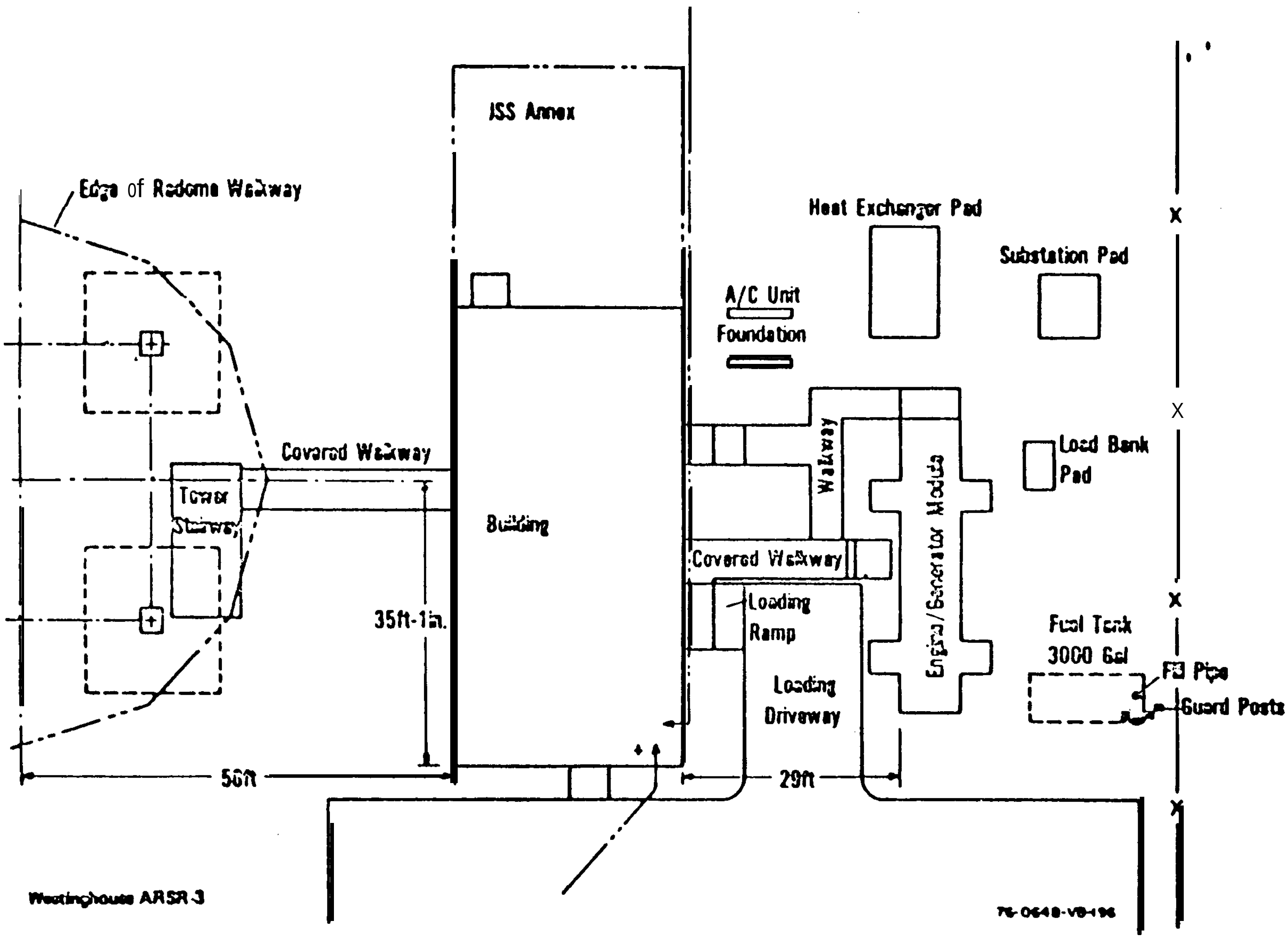
26. ELECTRICAL POWER FACILITIES. The ARSR equipment operates from a three-phase, four-wire 60-HZ source of 120/208 volts. As shown in figure 2-27, a transformer substation will normally be installed on site to provide this power from the commercial source. An auxiliary power source, -an engine-generator housed in a small prefabricated building, provides power in the event of failure of the commercial power.

27. REMOTING EQUIPMENT.

a. Leased Data Line. As discussed above, the broadband radar and beacon target data are converted to narrow-band signals suitable for transmission over data lines which can be leased from the telephone company, if available. This is the normal mode of data remoting from ARSR-3 sites.

b. Radar Microwave Link (RML). Where use of telephone company leased lines is not possible, a radar microwave link is required. In such a situation,

Figure 2-27 ARSR-3 SITE LAYOUT



the radar siting operation should include siting of the necessary RML equipment. The cost of necessary RML equipment should also be included in siting estimates.

28. HEIGHT-FINDER RADAR. At ARSR sites designated as JSS sites, an Air Force height finder radar will be co-sited with the ARSR equipment. In such cases the consideration of siting plans should be coordinated with appropriate Air Force siting personnel to assure satisfactory siting of both the ARSR and the height finder equipments.

29. ELECTRICAL GROUNDING SYSTEM. Both the lightning protection system and the neutral wire of the electrical power system require low-resistance connections to earth. The resistance depends on the extent of the electrical grounding rods and the buried wire counterpoise, as well as upon the resistivity of the soil. Exceptionally dry or rocky soil can cause large values of earth resistivity, and therefore require a more extensive and costly grounding system in order to achieve the desired low resistance to earth. For this reason, earth resistivity measurements should be made as part of every site evaluation.

30. RESERVED.

CHAPTER 3. ARSR AND ATCRBS SITING CRITERIA

SECTION 1. INTRODUCTION

31. INTRODUCTION

a. Siting Requirements. The primary requirement when siting ARSR and ATCRBS facilities is to provide the radar and interrogator coverage necessary to enable effective monitoring/tracking of aircraft in the enroute airspace. In the site selection process, a number of factors must be consideredin order to recommend the most suitable site. These may be grouped into the major categories of (1) coverage and facility requirements, (2) ARSR-3 and ATCRBS coverage capabilities, (3) operational limitations, and (4) installation requirements and limitations. Assumption is made that the number of sites required for most efficient provision of required coverage was determined at an earlier planning and budgeting phase.

b. Siting Responsibilities and Approvals. Operational requirements are the responsibility of the region in which the site is located, but coordination with all affected jurisdictions must be carried out where joint use sites or sites across regional boundaries are involved. Procedures, responsibilities and.approvals required are specified in Order 6300.5, Enroute Radar And Beacon Siting Procedures, Responsibilities, And Approvals.

c. Site Selection Process. The coverage requirements, basic facility requirements, and the coverage capabilities of the ARSR and ATCRBS equipment form the basis for selection of a few possible sites. This choice is further narrowed by considering the various physical restrictions such as land availability, cost, logistic support, etc. The effect of the site on operational radar performance must then be considered for each of the remaining sites. Generally speaking, all sites will have some operational disadvantages in terms of either reduced coverage or performance degradation. Therefore, a final choice is made on the basis of determining an optimum combination of adequate coverage (i.e., minimized degradation), reliability of service (readily accessible for maintenance and repair), and reasonable cost (including acquisition, construction and life-cycle maintenance). The purpose of this chapter is to discuss, in detail, factors comprising each of the above four categories.

SECTION 2. COVERAGE FACTORS AND FACILITY REQUIREMENTS

32. GENERAL

a. Coverage Requirements. Specific coverage requirements relative to the enroute sectors being served are obtained from the regional Air Traffic division. These requiements, which are the same for ARSR and the ATCRBS, will usually be specified in terms of:

(1) Navigational fixes within the enroute airspace,
(2) Air routes between fixes and expected variations,
(3) Handoff or transition points beyond outer fixes, and
(4) Aircraft type/maneuvers/ground speed.

b. Additional Considerations. Ideally, the site selected should be such that all specified fixes and-route corridors are operationally visible to both the ARSR and ATCRRS. However, it should be pointed out that this will not always be possible, in which event a satisfactory compromise must be worked out with the ATD personnel. The important coverage factors and facility requirements which must be considered in siting are discussed in the following paragraphs.

33. COVERAGE FACTORS.

a. Navigational Fixes. Navigational fixes are usually specified in terms of the minimum instrument mean sea level (msl) coverage altitude, and the geographical coordinates of their projected location on an area map. These three-dimensional coordinates of fixes are usually identified by air route intersections, VOR stations, important landmarks, and handoff points between terminal and enroute controllers. For en route radar/beacon systems, these fixes must be located within a 200nmiradiusand within the radar line-of-sight from the selected site.

b. Air Route Coverage, Radar coverage data includes the routes which will be flown between the specified navigational fixes for all types of controlled traffic. Coverage of the jet routes and airways beyond the outer fixes should be obtained so that the controllers will have maximum opportunity to identify aircraft prior to effecting hand-offs to or from other ARTCC's.

c. Minimum Enroute Altitude (MEA). Radar and beacon coverage must be provided for altitudes at and above the mea established for each air route within the required coverage area. If ARSR siting conditions do not allow coverage for altitudes at and above the published mea along some portion of a route, it is possible that revision of the published mea will be required. Such situations should be closely coordinated with the Air Traffic division.

d. Air-Route Variations.

(1) Causes. Variations in the air traffic routes within the various enroute sectors can generally be expected to produce changes in the coverage requirements and siting criteria for both the ARSR and beacon systems. New tangential course conditions can develop along with further coverage problems due to screening, cone-of-silence limits, lobing, false targets, etc. These route variations can be brought about by any or all of the following:

(a) Changes in weather conditions.

(b) An increase/decrease in traffic density.

(c) New airport construction.

(d) Changes in Federal Aviation Regulations/procedures

(e) Changing socio-legal requirements (e.g., noise control, safety, home tv interference, etc.).

(2) Consideration During Siting. The first item above generally results in a day-to-day change in air traffic routes. These route variations due to weather changes should be included in the coverage requirements specified by ATD prior to initial siting. The remaining items above pertain to relatively long-term or future changes in traffic patterns and can be somewhat uncertain, or altogether unknown. However, wherever possible, attempts should be made to identify plannedor knownchanges of this type and determine their effects on future air route patterns. In this way, some potentially troublesome future problems can be taken into account duringtheinitialsiting effort.

e. Aircraft Type. Theminimumradar target cross section of an aircraft is a very significant factor in determining the maximum range capability of the ARSR. Ingeneral,the smaller the aircraft the smaller will be its radar cross section,thereby limiting the ARSR detection range. Hence, for purposes of siting,it isnecessary to know the smallest type of aircraft to be detected in order to determine if the range between the candidate site location and each navigational fix is within the range capability of the ARSR. Except for unusual situations, this implies that ARSR coverage should be based upon detection of small general aviation and training aircraft which may utilize the controlled airspace. Frequently, a T-33 (2.2 m^2 cross section) is used for coverage calculations.

f. Aircraft Maneuvers. Unusual aircraft maneuvers such as a steep climb or sharp turn are unlikely in enroute airspace. However, if such a maneuver does occur, it can cause a fadeout of the ATCRBS operation due to shielding of the airborne transponder antenna by the vehicle airframe. Hence, as part of the coverage requirements obtained from ATD, care should be taken to identify and locate where sharp turns can occur in the airspace of interest. From this information, airspace where such shielding could result in any long-term ATCRBS fadeout can be identified.

g. Aircraft Ground Speed. The mti circuits of the ARSR are based on the Doppler effect produced by aircraft motion relativeto the ARSR site. To determine this relative motion, the nominal ground speeds of aircraft over each air route designatedin the enroute airspace should be obtained from ATD.

34. ATC FACILITY OPERATIONAL REQUIREMENTS. Certain criteria to be used in the selection of an ARSR/ATCRBS site will be dictated directly or indirectly by other ATC facilities. These criteria and how they relate to particular ATC facilities and/or operations are discussed below.

a. Equipment/Structure Clearance. It is desirable that a minimum separation of 2000 feet be provided between the ARSR/ATCRBS antennas and any above-ground structures or rf-generating equipment that may cause reflections or otherwise interfere with radar or beacon operation, as further described in Par 40.g. Exceptions, of course, occur for equipment necessarily co-sited with the ARSR/ATCRBS, such as the RML equipment, if required, and the height-finder radar, if the site is a JSS site. The relative location and relative height of the ARSR antenna and height-finder antenna should be chosen to assure that neither equipment will obstruct the other in its required coverage.

Particular attention should be given to ARSR coverage of the required navigational fixes and minimumen route altitudes. An additional requirementfor site selection is that the site must be not less than one-half mile from Weather Bureau radars and radiosonde equipment. Violation of the latter criterion requires a Washington waiver.

b. Other Radar/Beacon Facilities.

(1) Overlapping Coverage. Other en route or terminal radar systems operating within a vicinity of 200 miles may provide partial coverage of the en route airspace to be served by the new ARSR/beacon system being sited. The resulting overlap in coverage is useful in establishing handoff or transition zones between other enroute and/or terminal traffic controllers.

(2) Radar Frequency Assignment. The proximity of existing or planned radar installations in the ARSR frequency band must be taken into consideration (reference 15). Official procedures require that the frequencies for all ATC radars be assigned by Regional FAA Frequency Management personnel. They should be consulted early in the site selection process so that factors affecting electromagnetic compatibility can be weighed in the selection,

(3) Beacon Interrogation Rate. Of special concern when adding a beaconinterrogator in an en route area is thepossible increase in interrogation rate that aircraft operating in the terminal airspace can be expected to experience. If this effect is severe,overinterrogation canresult, saturating airborne transponders to the extent that they cannot reliably reply to any interrogator. Areas where such beacon interference is excessive (i.e., over 1000 interrogations per second) are commonly referred to as hot spots. The DOT Transportation System Center (TSC) and the DOD Electromagnetic Compatibility Analysis Center (ECAC) have each developed digital computer techniques which are capable of assessing the impact of adding a beacon interrogator in any location in the continentalunited States. Before siting of an ARSR/ATCRBS, in regions where hot spot problems are suspected, it is advisable that a computeranalysis of the increasedinterrogation rate resultingfrominstallation of a new beacon interrogator in the area be carried out. Arrangements for computer services by ECAC or TSC must be made by written request to the FAA Communications and Surveillance Division, APM-300, Washington, D.C. Pulse repetition frequency (prf) assignments for ATCRBS interrogatorsare coordinated by the FAA Systems Engineering Service, Spectrum Engineering Division. Assignments must take into consideration the overlapping coverage of the ATCRBS to avoid synchronous interference.

SECTION 3. ARSR/ATCRBS COVERAGE CAPABILITIES

35. INTRODUCTION. Basic coverage capabilities of the ARSR and ATCRBS equipment were briefly illustrated in chapter 2. These capabilities are described and illustrated more fully in the following paragraphs. It should be noted, however, that all radar and beacon coverage capabilities presented in this section are determined here for conditions which do not include the modifying effects of such phenomena as screening, vertical lobing, ground clutter, false targets, etc. The lattereffects, whichusually degradecoverage, are considered

in section 4 of this chapter. All of these effects should receive consideration when assessing **ARSR/ATCRBS** coverage capabilities from a particular site location.

36. ARSR COVERAGE

a. Coverage capability for ARSR system has been determined utilizing the methodology presented in reference 5. The maximum range, R, at which a target can be detected is given in nautical miles by the expression:

$$R = 129.2\left[\frac{P_t \tau G_t G_r \sigma}{f^2 T_s (s/n) C_B L}\right]^{1/4} \quad (3\text{-}1)$$

where P_t = peak power transmitted (in kW)

τ = pulse duration (in μs)

G_t = transmitting antenna gain in the target direction

G_r = receiving antenna gain in the target direction

σ = target radar cross section (in square meters)

f = radar frequency (in MHz)

T_s = system noise temperature in ^oK)

s/n = signal-to-noise power ratio

C_B = bandwidth correction factor

L = system loss factor.

P_t, τ, G_t, G_r, and f are determined directly from table 2-1 and the system antenna patterns. Comoutations performed here for the ARSR-3 use antenna pattern data shown in figures 2-2 and 2-3.

b. System input noise temperature, T_s, takes into account noise from the antenna, from the receiving transmission line, and from the receiver (the effect of receiver noise figure), and also the effect of the loss factor of the receiving transmission line. Since the transmission line losses and the noise figures are different for the upper beam and lower beam receivers, their values of T_s differ slightly, The values used here for the ARSR-3 are 627 degrees for the upper beam, and 727 degrees for the lower beam, as given in reference 6.

c. The **signal-to-noise** (s/n) ratio is the required single-pulse s/n for acceptable target detectability considering the number of radar pulses per beamwidth (hits/scan), the fading characteristics of the target, and the false alarm probability. For the ARSR-3 operating in the frequency diplex mode (two channels with frequencies greater than 25 MHz apart), the signal fading follows the Swerling detection model for case III target fluctuation. For this case, and with a 0.8 probability of detection, 10^{-6} false alarm probability, and 25 hits/scan, the required s/n is 5.2 dB.

d. The bandwidth correction factor, C_B, represents any signal loss due to a non-optimum receiver passband characteristic relative to the transmitted pulse. It is assumed that no mismatch occurs, so that CB = 1 (reference 10).

e. System loss factor, L, accounts for antenna pattern beamshape loss, transmitter transmission line loss, and the atmospheric absorption loss. The atmospheric absorption loss depends on target elevation angle and range. For the ARSR-3 frequency of 1250 to 1350 MHz, the absorption loss can vary from a negligible value at short range and high angle up to 2 dB at long range and low angle. The other loss factors are assumed to total 3 dB, for the ARSR-3.

f. The radar cross section, σ, used in computation was selectedto cover virtually all targets of interest to siting engineers. Values usedarelabeled in dB on theplotted results, to correspondwiththoseindicated in table 3-1.

g. Computed radar coverage for the ARSR-3 is shown in figures 3-1 and 3-2. The diagrams shown assume linear polarization and an antenna tilt angle (-3 dB point on bottom side of lower beam) of 0 degrees. These coverage plots include the effect of atmospheric absorption, but not the effects of terrain for example, screening and vertical lobing). With circular polarization the maximum detection range will be approximately 75 percent of the maximum range with linear polarization. This results from an approximate 5 dB reduction in targetcross sectionfor circularpolarization (reference 2). Site-related factors causing degraded radar performance are discussed in section 4.

37. ATCBI COVERAGE.

a. Limiting Factor. Of the two links in ATCBI operation, the interrogation link and the reply link, the interrogation link is generally the factor which limits beacon system maximum range. This means that if the interrogation is successful, successful reply may be expected. If the maximum interrogator output power is transmitted, the range of the interrogation link, and therefore of the ATCBI system, far exceeds the maximum instrumented range of the ARSR-3 (200 nmi) and can lead to interrogation of aircraft far outside the desired coverage region, resulting in extraneous second-time-around echoes. In order to prevent such undesired interrogation and limit the errors and equipment saturation which could result, the interrogator transmitter power is correspondingly reduced.

b. Maximum Interrogation Range. The maximum range for successful interrogation of the transponder is given by:

$$R = \frac{\lambda_i}{4\pi(1852)} \sqrt{\frac{P_{oi}\ G_i\ T_t}{S_{min,t}\ L_t\ L_\alpha}} \qquad (3-2)$$

Table 3-1

TYPICAL AIRCRAFT AVERAGE CROSS SECTION
(Linear Polarization)

Aircraft Type	Radar Cross Section Sq.meters	Radar Cross Section dB, rel to 2.2 m^2
Military		
B-52	21.9	10
C-47	11	7
C-54	27.5	11
C-97	69.3	15
C-121	21.9	10
C-135	13.8	8
F-84	2.2	0
F-86	2.8	1
F-100	3.5	2
F-104	2.8	1
F-106	4.4	3
F-4	2.8	1
T-33	2.2	0
Commercial		
DC-3	12.6	7.5
DC-4	31.6	11.5
DC-6A	50	13.5
DC-7	63	14.5
DC-8	25	10.6
F-27, F-27A, F-27B, F27J	16	8.5
Boeing707 (300Series)	20	9.6
Boeing 720	16	8.5
Boeing 727 (all)	16	8.5
Boeing 737 (100 & 200	10	6.5
Boeing 747	63	14.5

Aircraft Type	Radar Cross Section Sq.meters	Radar Cross Section dB, rel to 2.2 m^2
Commercial (Cont.)		
DC-10	25	10.6
Convair 440	25	10.5
Convair 880	15.8	8.5
Convair 990	20	9.6
Lockheed 1049G	79	15.5
Lockheed Electra	50	13.5
Martin 202	20	9.6
DC-9	10	6.5
General Aviation		
Aero Cmdr (twin engine)	3.2	1.6
Beech Baron D-55	2	- 0.4
Beech Bonanza	.8	- 4.4
Lear Jet	2	- 0.4
Lockheed 1329 Jetsta	4.0	2.6
Cessna 336 Skymaster	1.3	- 2.4
Aero Jet Commander	2.5	0.6
Sabreliner	3.2	1.6
Grumman Goose	4.0	2.6
Grumman Gulfstream	6.3	4.5

FIGURE 3-1 ARSR - 3 RANGE COVERAGE, LOWER BEAM RECEPTION

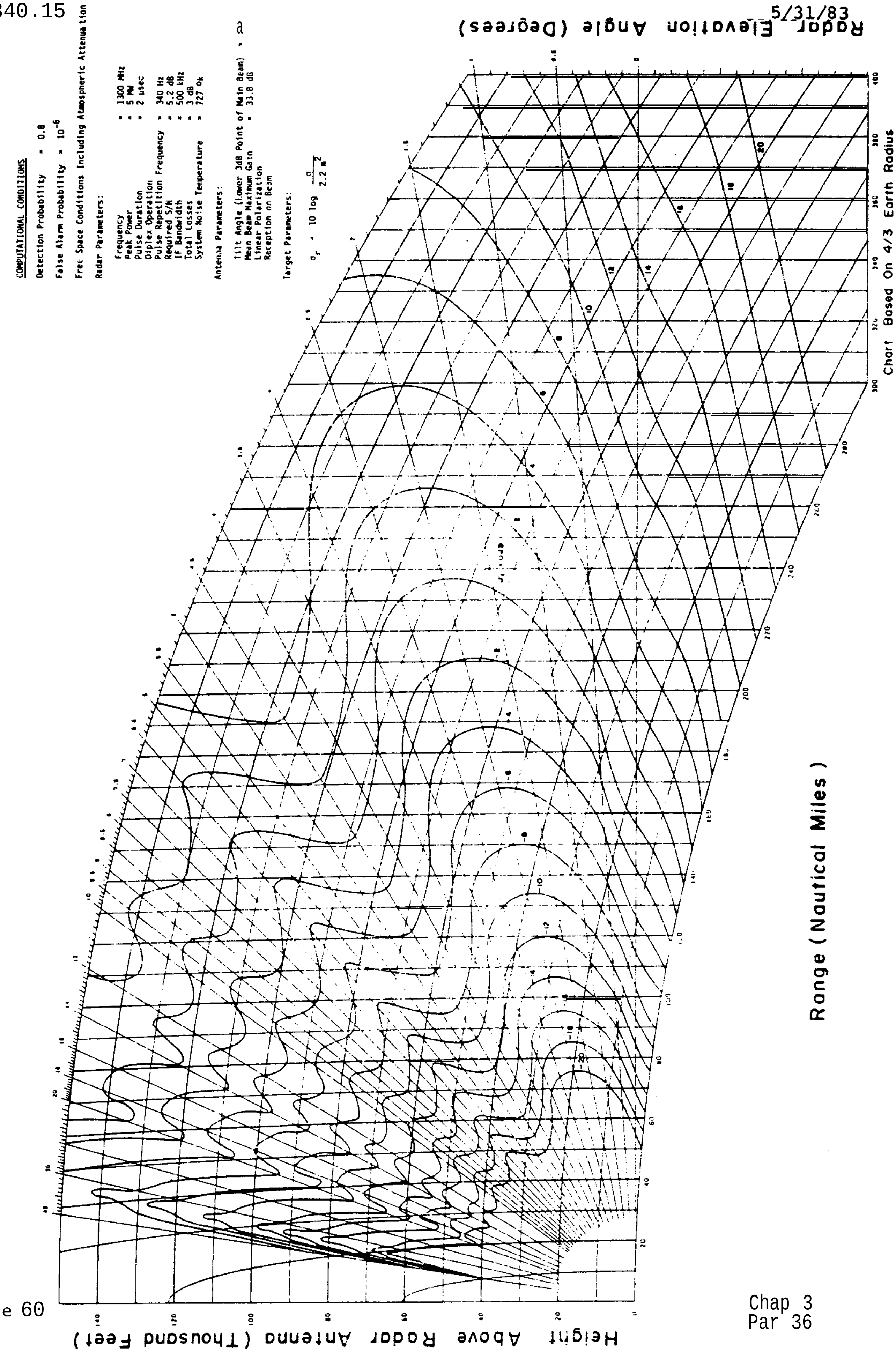
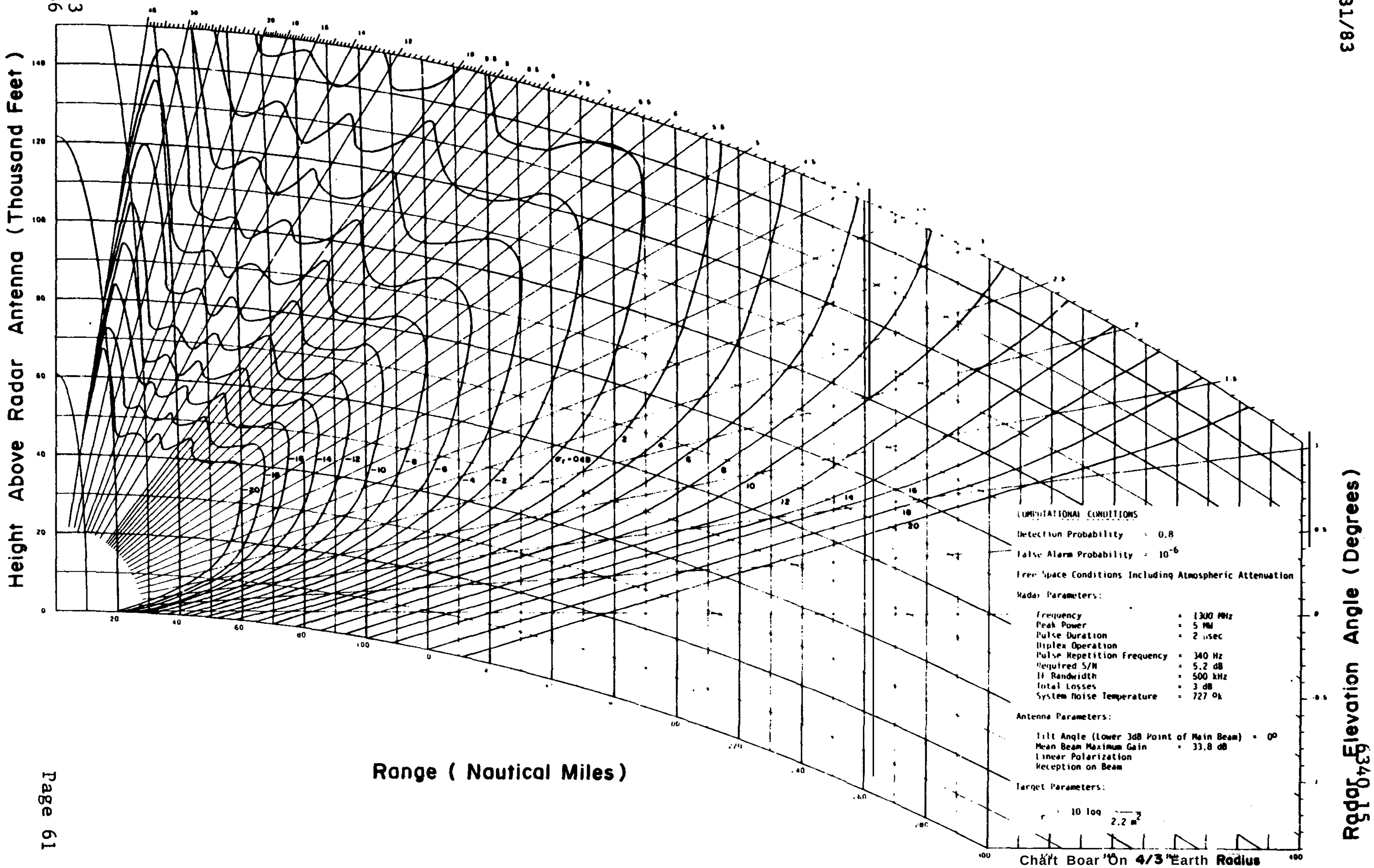


FIGURE 3-2 ARSR-3 RANGE COVERAGE, UPPER BEAM RECEPTION



where

R = maximum interrogation range in nautical miles

P_{Oi} = ATCBI output peak power (at antenna input) in watts

$S_{min,t}$ = transponder minimum sensitivity in watts

G_i = interrogator antenna gain in direction of target

G_t = transponder antenna gain in direction of radar site

L_t = transponder losses (cables and connectors, ≃ 5.5 dB)

λ_i = interrogation wavelength (a.291 meters)

L_α = atmospheric absorption loss.

c. Parameter Values. For purposes of calculation it is assumed that:

(1) G_i varies substantially as shown in figure 2-12 for the ATCBI-5, with a maximum antenna gain of + 31 dBir (1259 x isotropic gain).

(3) $G_t = L_t$.

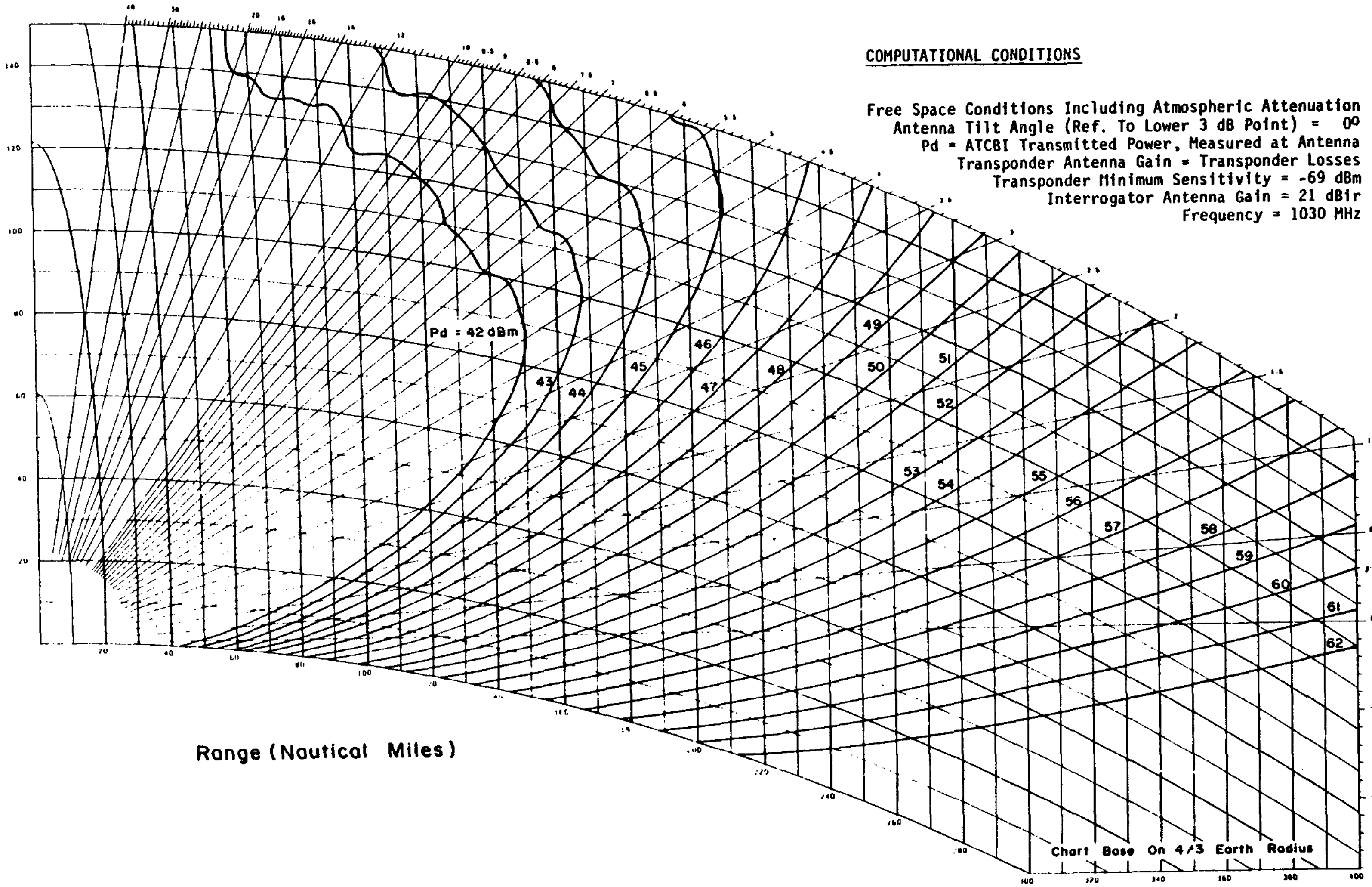
(3) $S_{min,t}$ = -69 dBm (1.26 x 10^{-10} watts). This corresponds to a low sensitivity transponder and provides a conservative computed result.

d. Computed Beacon Coverage. Maximum ATCBI range is plotted in figure 3-3 with Poi as a parameter. The coverage determined here includes the effect of atmospheric absorption loss (1 dB maximum), but does not include terrain effects such as screening or vertical lobing. These effects must be included, however, when establishing a radar site; procedures for doing so are discussed in the following section.

SECTION 4. OPERATIONAL LIMITATIONS

38. INTRODUCTION. In any installation, the free-space theoretical radar and beacon coverage is affected, usually adversely, by the operational environment. The local terrain features can produce radar screening, vertical lobing, ground clutter, and false targets, In addition, coverage may be degraded generally by the effects of precipitation and interference, and in specific areas due to tangential courses. Each of these effects is important and must be carefully considered at the time of siting. These effects and their sources are discussed in the following paragraphs.

FIGURE 3-3 ATCB I-S RANGE COVERAGE CAPABILITY



39. DEGRADED PERFORMANCE EFFECTS.

a. Screening.

(1) Within the range and scan limits of the radar/beacon system there exists regions of ground terrain.and navigable airspace which are not illuminated by the radar or beacon system. Those regions are created by the screening or shadow effects of ground terrain features and/or any of a variety of man-made structures about the ARSR/ATCRBS site. For purposes of ARSR/ATCRBS siting, two types of screening are of interest. One concerns the screening of portions of the navigable air-space where aircraft may be present but remain undetected. The other involves the deliberate use of screening to shield ground, terrain, structures, roads, etc., from the ARSR/-beacon illumination. The latter is very important as a technique for reducing, if not eliminating, many of the operational shortcomings, (i.e., clutter, lobing, false targets, etc.) of the ARSR ATCRBS produced by reflections from ground terrain, buildings, etc.

(2) The effects produced by screening are determined from geometric considerations only. When the earth is smooth, the curvature of the earth causes the area beyond the horizon to be invisible to the radar beam. as shown in figure 3-4. If there are hills, mountains, cr man-made objects in the radar path above the horizon, the screened area is increased and the radar visibility is reduced, as shown in figure 3-5. On the earth's surface the three principal parameters for determining screen effects are the msi height of the antenna, the msl height of the screen object, and the distance between the antenna and screening object. Frequently, these parameters are combined to determine a screening angle that is used extensively in assessing line-of-sight (los) coverage.

(a) Radar Line-of-Sight.

1 The signal path from the radar antenna to the upper limit of a screening object, whether it be a hill, a structure, or the horizon, is called the radar los. Over the earth's surface, this los path is curved, usually downward, as shown in figure 3-6, due to refraction by the earth's atmosphere. This curved signal path can be considered a straight line, shown in figure 3-7, by replacing the actual radius of the earth, a, by an equivalent earth of radius ka, where k = 4/3 for a standard earth atmosphere. Any change in atmospheric conditions which results in a change in the standard curvature of the radar oath can be accounted for by a change in the value of k.

2 The radar los establishes the maximum theoretical range obtainable at-a given altitude and is used to determine the airspace coverage about the radar/beacon site. This range or cutoff is generaliy measured along the radar los to the intersection with the altitude curve of interest shown in figure 3-5. However, for assessing los coverage about the site location, the projection of this range onto the surface of the earth is preferred. This range projection is indicated in figure 3-5, as tne altitude cutoff distance.

Figure 3-4 CURVED EARTH SCREENING

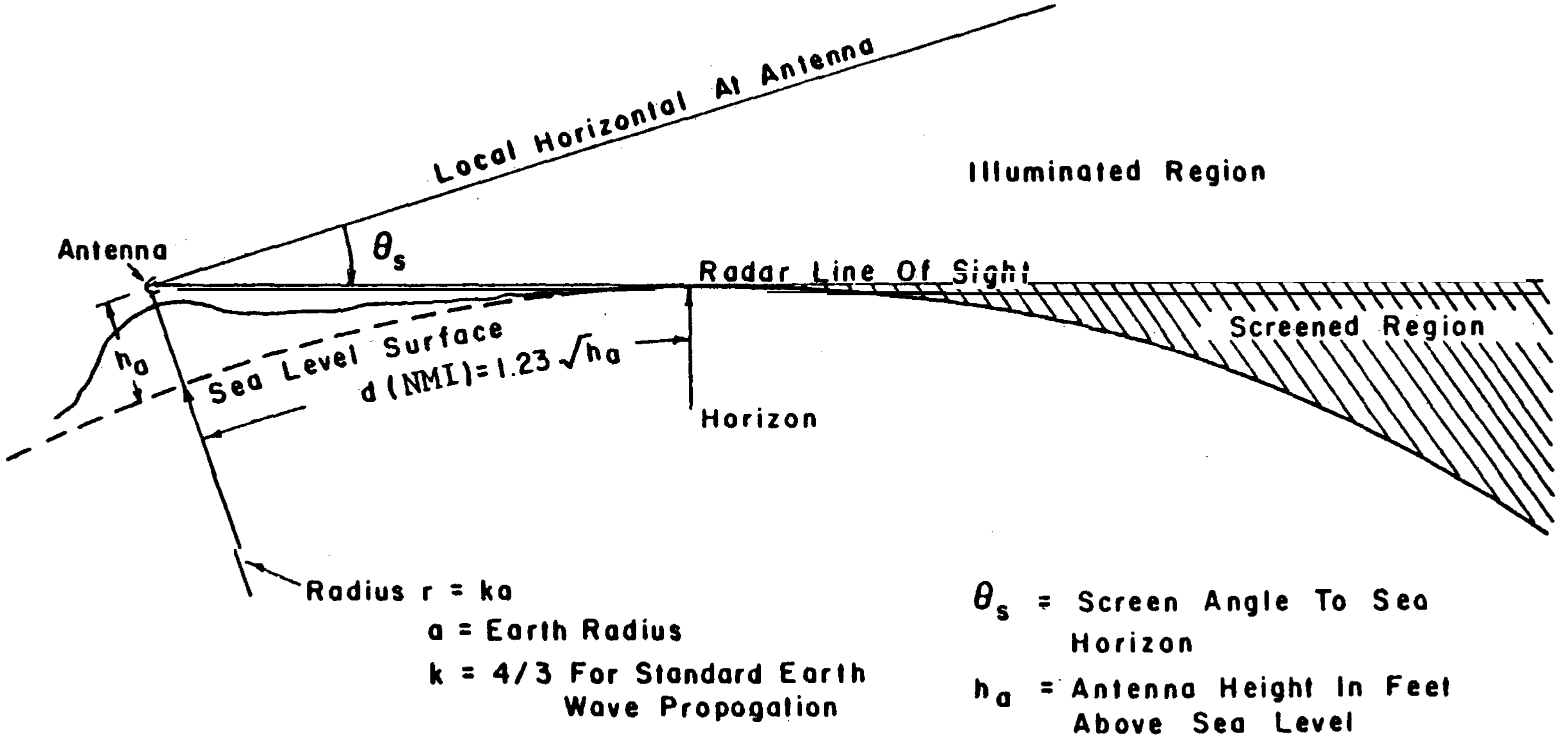


Figure 3-5 OBSTACLE SCREENING

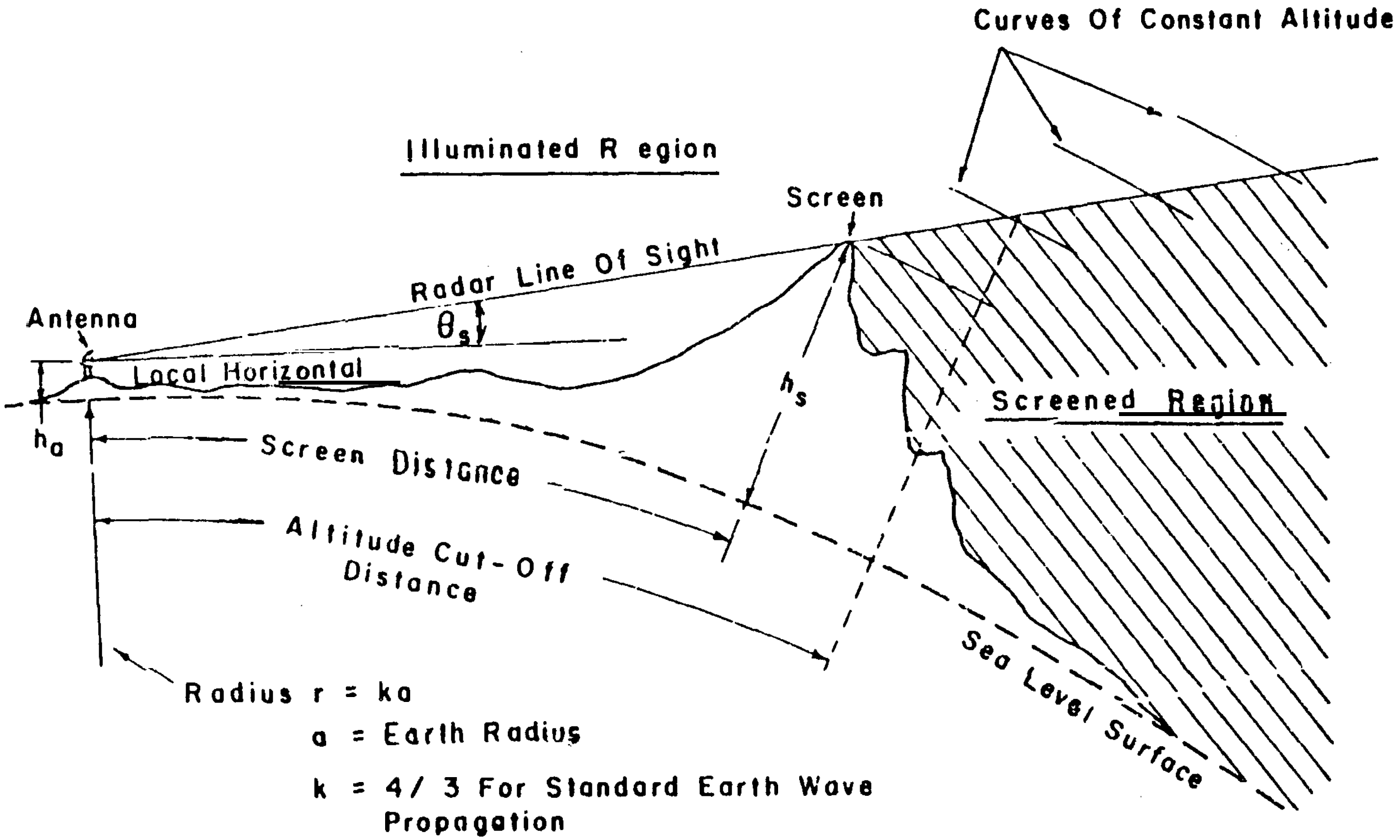


Figure 3-6 BENDING OF ANTENNA BEAM BECAUSE OF REFRACTION (TRUE EARTH RADIUS, a)

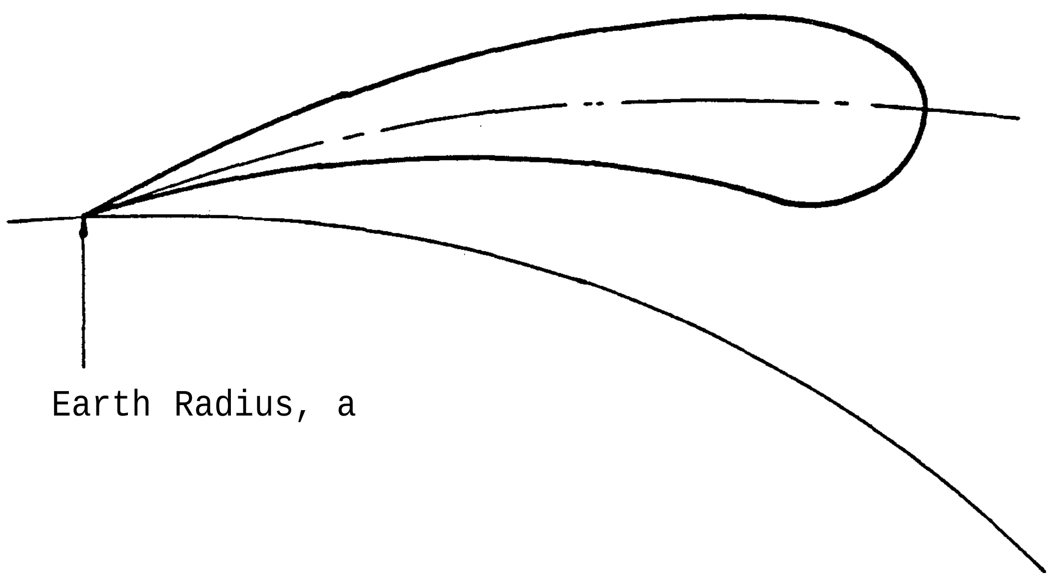
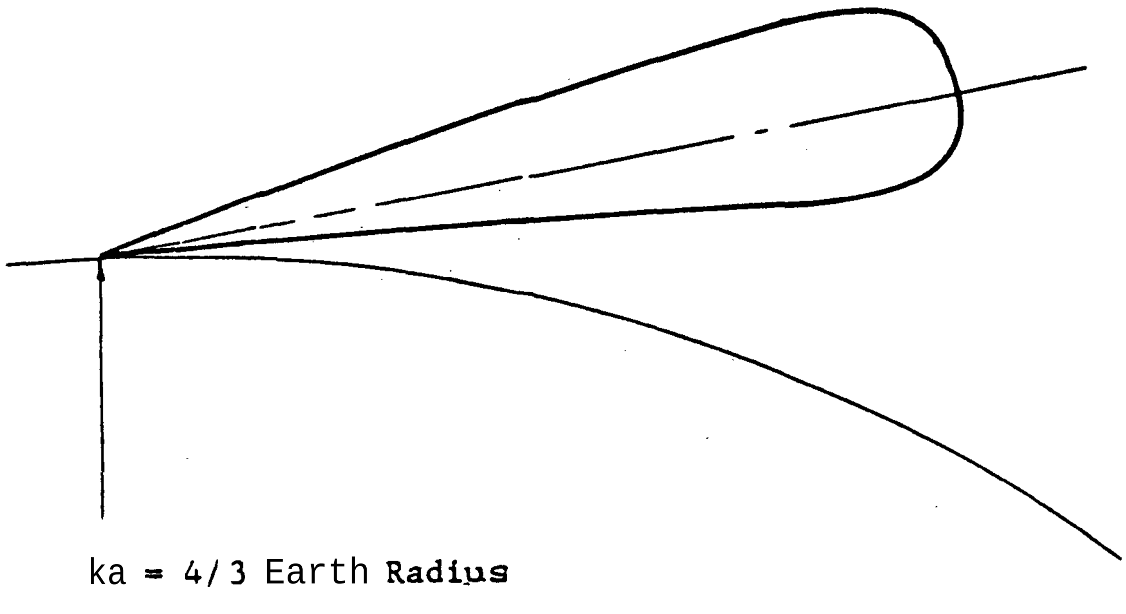


Figure 3-7 SHAPE OF ANTENNA BEAM IN EQUIVALENT-EARTH REPRESENTATION (RADIUS = 4/3 a)



(b) Screening Angle. The amount of screening associated with radar/beacon site can be expressed in terms of the screening angle (θ_s). This is the angle formed by the radar los and the horizontal reference line at the radar antenna as shown in figures 3-4 and 3-5. The angle may be positive or negative depending on the elevation of the antenna site and the range and elevation of the screening object. If the los is above the local horizontal at the radar, then the screening angle is positive.

(c) Curved Earth Screening.

1 As illustrated in figure 3-4, the curvature of the earth causes screening of the airspace beyond the horizon. The range to the sea horizon for a given antenna height is given by the relationship

$$d = 1.0634 \sqrt{kh_a} \qquad (3\text{-}3)$$

where

d = distance in nautical miles to the sea horizon

h_a = antenna height -in feet (msl)

k = equivalent earth radius factor.

2 Comparing the optical los distance, $d_{7/6}$ (for which k = 7/6 to account for-optical refraction), and the radar los distance, $d_{4/3}$ (where k = 4/3 for standard atmosphere), we see that:

$$d_{4/3} = 1.07\, d_{7/6} \qquad (3\text{-}4)$$

3 Hence, because of the bending of the radio waves, the visible radar horizon is extended 7 percent beyond the optical sea horizon. For other values of k, this radar los distance will be proportionally larger or smaller. Figure 3-8 provides a graphical means for determing radar range, d, to the sea horizon as a function of antenna height for several values of k. In this plot, the antenna height is the elevation of the antenna relative to the msl. For a smooth earth where the ground terrain is above sea level, these curves can be used to determine range to the horizon by referring them to the effective antenna height, that is, the height above the elevation of the earth terrain.

(d) Obstacle Screening.

1 The effect of raising the radar los, and thereby increasing the screeing angle, is to reduce the maximum range at which aircraft at a given altitude are visible. This effect is illustrated in figure 3-9. In the figure, the antenna height is at sea level and the maximum range at which the 15,000-foot altitude level is visible for a 0-degree screen angle is 150 nmi. If the radar los is changed to produce a screening angle of +1 degree, the limit for 15,000-foot altitude is reduced to 90 nmi -- a reduction in range of 60 nmi, or 40 percent.

Figure 3-8. LOS DISTANCE VS. ANTENNA HEIGHT

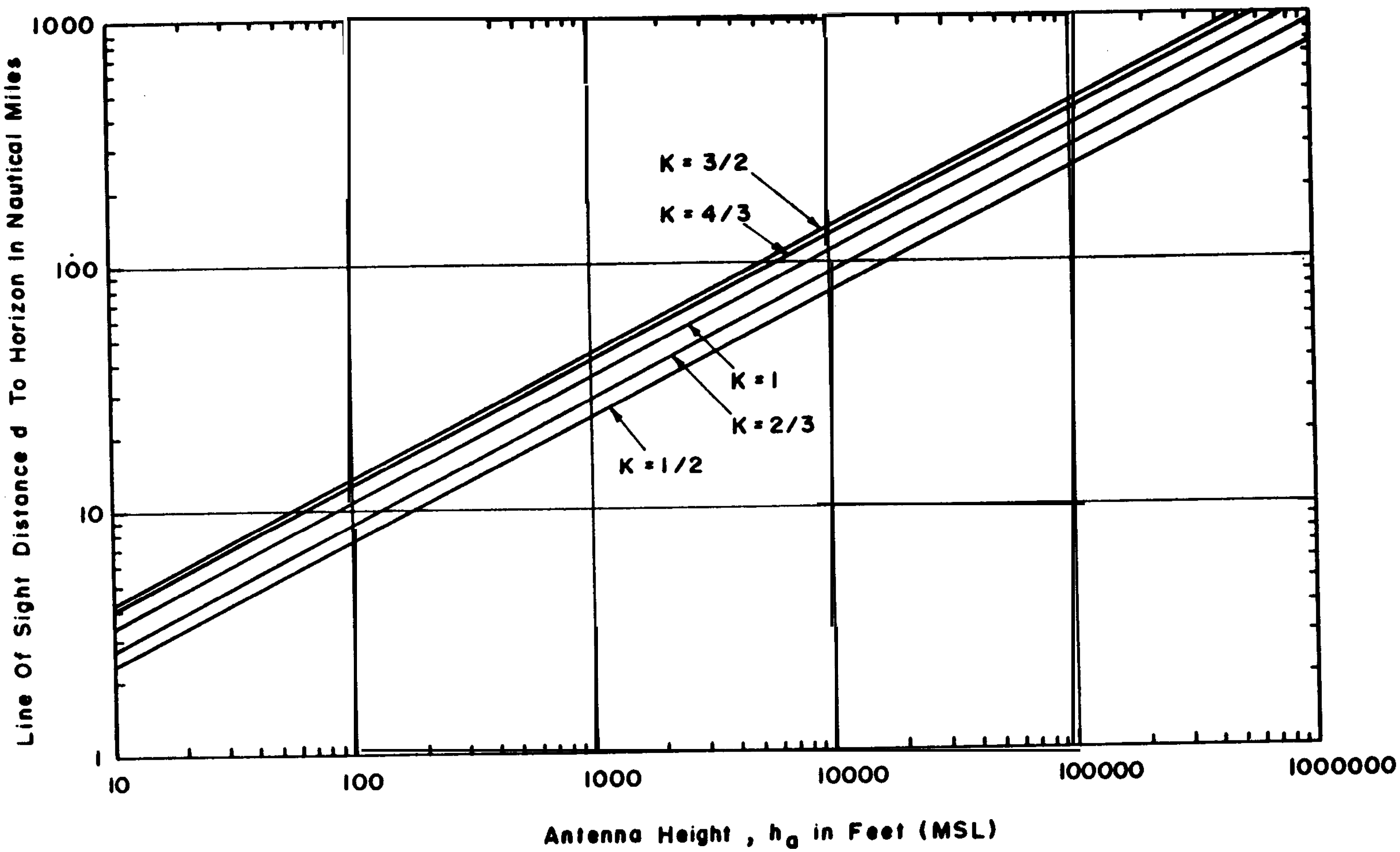
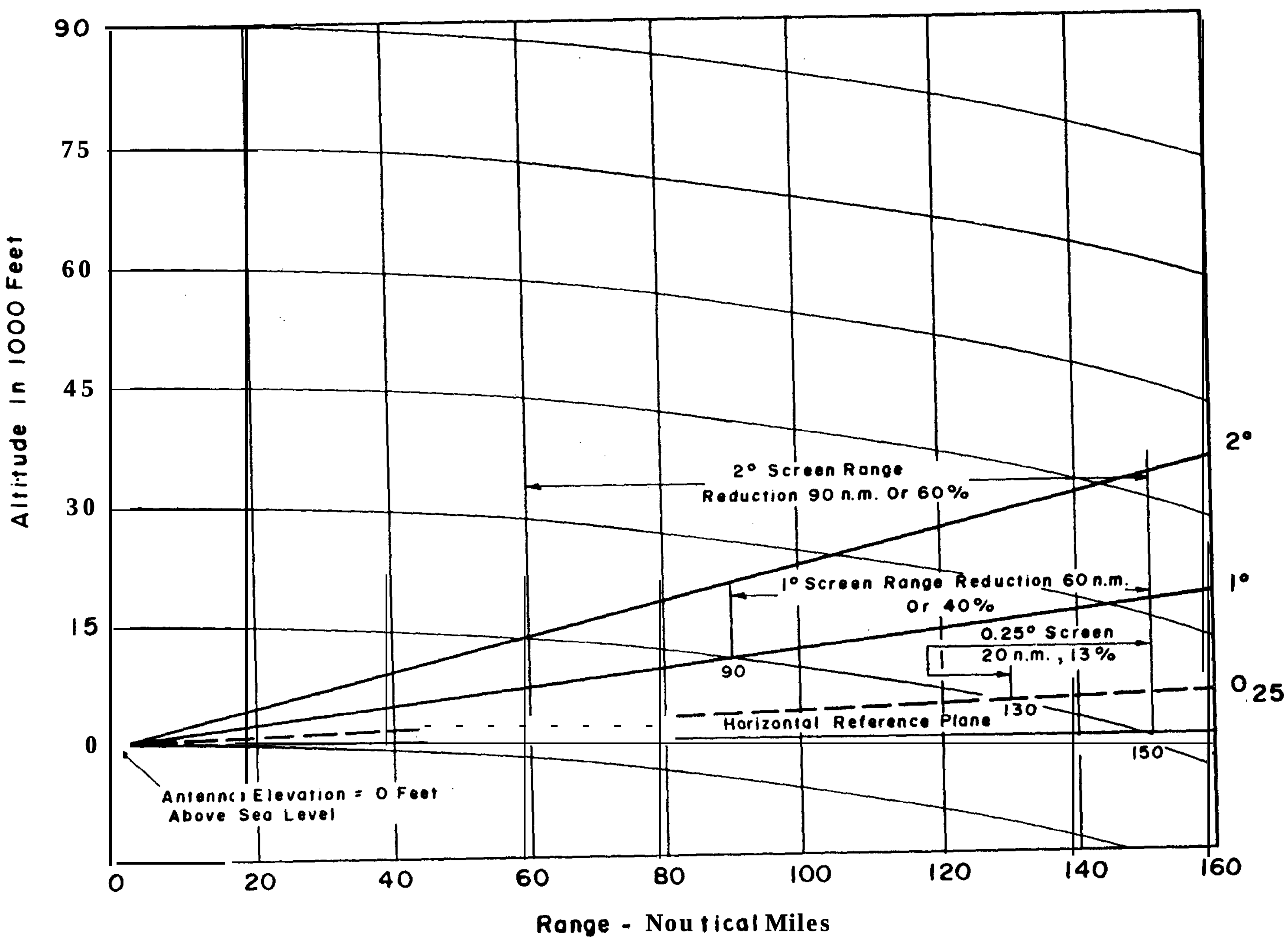


Figure 3-9. SCREENING ANGLE VS. RANGE



2 For the type of obstacle screening depicted in figure 3-5, the los boundary between the illuminated and screened airspace is defined by the following equations (these equations are also the basis for figure 3-9).

$$\tan \theta_s = \frac{h_s - h_a}{6080\, d_s} - \frac{d_s}{6874\, k}, \tag{3-5}$$

which for small angles (i.e., θ_s z 10°) can be written approximately as:

$$\theta_s = \frac{h_s}{106\, d_s} - \frac{h_a}{120\, k} \tag{3-6}$$

where

θ_s = screening angle in degrees above the local horizontal at the radar

h_s = msl elevation of the screening object, or any other desired point, in feet

h_a = msl elevation of the antenna phase center in feet

d_s = ground distance in nautical miles between antenna and screening object

k = equivalent earth radius factor.

3 By inspection, this equation shows that the value of the screen angle, θ_s, depends on the equivalent earth radius factor, k, for a given antenna height, and screening object distance and height. If the value k = 7/6 is used, the angle obtained represents the screen angle established by the optical los to the screening object. If k = 4/3, the value obtained corresponds to the screen angle established by the radar los to the object. Since screening angles are measured optically during site surveys, it is of interest to compare these two angles. If equation 3-6 (above) is solved using k = 7/6, the optical screen angle, θ_{os} is given by:

$$\theta_{os} = \frac{h_s - h_a}{106\, d_s} - \frac{d_s}{140} \tag{3-7}$$

and if k = 4/3, the equivalent radar screen angle, θ_{rs}, is:

$$\theta_{rs} = \frac{h_s - h_a}{106\, d_s} - \frac{d_s}{160} \tag{3-8}$$

which can be written as:

$$\theta_{rs} = \theta_{os} + \frac{d_s}{1120} \quad . \tag{3-9}$$

4 From thisrelationship (which is plotted in figure 3-10), it is seen that the radar screen angle is always more POSITIVE (i.e., higher)than the corresponding optical screen angle, This should not be interpreted, however, to mean that because of this increase in radar los angle the airspace screened from the radar is increased. The airspace screened by the optical los is measured relative to the curved surface of an equivalent 7/6 earth radius, whereas the airspace screened by the radar los is measured relative to the curved surface of an equivalent 4/3 earth radius, Because of this difference in the two curvatures, the screened airspace beneath the radar los is actually less thhn the optically screened area.

5 One consequence of this reduced radar screening region is that it is sometimes possible to get radar returns from objects beyond the screening obstacles that are not visible optically. Also, it is possible for the radar to detect aircraft at altitudes that are below the optical los. This difference in altitude coverage is attributable to the bending of the radar signals through the earth's atmosphere which is accounted for in terms of the equivalent earth radius factor k. Mathematically, this difference in altitude coverage can be expressed by the relationship:

$$h_o - h_r = \frac{0.758\ d\,(d-d_s)(k-7/6)}{k} \tag{3-10}$$

where

h_o = altitude or object height in feet along the optical los

h_r = altitude or object height in feet along the radar los

d_s = ground range to screening object in nautical miles

d = ground range to altitude cut-off in nautical miles, as shown in figure 3-5 ($d > d_s$.)

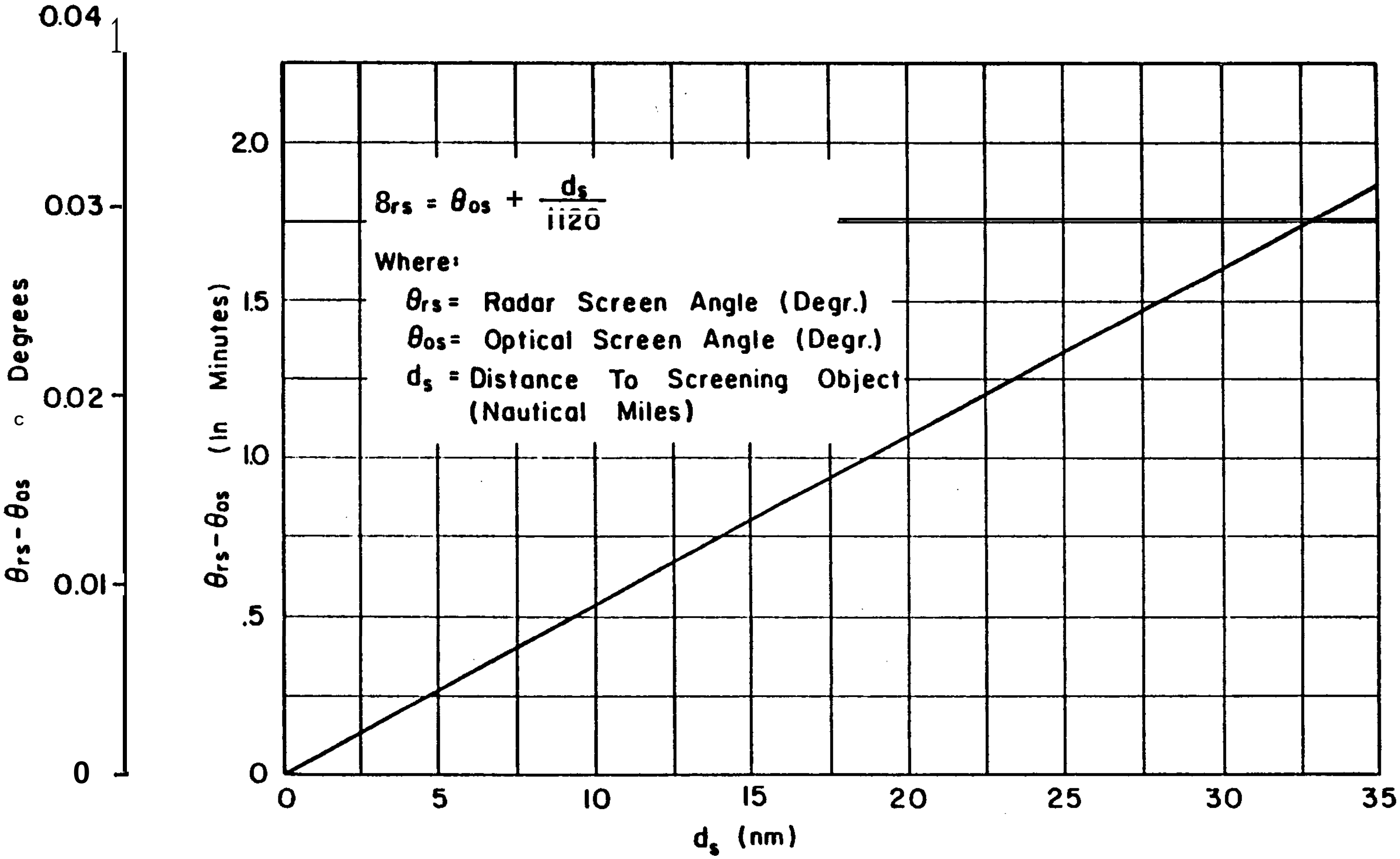
6 As an example, if the distance, d_s, to thescreen object is assumed to be 10 nmi, then the difference between the optical and radar altitudes visible at a cutoff range d - 50 nmi is

$$h_o - h_r = \frac{1516(k-7/6)}{k} \text{ feet} \tag{3-11}$$

which for k = 4/3 is

$$h_o - h_r = 189.5 \text{ feet.}$$

Figure 3-10 RADAR-OPTICAL SCREENING ANGLE CORRECTION



7 This shows that at a range of 50 nmi the altitude coverage for the radar is 189.5 feet below that which is opticaly visible. Hence, if the minimum altitude that is optically visible at 50 nmi is 5000 feet, then the radar can see objects down to (5000-189.5) or 4810.5 feet. Figure 3-11 shows plots of this altitude coverage difference for various screen object distances. As can be seen in these plots, the difference in altitude visibility can be quite substantial, for example, several thousand feet. The difference is more pronounced when the screen objects are close to the radar site. For distant screen objects, the effect is still present; however, not as great.

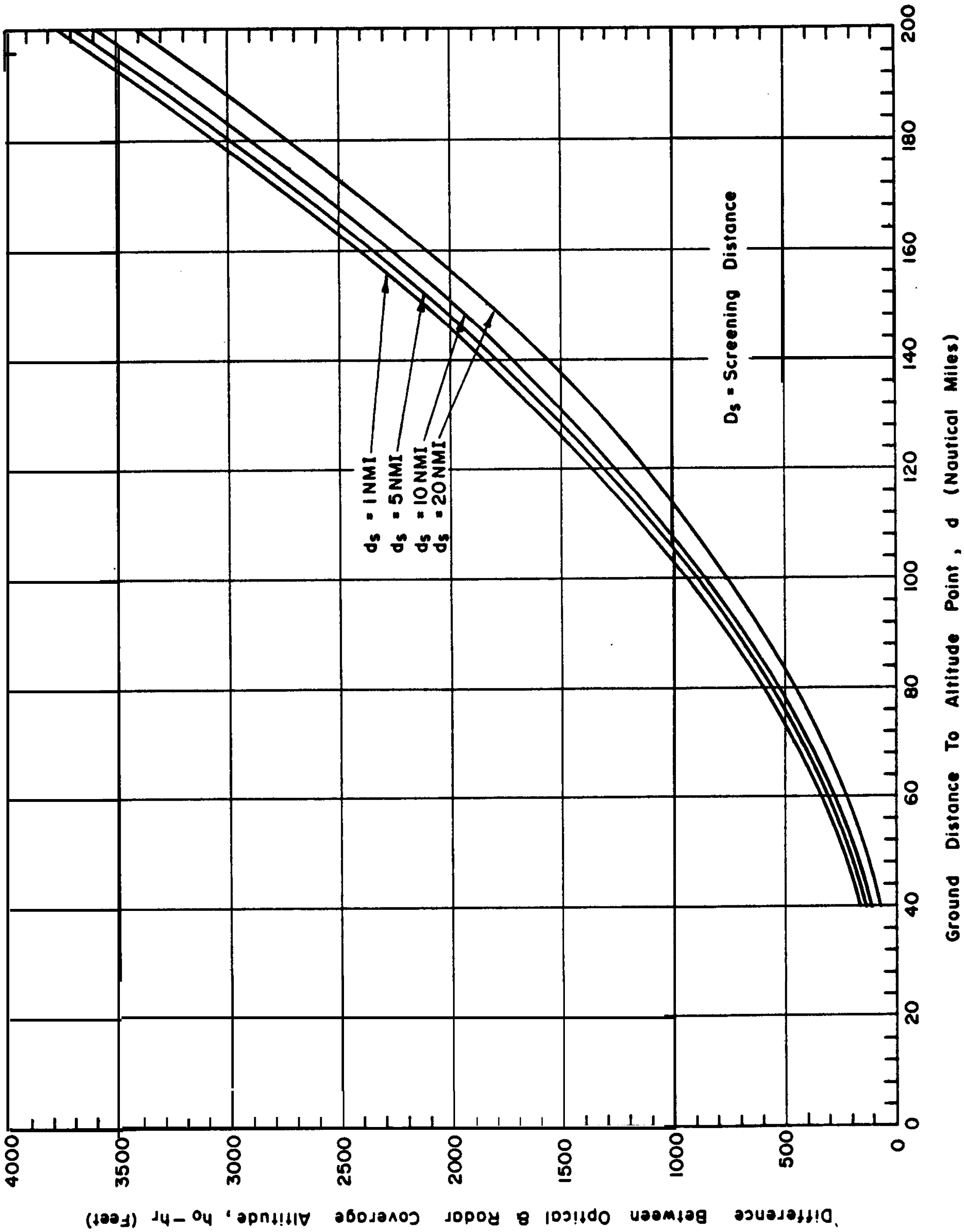
(e) Shielding

1 Terrain, fixed structures, and surface traffic within visual range of the-ARSR/beacon antenna system reflect radar energy which cn degrade performance of the ARSR/beacon system. Such reflections can produce lobing of ARSR and ATCBI radiation patterns, severe ARSR ground clutter, and false-target displays for both the ARSR (due to moving traffic) and beacon. It is desirable, therefore, to minimize the extent of the ground surface and obstacles surrounding the site which are directly exposed to illumination by the ARSR and beacon. A site surrounded by close-in screening objects, or terrain, where these obstacles cast shadows on the ground surface and objects beyond them, is highly desirable for these purposes. When these screening or shielding objects are relatively close to the site (within 2 nmi), the screening angle can generally be controlled by choice of the effective antenna height (37, 49½, 62, 74½, or 87 feet). This is important since too great a screening angle can result in a significant loss in airspace coverage. For example, each one-tenth of a degree increase in screening above the horizon sacrifices about 600 feet of vertical coverage at a distance of 60 nmi.

2 Shielding up to 0.25 degree screening angle above the local horizontal may, in certain cases, be considered worth the sacrifice in coverage to reduce ground reflections. If a screen angle of 0.25 degrees is selected, the range reduciton at an altitude of 15,000 feet is 20 nmi as shown in figure 3-9. However, whatever the value actually selected, due consideration should be given to the resulting loss in airspace coverage with respect to the operational coverage requirements.

3 The use of obstructions close to the antenna for shielding, although not affecting low angle coverage, may still create problems due to diffraction. Special attention should be given to this effect when selecting sites with obstructions (towers, fences, buildings, etc.) closer than 2500 feet. The effects of diffraction are more pronounced from obstructions and/or shielding objects close to the antenna.

Fig. 3-11 DIFFERENCE BETWEEN OPTICAL AND RADAR SCREENING



b. Vertical Lobing.

(1) Ground reflection occurs when the bean radiated from the antennastrikes the surface of the earth and bounces upward. The vertical coverage of a radar can vary greatly due to ground reflections since the reflected wave may arrive atthetarget on a phase relationship which will either aid or oppose the direct wave. This effect causes a decrease in the overall amount of power strikingthetarget at certain altitudes and anincreaseinthe amount of power striking the target at other altitudes. The algebraic addition of the reflected wave and the direct wave phasors creates a vertical radar coverage pattern consisting of areas of minimum power,called nulls, and maximum power, called lobes, as shown in figure 3-12.

(2) Groundreflectionis a variablefactor,depending mainlyonthetype of terrain. Reflection is greatest when the reflecting surface is smooth,such as a calm sea. Whenthereflectingsurfaceis uneven,such as encountered on land or a choppy sea, reflection is decreased. Uneven land areas, trees, grass, or a choopysea may absorb a large portion of the radiated energy or cause a scattering of the energy,thus reducing the amount of reflected energy adding to or subtracting from the direct wave.

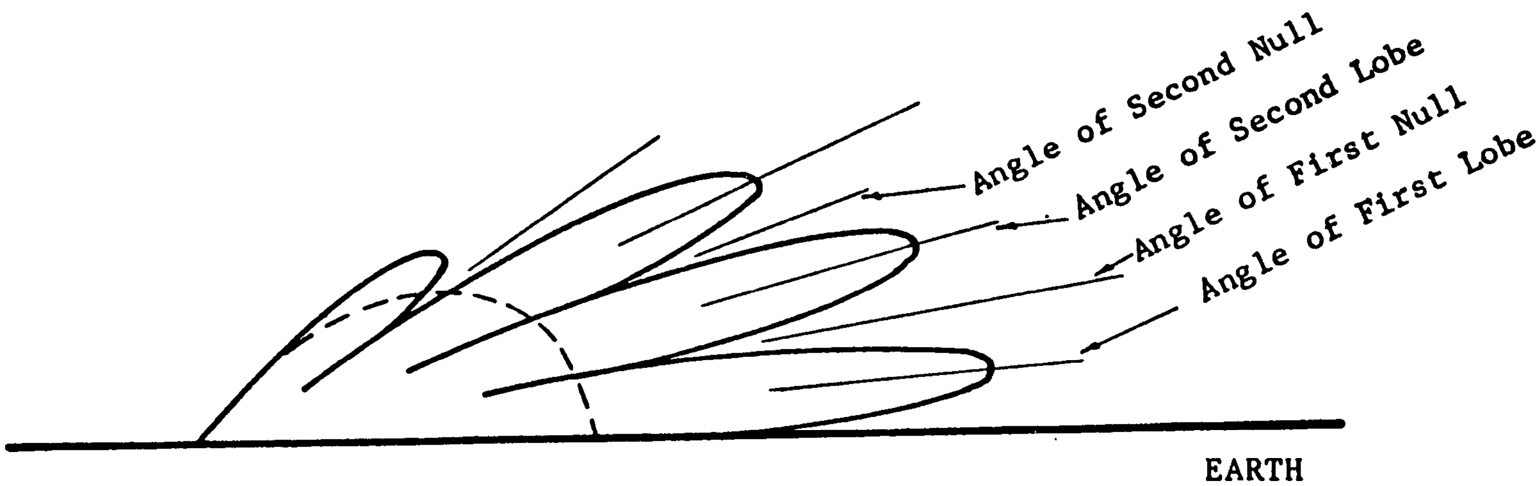
(3) The verticallobing pattern resulting from ground reflections is dependent upon radar design characteristics and upon several other factors determined at the time of site selection. Important equipment characteristics include the radar and the beacon frequency, and the vertical patterns oftheradar and the beacon antennas. The ARSR-3 and ATCBI antennas have sharp cutoff ofradiation at angles below the horizontal in order to minimize ground-reflected energy, and therefore minimize the depth of vertical lobing nulls. This radiation cutoffisincluded in the calculated radar coverage patterns shown later (figures 3-31 and 3-32). Another effectnotincluded in figures 3-31 and 3-32, nor in the discussions of lobing, is the possible phase variation of the antennaradiationinthe sharp cutoff region below the horizontal. This phase characteristic of an antenna is generally not known, but it could not only shift the lobing pattern which would otherwise be expected,butitcould also change the angular spacing between lobs, even causing a more non uniform lobe setting. Because of this effect,the procedures given here for estmatingthelocations of lobes and nulls should be considered approximate. The procedures can, however,be expected to give reasonably accurate predictions, atleastforthe first few lobes and nulls.

(4) Important siting factors which affect verticallobinginclude: antenna height above the reflecting surface, antenna tilt angle, and surface reflection characteristics. Careful consideration should be given to these factors so as to minimize the occurrence oflobing, and to control the location of unavoidable lobes suchthatoverllradar and beacon performance is not impaired. Means for considering these factors are discussed below.

(a) Lobing Analysis.(A more detailed treatment may befoundin reference 7.)

1 Consider an antenna mounted at height, h_a, above a smooth flat reflecting surface, and a target at range R, and altitude h_t, as shown in figure 3-13. Energy radiated by the radar antenna arrives atthetargetbytwo separate paths --the direct path and the path reflected from the smooth surface. Modification of the field strength atthetargetcaused by the presence of the ground may be expressed by the ratio (sometimes called earth gain factor):

Figure 3-12 TYPICAL VERTICAL RADIATION PATTERN WITH GROUND REFLECTION

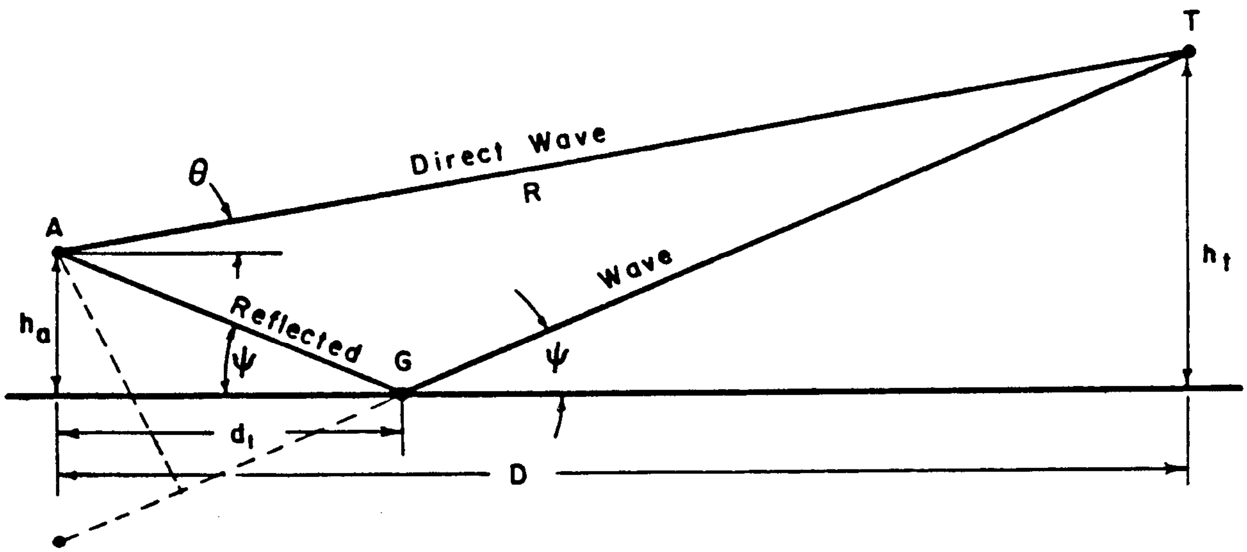


LEGEND:

DOTTED LINE = FREE-SPACE PATTERN

SOLID LINE = GROUND REFLECTED PATTERN

Figure 3-13 VERTICAL LOBING PATH GEOMETRY



$$\eta = \frac{\text{Field strength at target in presence of ground}}{\text{Field strength at target if in free space}} \qquad (3\text{-}12)$$

2 The phase difference between direct and reflected signals corresponding to the difference in path length is

$$\phi_d = \frac{2\pi}{\lambda}\,\frac{2h_a h_t}{R} \qquad (3\text{-}13)$$

3 This is based on assuming (1) h $>> h_a$, (2) $\theta = \psi$, (3) θ & ψ are small angles. Under these condition;

$$\sin\psi = \tan\psi = \psi$$

$$\psi = \theta = \frac{h_t}{R} \quad .$$

4 To ϕ_d must be added the phase shift resulting from the reflection of the wave at the ground. The reflection coefficient, Γ, of the ground may be written as

$$\Gamma = \rho \quad e^{-j\phi_r} \qquad (3\text{-}14)$$

where ρ represents the amplitude change, and ϕ_r represents the phase change upon reflection. Determination of Γ, which may entail some difficulty, is dependent upon signal polarization and terrain characteristics. This is discussed in a subsequent subparagraph. For purposes of this analysis, a conservative result is obtained by assuming $\rho = 1$, $\phi_r = \pi$. This gives

$$\phi = \phi_d + \phi_r = \frac{4\pi}{\lambda}\,\frac{h_a\, h_t}{R} + \pi \quad . \qquad (3\text{-}15)$$

5 The resultant, E_r, of two signals with field strength amplitudes E_1 and E_2 and phase difference ϕ is

$$E_r = (E_1^2 + E_2^2 + 2\,E_1 E_2 \cos\phi)^{1/2} \qquad (3\text{-}16)$$

6 Therefore, the ratio of signal incident on the target to that which would be incident if the target were located in free'space is

$$\eta = \frac{E_r}{E_1} = \left[1 + \frac{E_2^2}{E_1^2} + 2\,\frac{E_2}{E_1}\cos\left(\frac{4\pi\, h_a h_t}{\lambda R} + \pi\right)\right]^{1/2} \qquad (3\text{-}17)$$

which reduces to

$$\eta = \left[1 + \frac{E_2^2}{E_1^2} - 2\frac{E_2}{E_1}\cos\left(\frac{4\pi\ h_a h_t}{\lambda R}\right)\right]^{1/2} \qquad (3\text{-}18)$$

7 The field strength ratio is related to the antenna gain ratio by $E_2/E_1 = \rho\sqrt{G_2/G_1}$, which for $\rho = I$

$$\frac{E_2}{E_1} = \sqrt{\frac{G_2}{G_1}} \qquad (3\text{-}19)$$

where

G_1 = numerical antenna power gain in direction of target

G_2 = numerical antenna power gain in direction of reflection point.

Hence,

$$\eta = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}}\cos\left(\frac{4\pi\ h_a h_t}{\lambda R}\right)\right]^{1/2} \qquad (3\text{-}20)$$

and, since under the assumptions made previously

$$\theta = \frac{h_t}{R}\ , \qquad (3\text{-}21)$$

$$\eta = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}}\cos\left(\frac{4\pi\ h_a\theta}{\lambda}\right)\right]^{1/2}\ . \qquad (3\text{-}22)$$

8 Minimum values of η occur when

$$\cos\left(\frac{4\pi\ h_a\theta_{min}}{\lambda}\right) = 1$$

or when

$$\frac{4\pi\ h_a\theta_{min}}{\lambda} = n\pi \qquad n = 0,\ 2,\ 4,\ \ldots \qquad (3\text{-}23)$$

9 Rearranging for use with common units and noting that $\lambda = c/f$, η_{min} occurs when

$$\theta_{min} = \frac{14098n}{h_a f}(deg) \quad n = 0, 2, 4, \ldots \tag{3-24}$$

where

h_a = antenna height in feet

f = frequency in MHz.

10 Under this condition

$$\eta_{min} = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}}\right]^{1/2} . \tag{3-25}$$

θ_{min} is plotted in figures 3-14 and 3-15 for ARSR and ATCBI frequencies and η_{min} is plotted in figure 3-16 as a function of G_2/G_1.

11 In a similar manner, maximum values of η occur when

$$\theta_{max} = \frac{14098n}{h_a f}(deg) \quad n = 1, 3, 5, \tag{3-26}$$

where

h_a = antenna height in feet

f = frequency in MHz.

12 At these angles

$$\eta_{max} = \left[1 + \frac{G_2}{G_1} + 2\sqrt{\frac{G_2}{G_1}}\right]^{1/2} \tag{3-27}$$

θ_{max} and η_{max} are plotted in figures 3-17, 3-18 and 3-19.

13 Squaring equation 3-12 (p. 77) shows that η^2 represents the ratio of POWER at the target with and without ground reflection. Therefore, η^2 may also be used to determine the effect on range coverage when the transmitted power is held constant.

Figure 3-14. NULL ANGLES AT 1300 MHz

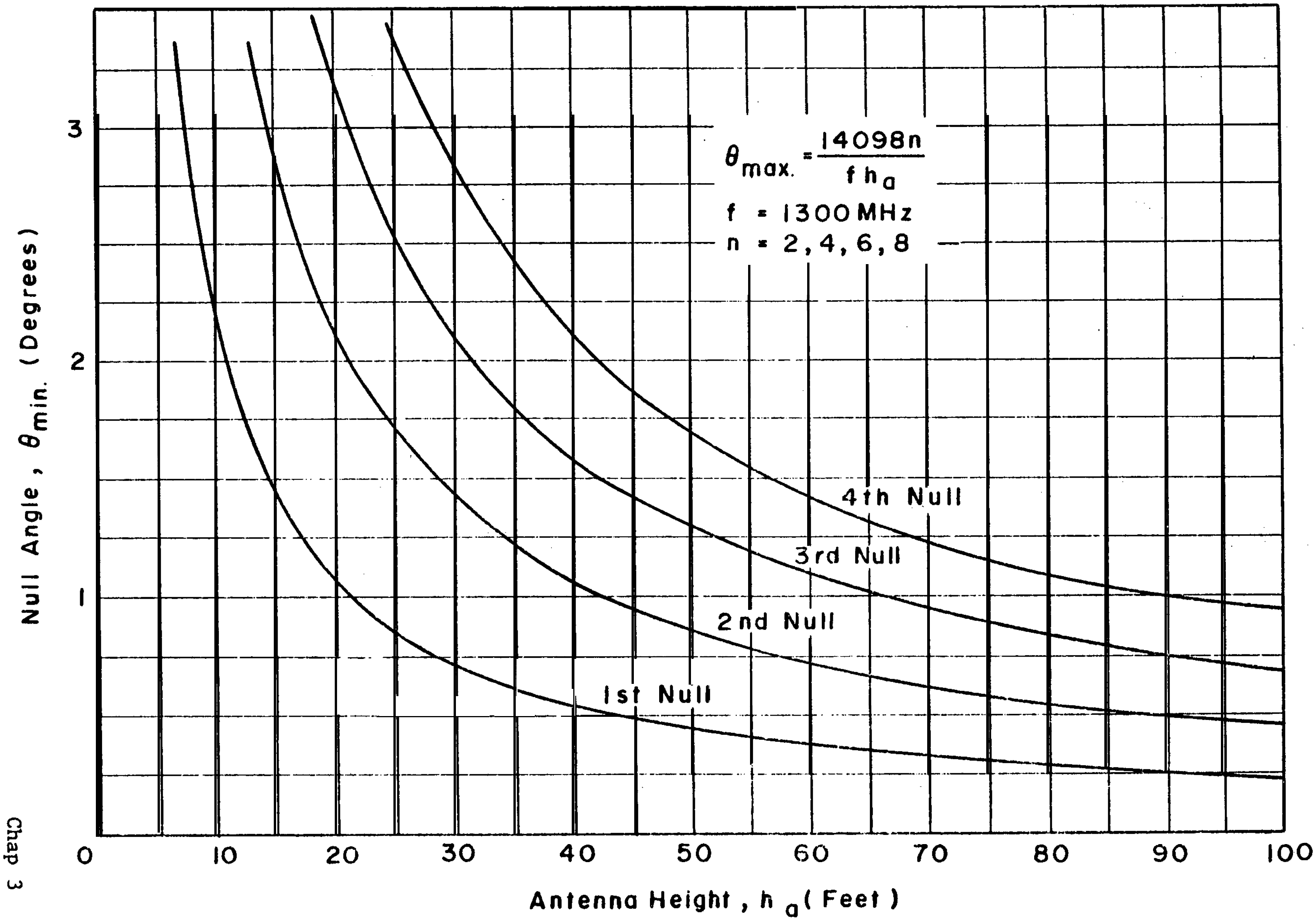


Figure 3-15 NULL ANGLES AT 1030 MHz

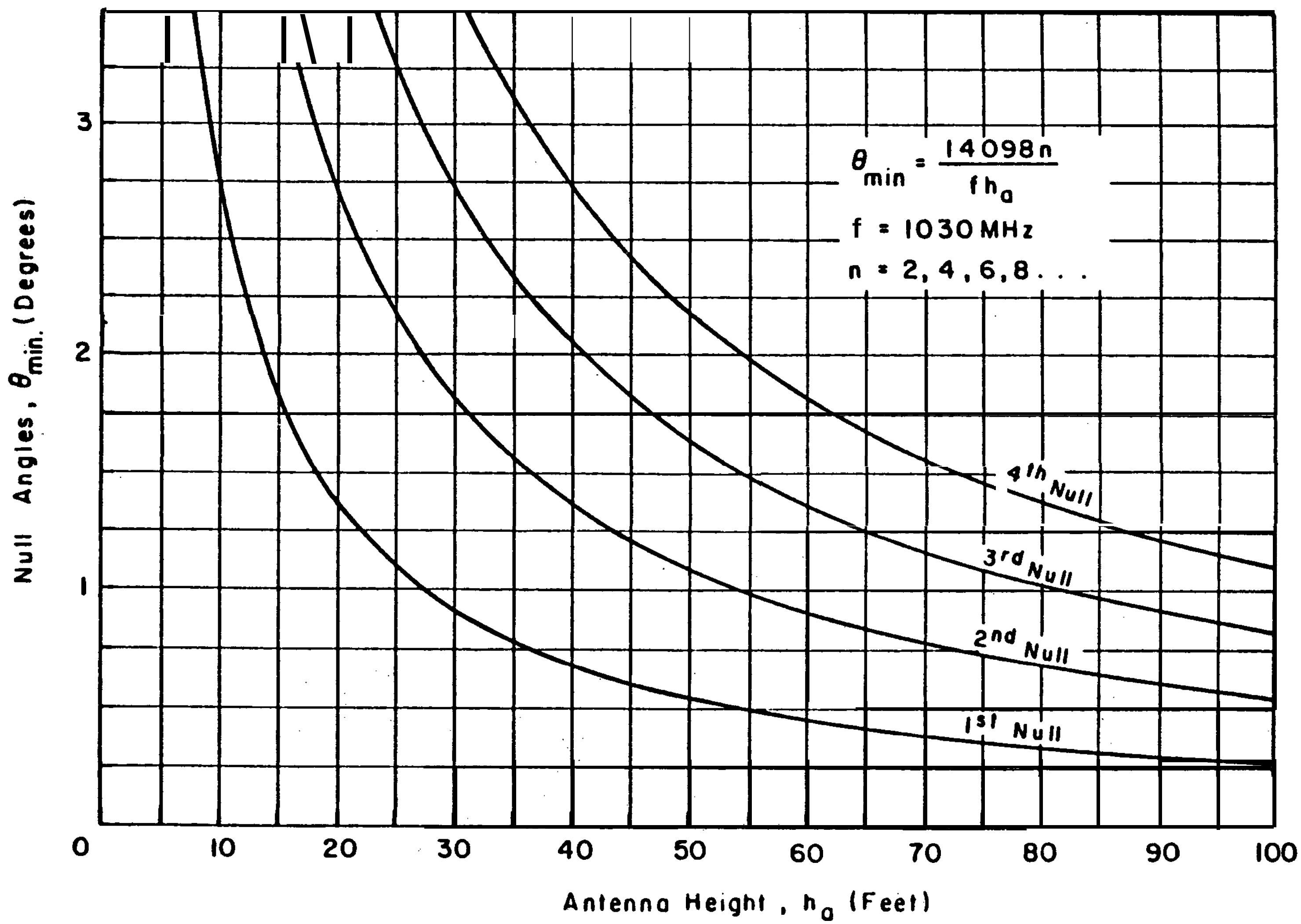


Figure 3-16 MINIMUM VALUE OF EARTH GAIN FACTOR (η)

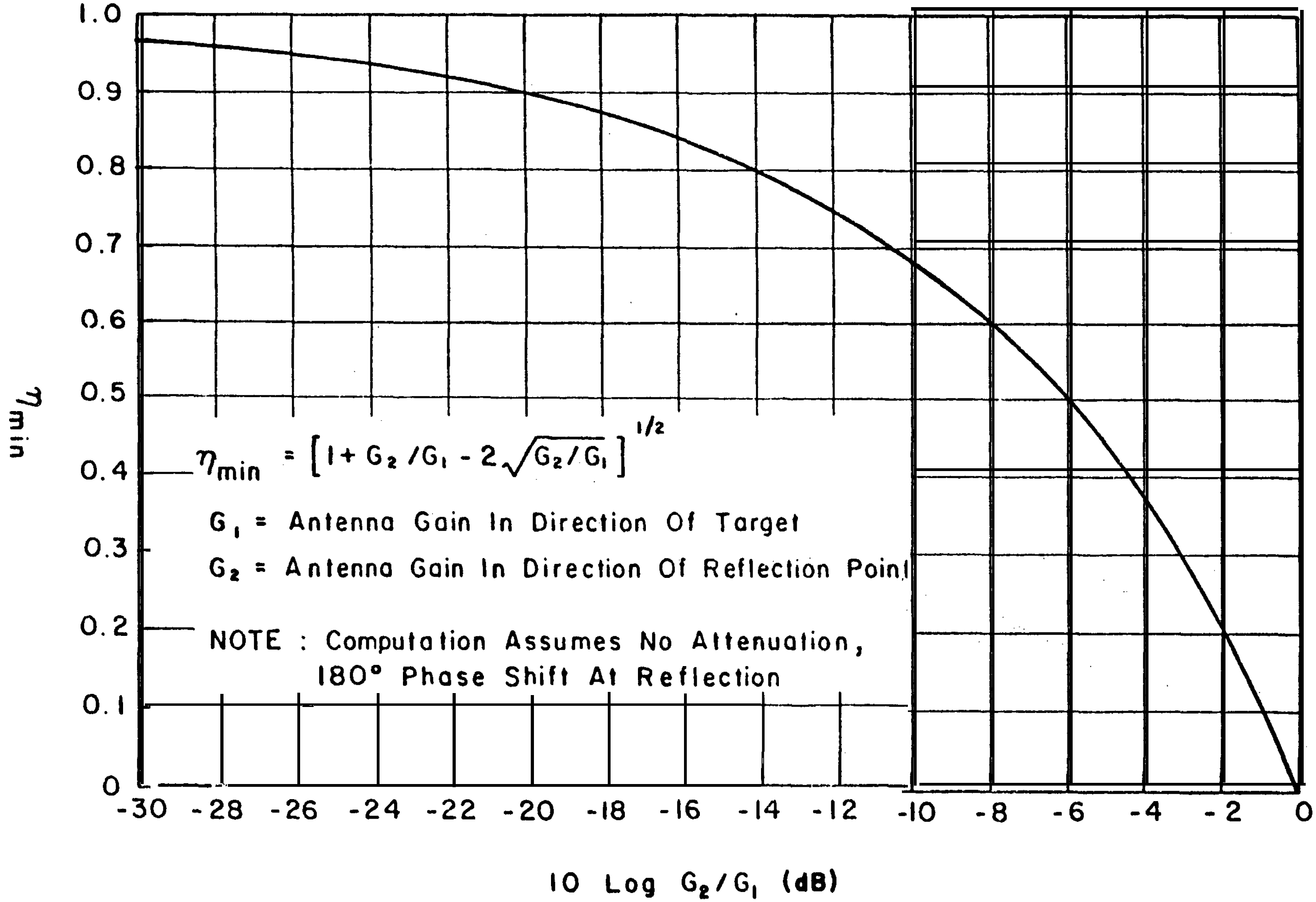
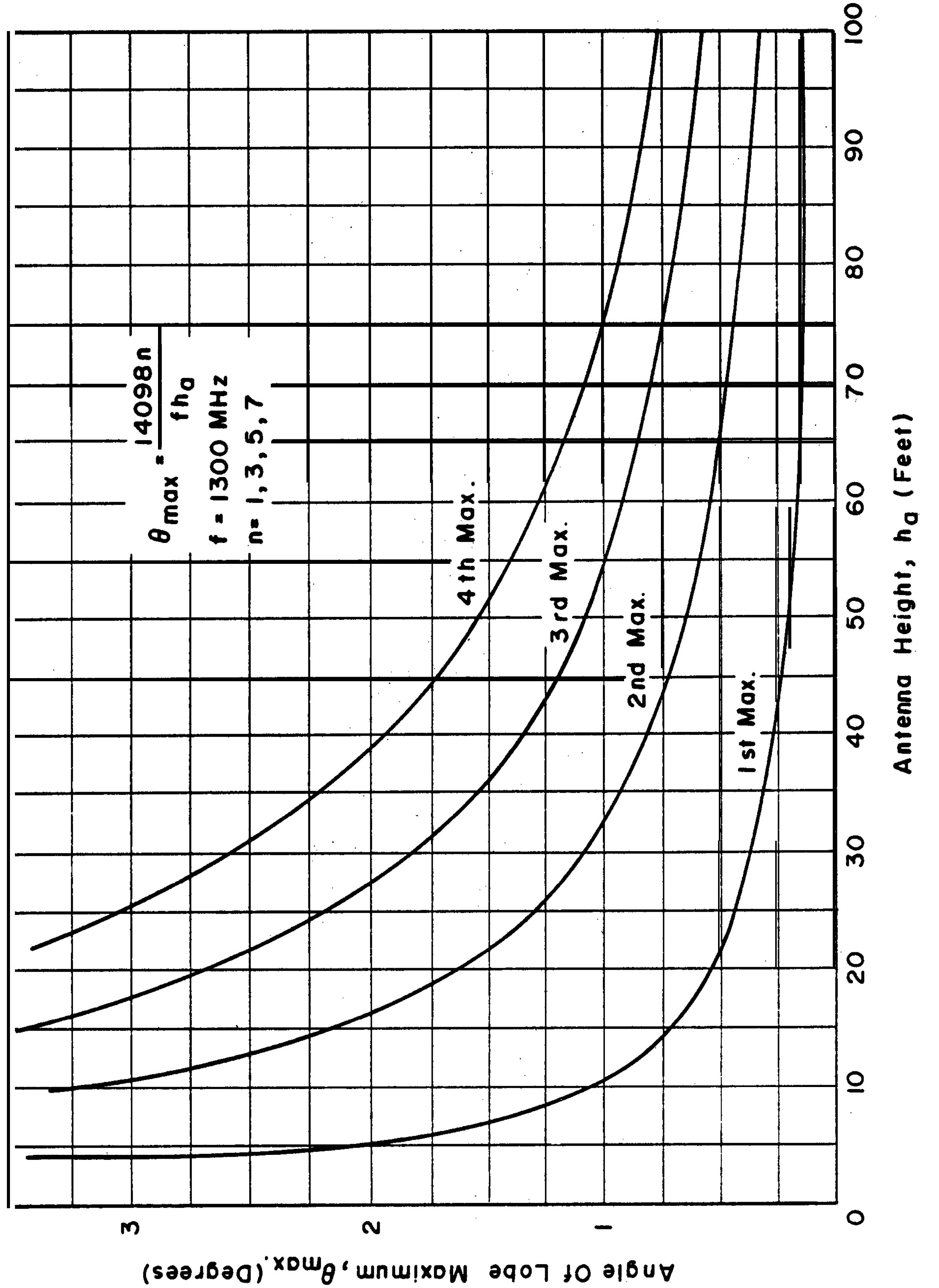


Figure 3-17. LOBE PEAK ANGLES AT 1300 MHz



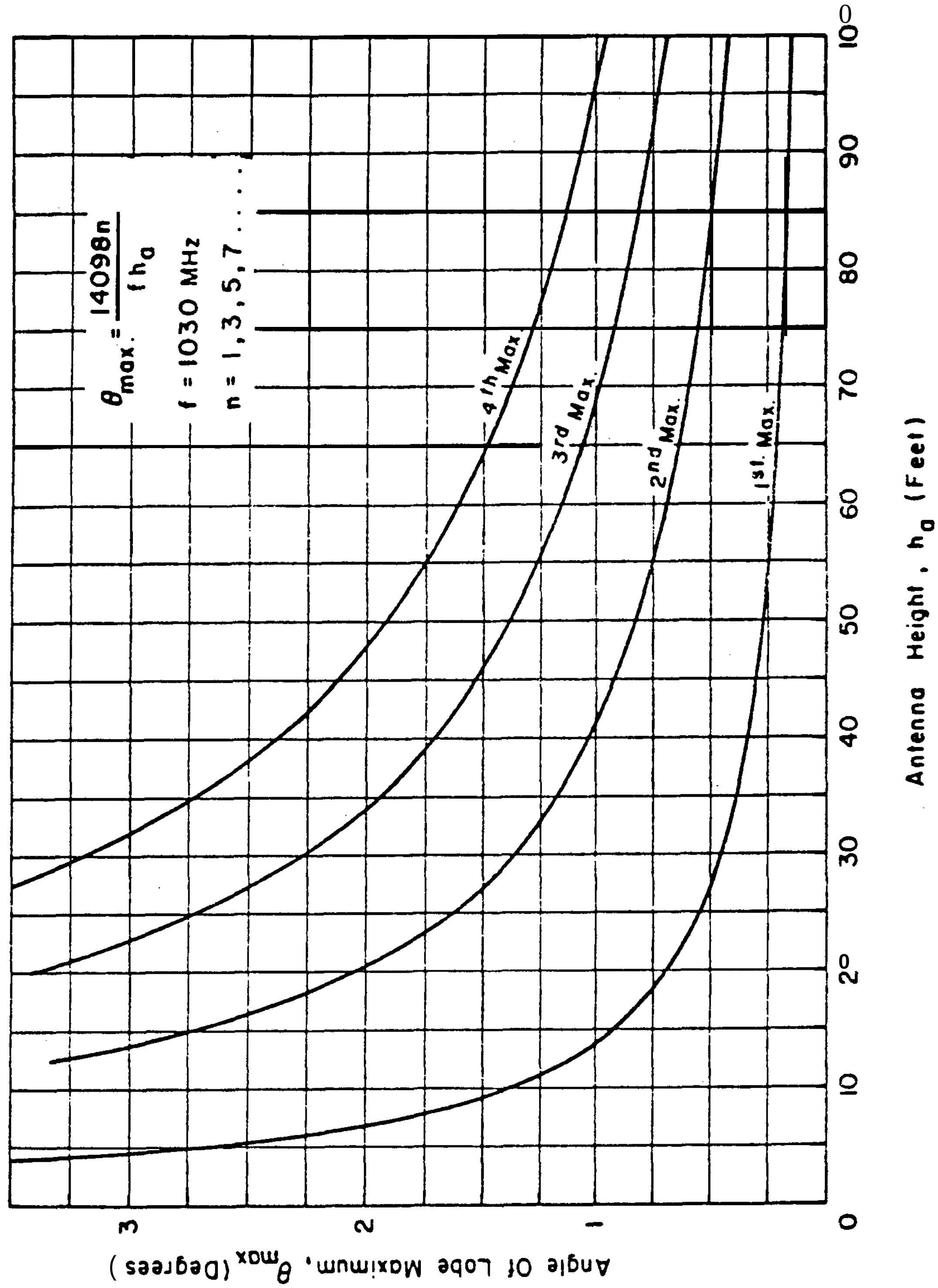
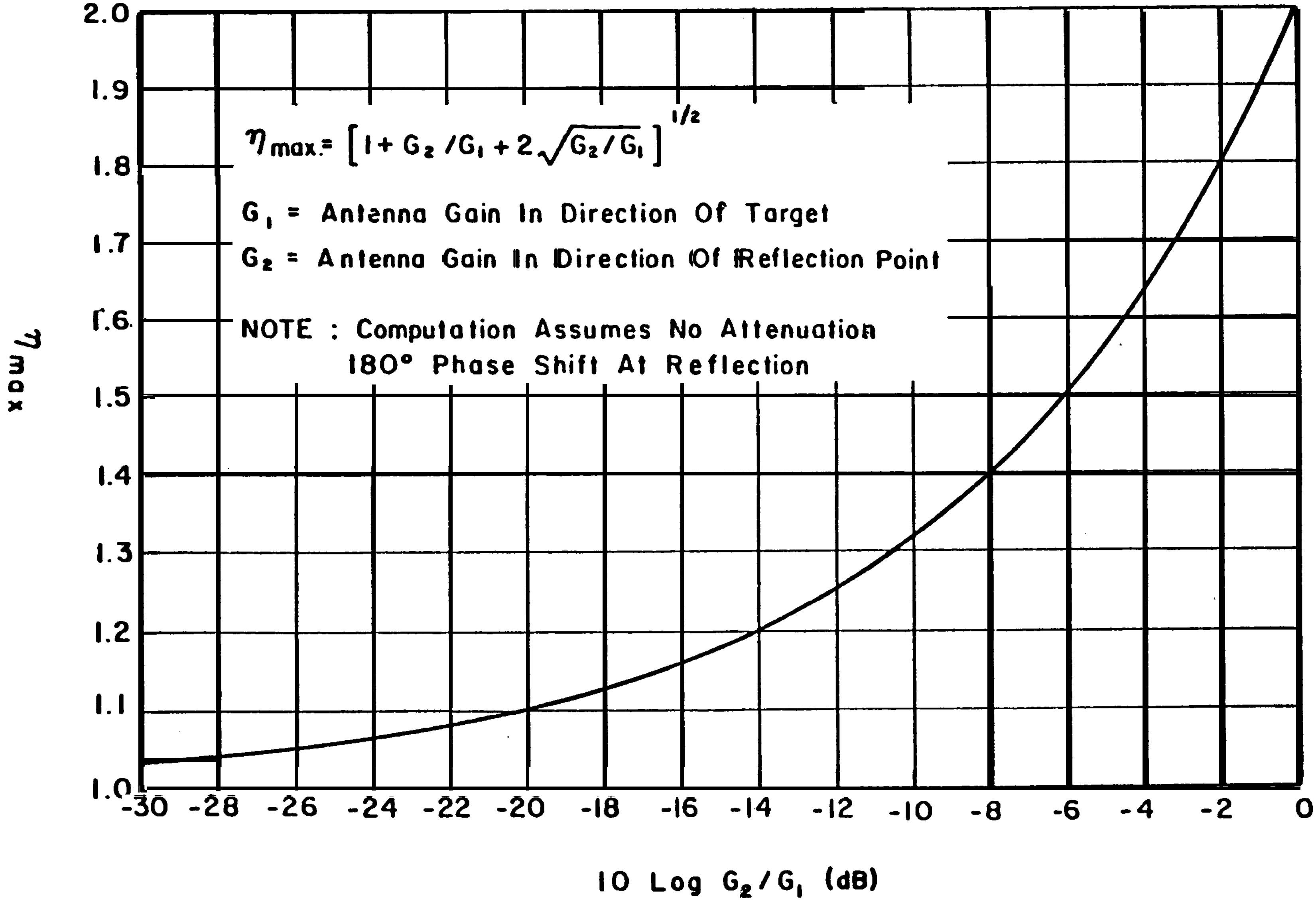


Figure 3-18 LOBE PEAK ANGLES AT 1030 MHz

Figure 3-19 MAXIMUM VALUE OF EARTH GAIN FACTOR (η)



14 ATCBI Case. For beacon operation, the minimum detectable transponder input is reached at a free-space range (terms defined as in equation 3-2, p. 57).

$$R_f = \frac{\lambda_i}{4\pi(1852)} \sqrt{\frac{P_{oi} G_i T_t}{S_{min,t} L_t L_\alpha}} \quad . \tag{3-28}$$

With ground reflections this range becomes R_r, where

$$R_r = \eta R_f \quad . \tag{3-29}$$

Range coverage with reflections is thus simply η times the free-space range.

15 ARSR Case. For ARSR operation, a two-way radar path is involved, and by reciprocity, the same type of reflection effect occurs for both the transmitted signal and the echo signal. In this case, therefore, the ratio of radar return power with ground reflection to return power in free space is $\eta_t^2 \eta_e^2$, where the subscripts t and e refer to the transmit and the echo paths, respectively. For ARSR-3 operation, if the antenna both transmits and receives on the lower beam, then $\eta_t^2 = \eta_e^2 = \eta^2$, and the return power ratio is η^4. Under this condition, the modification in coverage range for detection at the same power level is

$$R_r^4 = \eta^4 R_f^4$$

or

$$R_r = \eta R_f \tag{3-30}$$

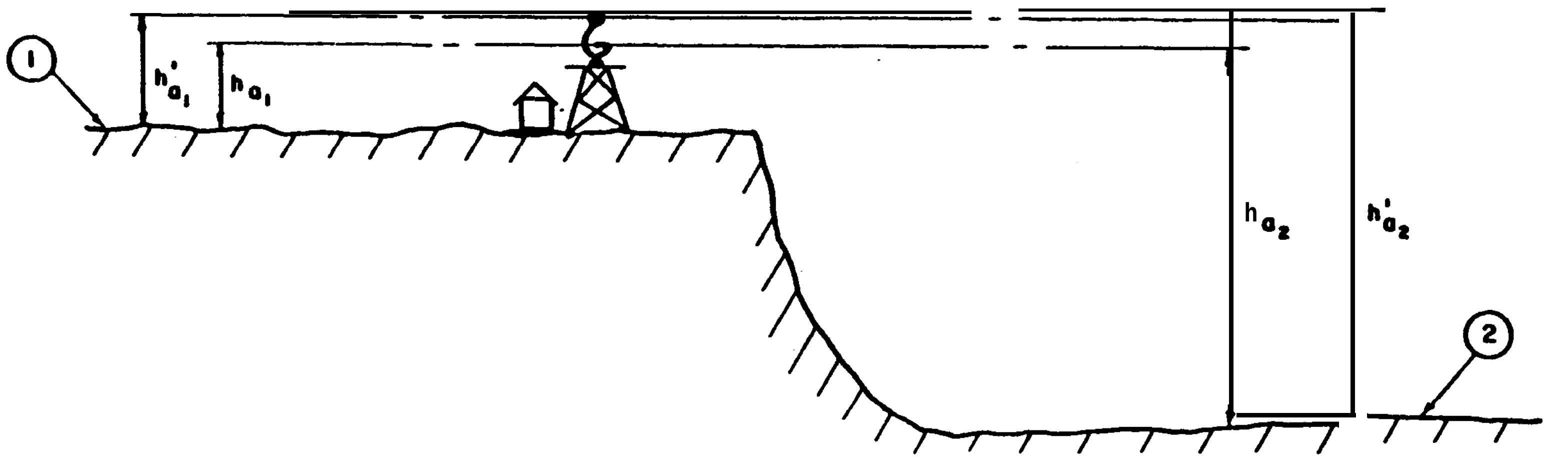
where the free-space range, Rf, for the ARSR-3 can be determined from figure 3-1 for one particular beam-tilt angle.

16 For near-range operation the ARSR-3 may use the upper beam for reception.-In this situation $\eta_t^2 \neq \eta_e^2$ due to the different antenna patterns (transmit on lower beam, receive on upper beam). The range modification for this case is

$$R_r = R_f \sqrt{\eta_t \eta_e} \quad . \tag{3-31}$$

17 To summarize, the effects of vertical lobingmay beexamined by determining the angles of nulls and lobes from figures 3-14 and 3-15, or 3-17 and 3-18 for the particular radar antenna height and frequency. It should be noted that radar height here means height of the particular antenna above the smooth reflecting surface. This may differ considerably from the height above ground as illustrated in figure 3-20. As mentioned above, the analysis given here assumes a flat earth. While this assumption generally produces little error in en route ARSR/ATCBI siting, a more accurate curved earth analysis should be used for values of h_a above 100 feet. For this case, null angles may be determined using techniques described in reference 7.

Figure 3-20 ANTENNA HEIGHT FOR LOBING CALCULATIONS



h_{a_1} = ARSR Antenna Height Used in Lobing Calculations for Reflections from Surface 1

h_{a_2} = ARSR Antenna Height Used in Lobing Calculations for Reflections from Surface 2

Primed Dimensions Indicate the Corresponding Heights for ATCBT Lobing Calculations

18 **The first null** ($n = 2$) is the one which will cause the greatest trouble with the second and third nulls being lesser in importance, for air route and fix coverage where aircraft are flying at a relatively constant altitude. The null angle can be critical when it approaches the glide slope angle of aircraft arriving at airports for terminal radar, but higher order nulls may also be detrimental to air traffic coverage. Higher order nulls can also affect high-altitude fix coverage. The plotted lobe null and maximum angles indicate that the ATCBI will experience fewer lobes below a given altitude than will an ARSR system.

19 Once the eleoation angles of the lobe peaks at-id nulls are determined (with respect to horizontal), the corresponding earth gain factors, η, can be found. To do this the antenna power gains G_1 and G2 at angles $\pm \theta_{min}$ and/or $\pm \theta_{max}$ are found. These may be determined from the appropriate antenna elevation pattern diagrams given in chapter 2. It should be noted, however, that the gain determinations must account for antenna tilt angle as this can alter computational results. The angular relationship is illustrated in figure 3-21. In like manner, any slope of the reflecting surface must be taken into account for proper determination of θ_{min} end θ_{max}.

20 With G_1 and G_2 determine, η_{min} and η_{max} are founa directly from figures 3-16 and 3-19. For ATCBI systems, the range coverage at each critical null or maximum angle is then found by direct multiplication of free-space range, as determined for the plots in section 3, by the corresponding value of η. For the ARSR-3 this is slightly more difficult since use of both antenna patterns will produce two values of η_{min} and η_{max} for each critical angle. The approximate range multiplier in this case is-the square root of the product of the η_{max}'s or η_{min}'s.

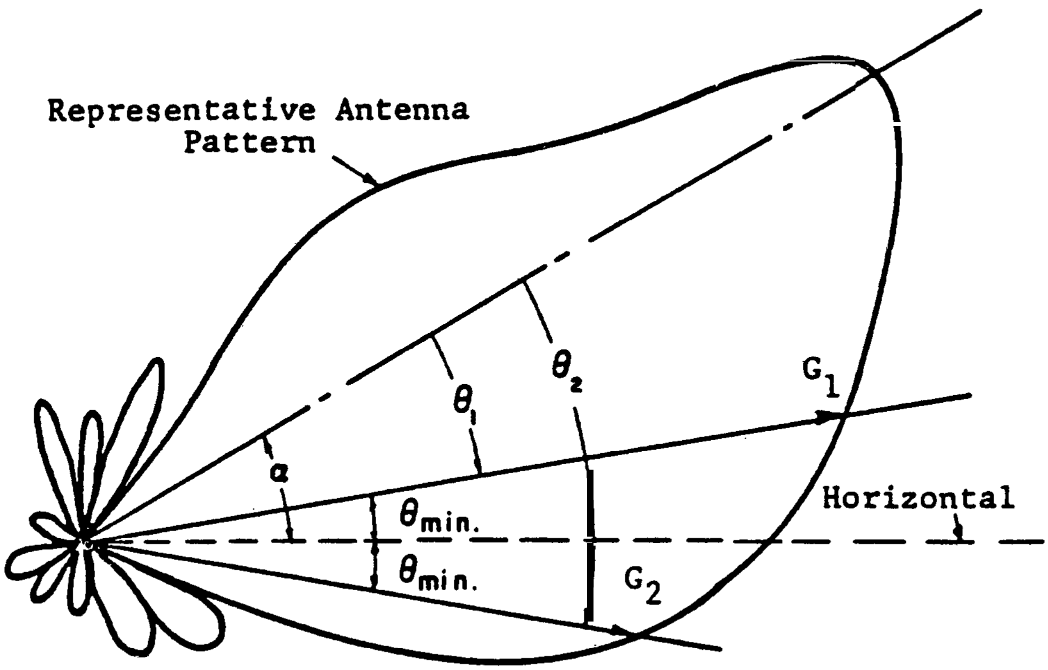
21 The development shows that the values of the null angles are dependent only upon antenna height for a given radar or beacon. This is demonstrated by the curves in figures 3-14 and 3-15. The depth of null, however, is dependent upon antenna tilt angle as shown in figures 3-22 through 3-30. This is illustrated by the partial radar coverage diagrams sketched in figures 3-31 and 3-32.

22 It should be remembered that the development given here also assumes a smooth reflecting surface which provides no attenuation and 180° signal phase shift, and assumes small angles and distant targets such that $\theta = \psi$ in figure 3-i3. The latter assumption provides little error when h_a < 100 feet; the effects of the other assumptions are discussed in the following subparagraphs.

(b) Terrain Roughness Effects.

1 Vertical lobing effects, as mentioned above, are quite dependent upon the terrain surface. Reflection is greatestwhen therefiecting surface is smooth, and is decreased when the reflecting surface is uneven. Uneven land areas, trees, grass, rough sea, etc., may, in fact, absorb or scatter a large portion of the incident energy, thus virtually nullifying any effect of reflected signals upon the direct wave. On the other hand, large

FIGURE 3-21 ANGULAR RELATIONSHIPS FOR NULL DEPTH DETERMINATION



α = Antenna Tilt Angle (to nose of beam)

θ_1 = Antenna Elevation Angle (below nose of beam) of Target

θ_2 = Antenna Elevation Angle (below nose of beam) of Reflection Point

Figure 3-22 TILT ANGLE EFFECT ON ATCBI-5 NULL

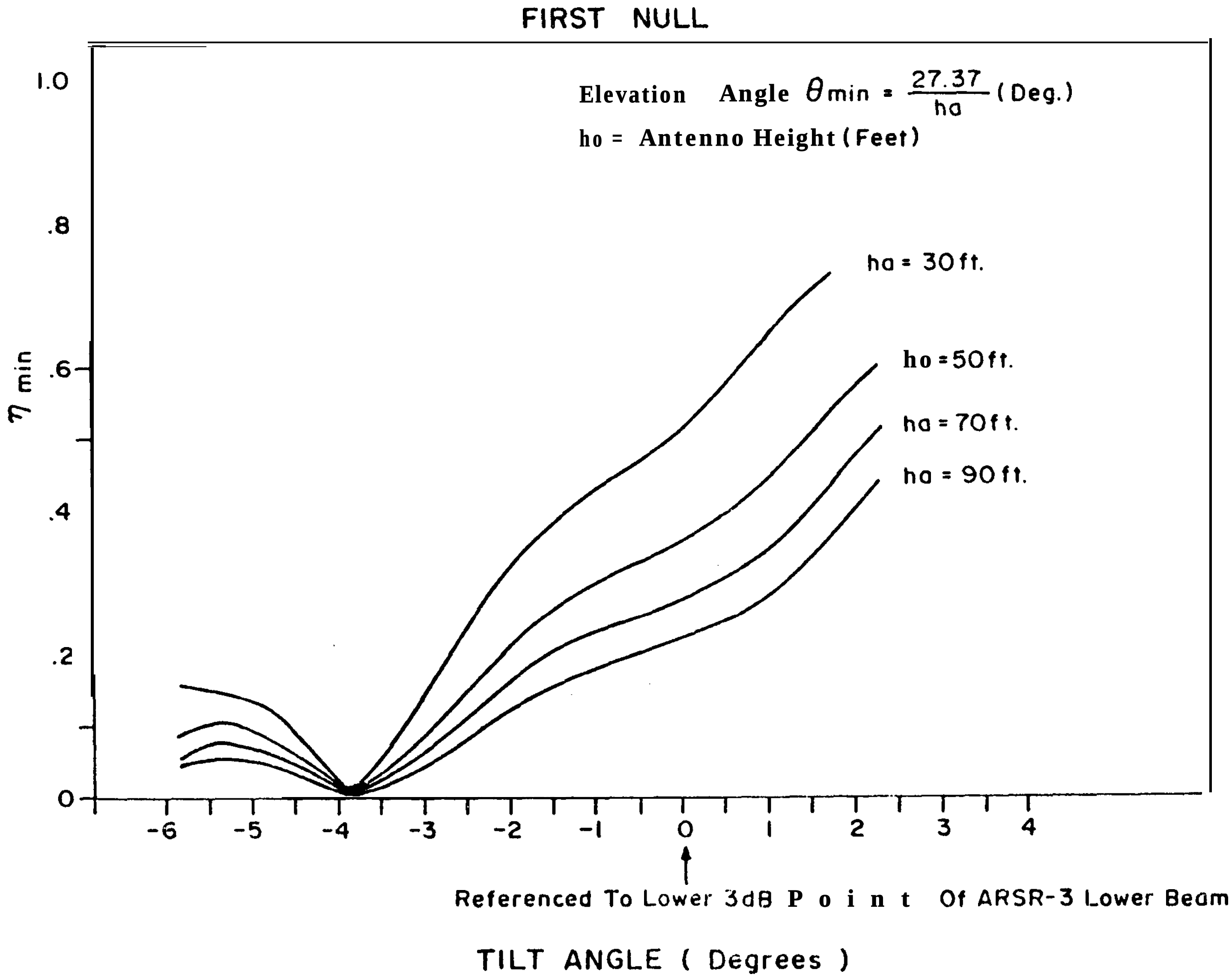


Figure 3-23 TILT ANGLE EFFECT ON ATCBI-5 NULL

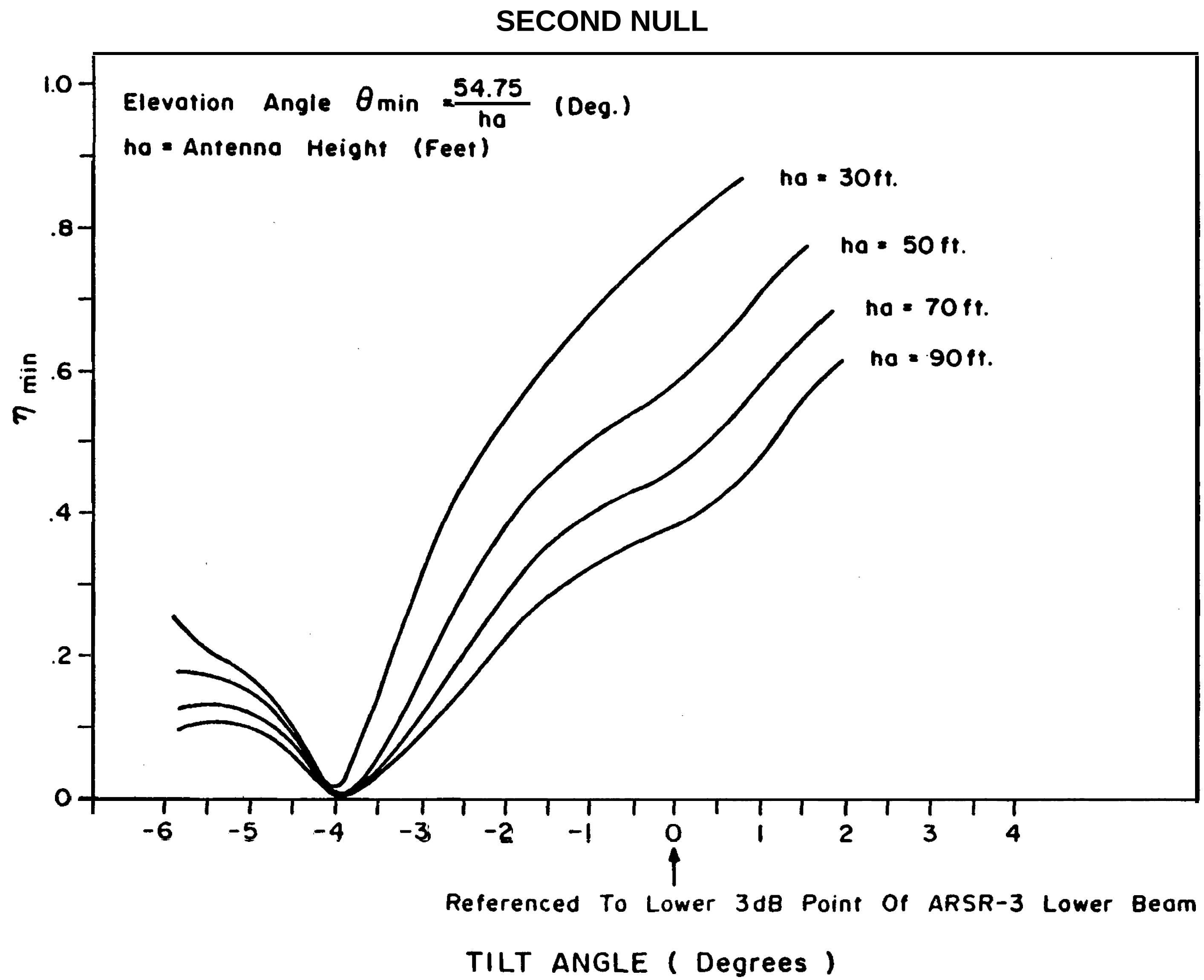


Figure 3-24 TILT ANGLE EFFECT ON ATCBI-5 NULL

THIRD NULL

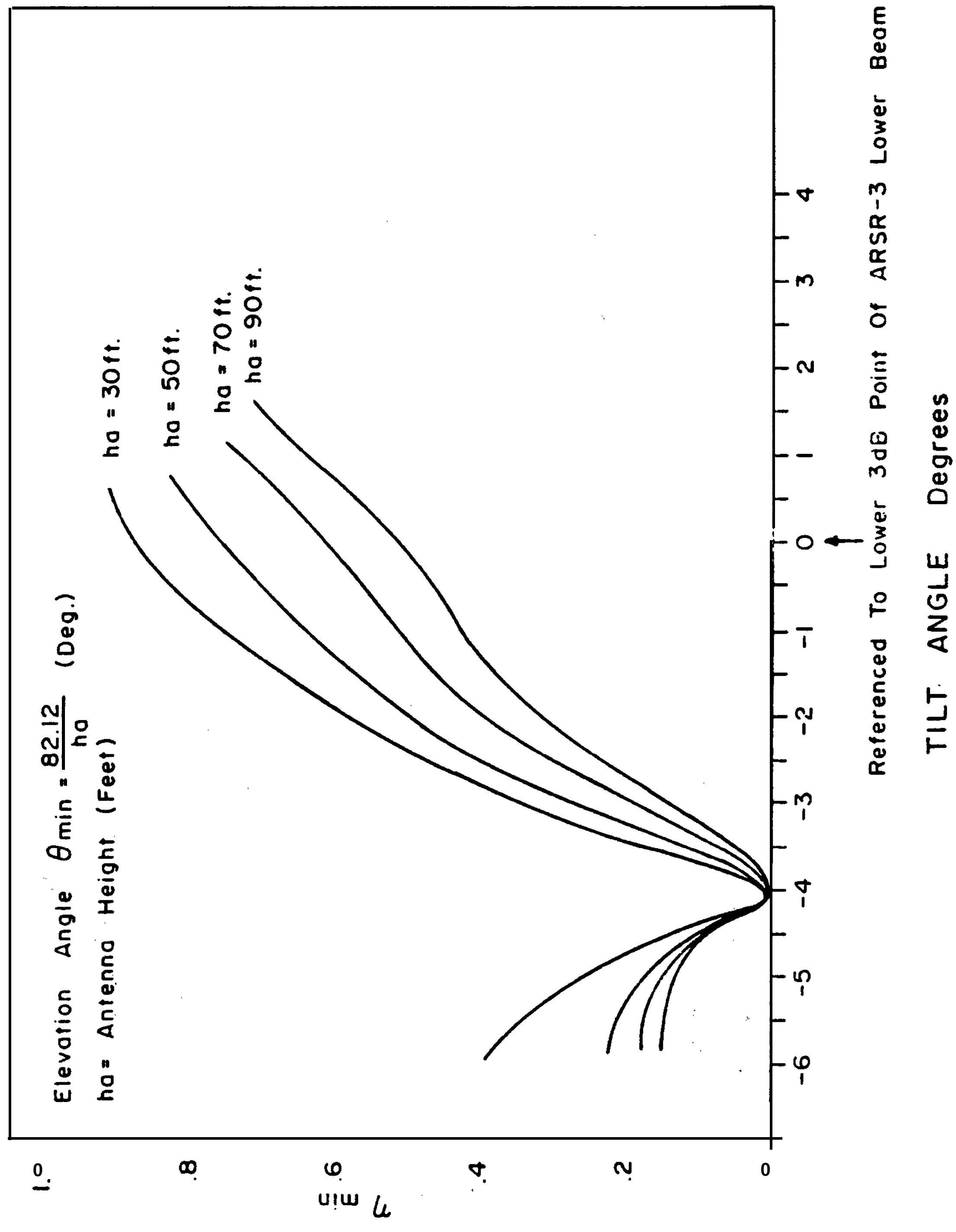


Figure 3-25 TILT ANGLE EFFECT ON ARSR-3 (LOWER BEAM) NULL

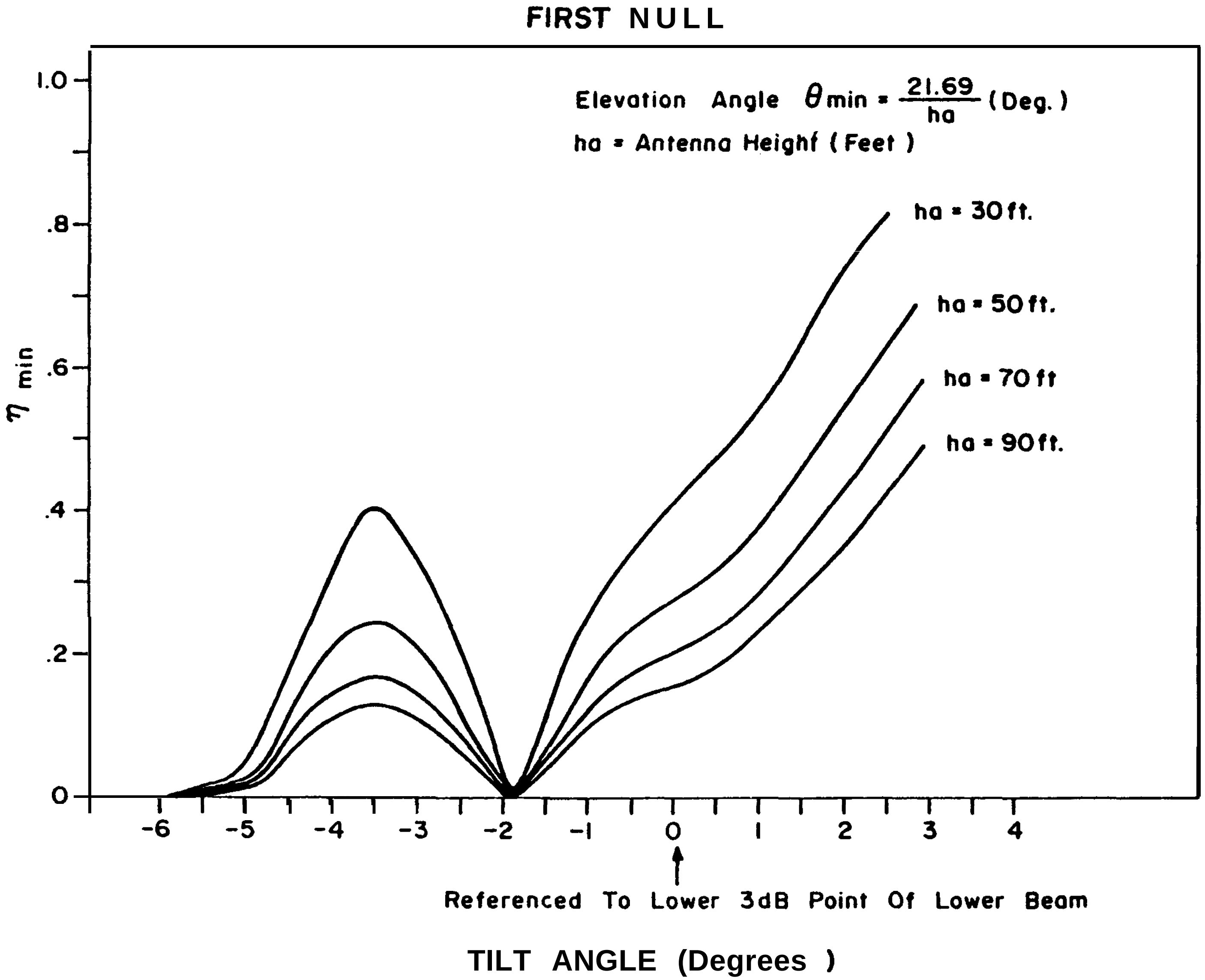


Figure 3-26 TILT ANGLE EFFECT ON ARSR-3 (LOWER BEAM) NULL

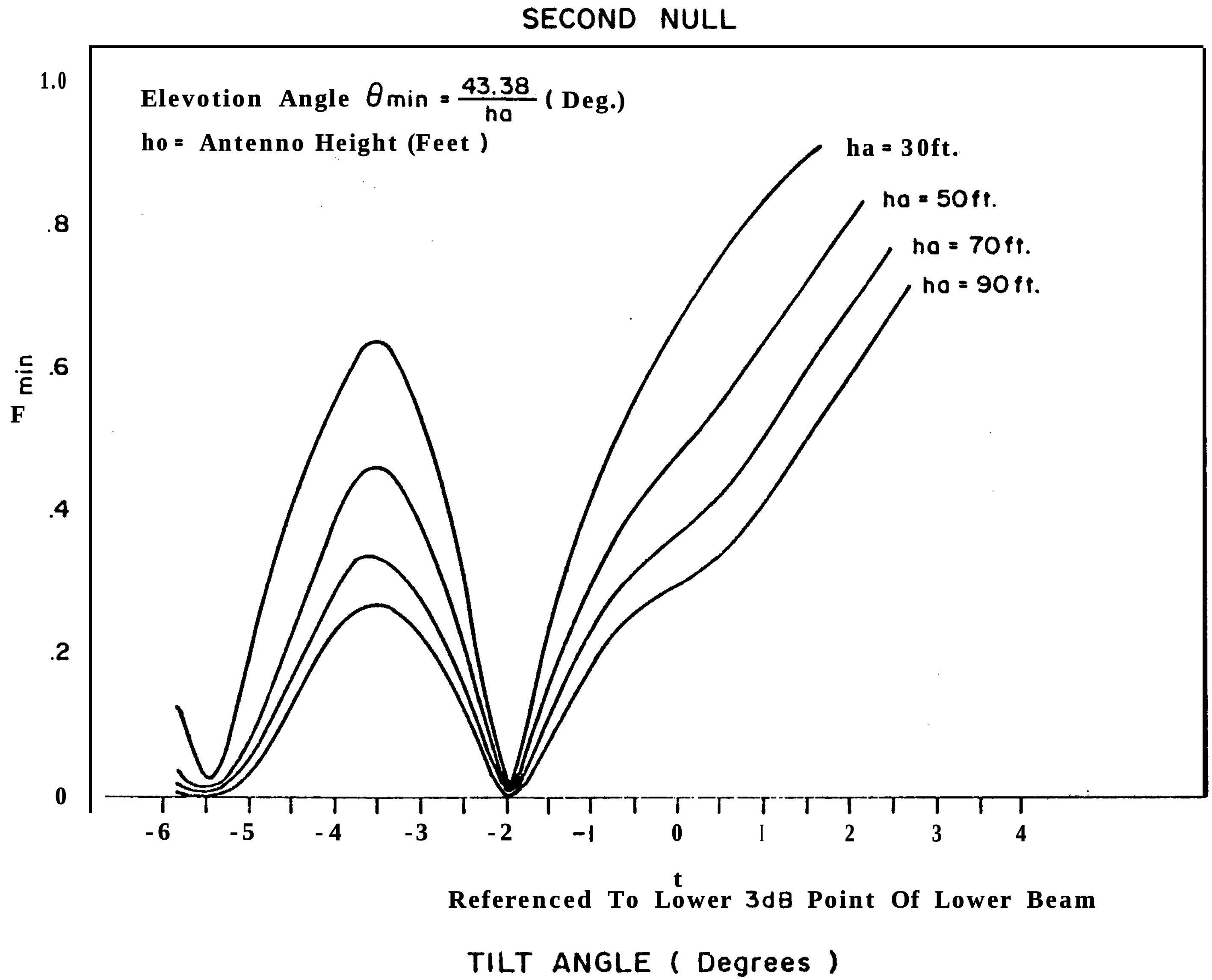


Figure 3-27 TILT ANGLE EFFECT ON ARSR-3 (LOWER. BEAM) NULL

THIRD NULL

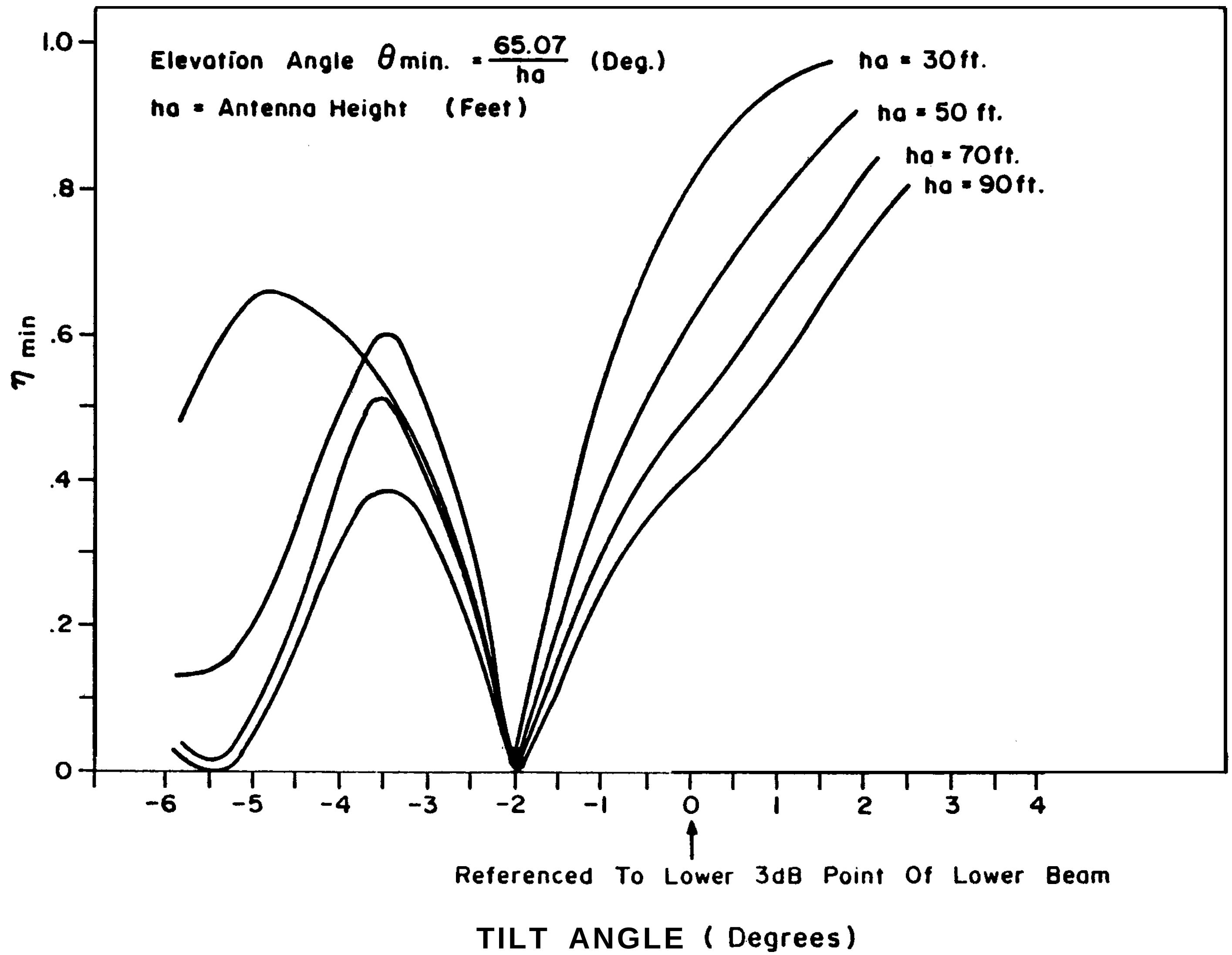


Figure 3-28 TILT ANGLE EFFECT ON ARSR-3 (UPPER BEAM) NULL

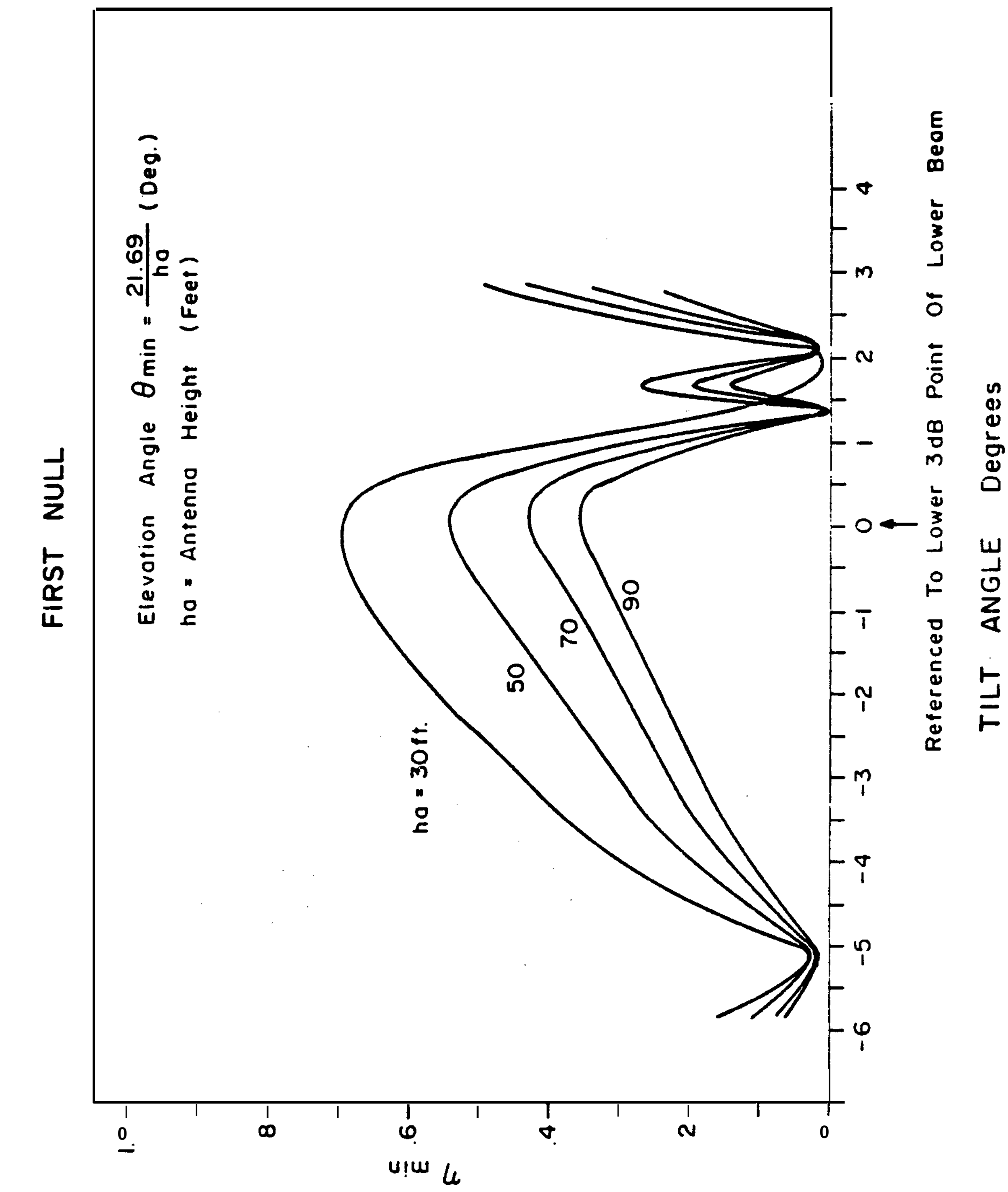
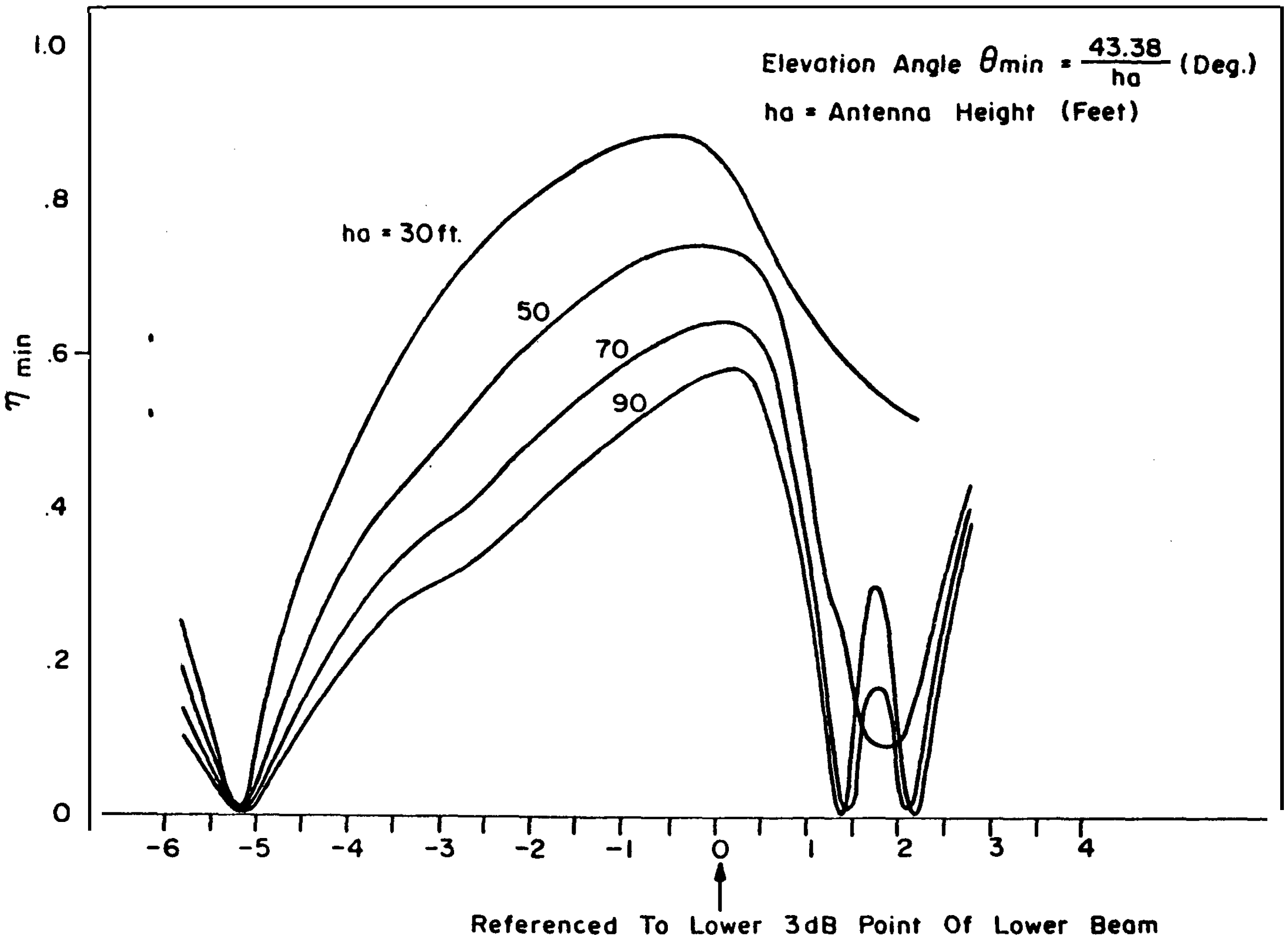


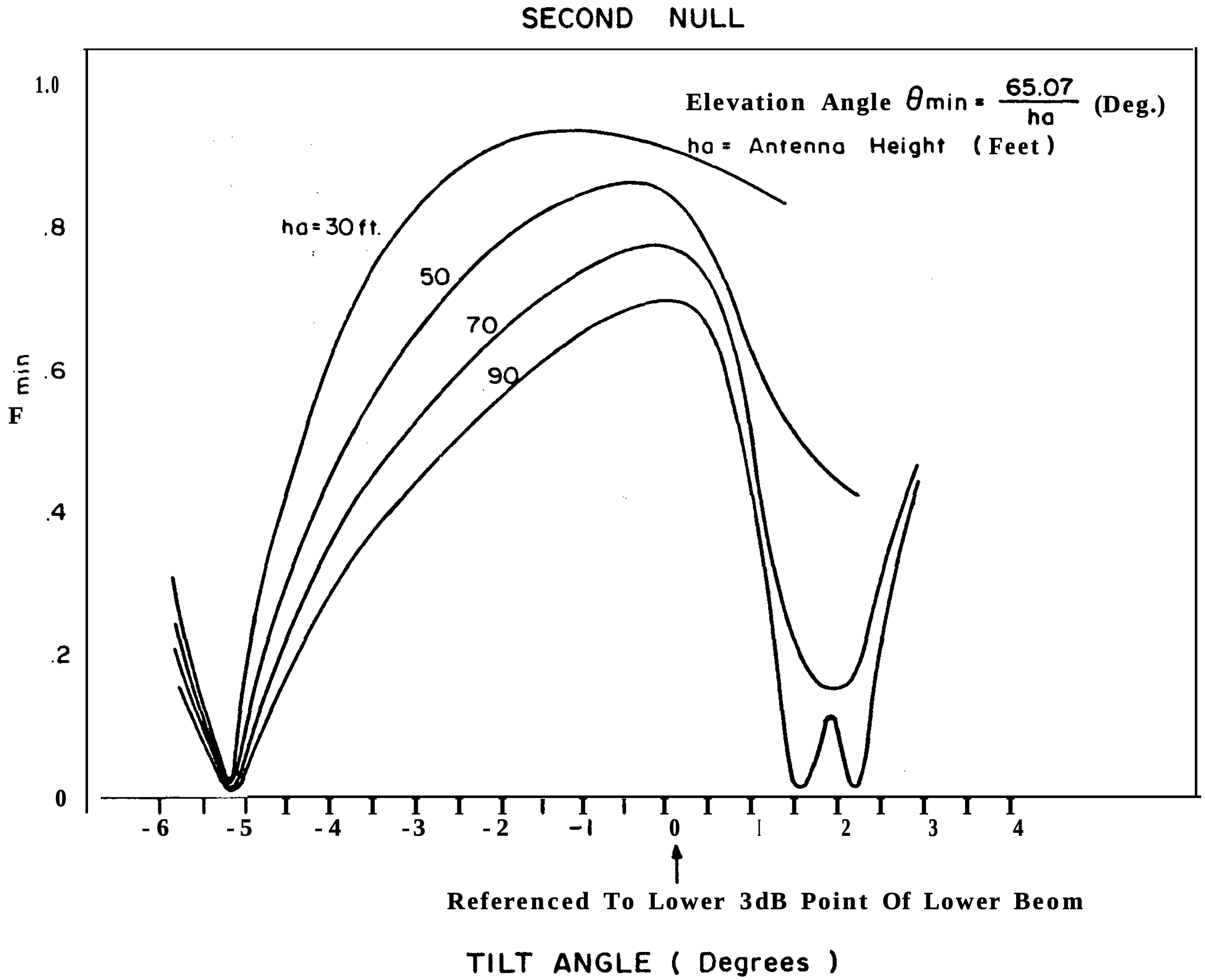
Figure 3-29 TILT ANGLE EFFECT ON ARSR-3 (UPPER BEAM) NULL

SECOND NULL



TILT ANGLE (Degrees)

Figure 3- 30 TILT ANGLE EFFECT ON ARSR-3 (UPPER BEAM) NULL



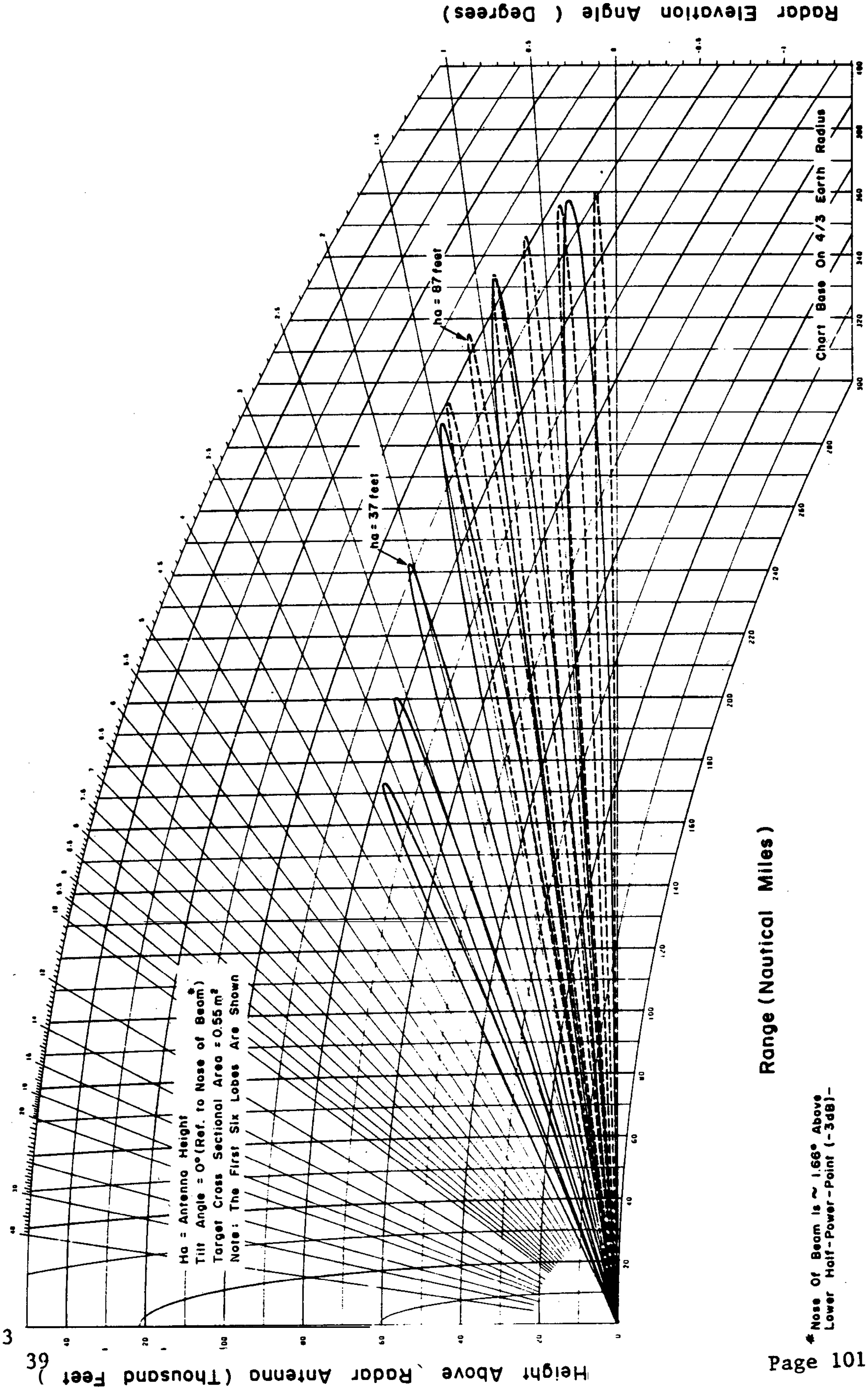
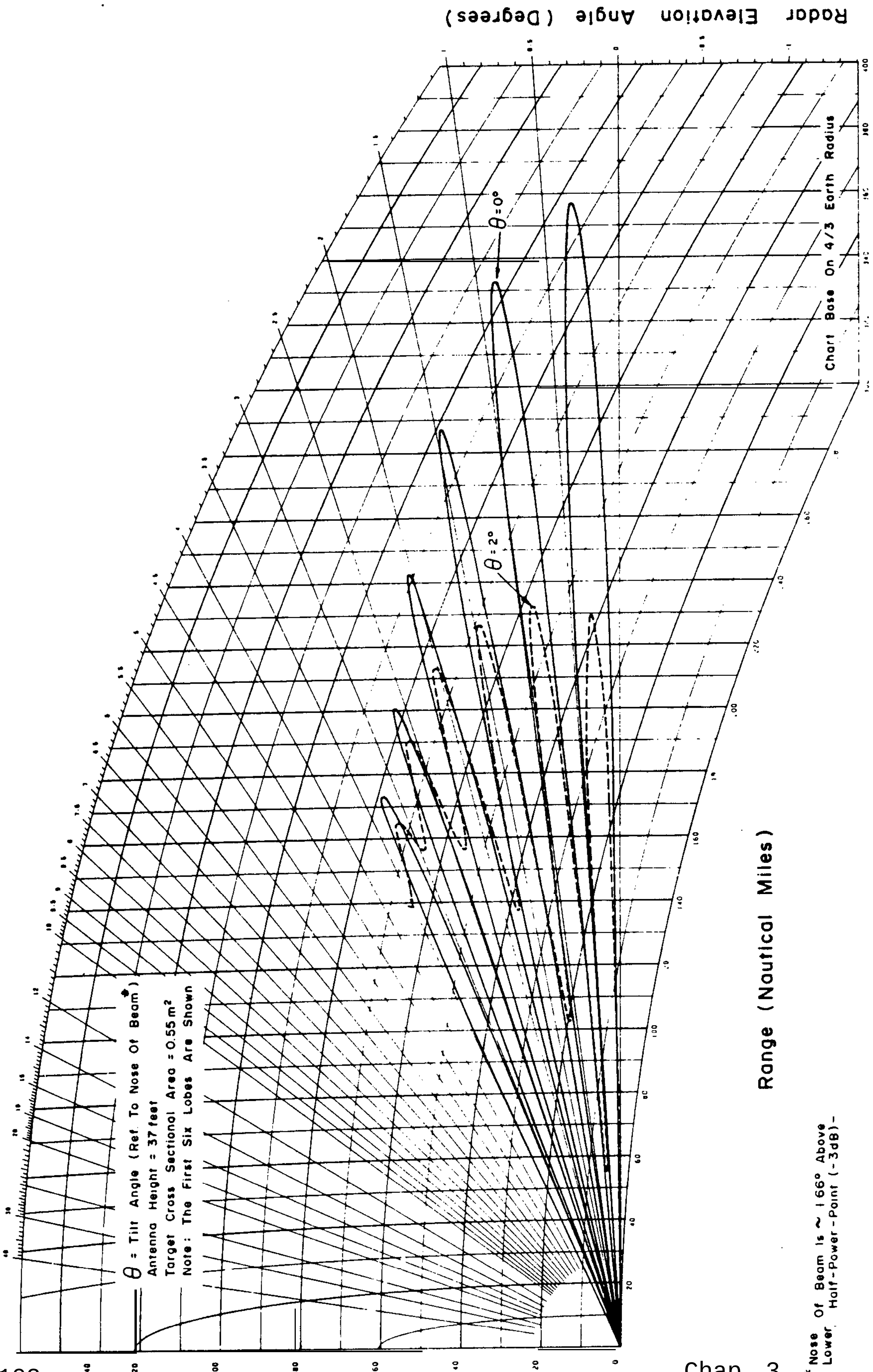


FIGURE 3-31 EFFECT ON LOBE PATTERN CAUSED BY VARIATION IN ANTENNA HEIGHT ARSR-3, LOWER BEAM RECEPTION

FIGURE 3-32. EFFECT ON LOBE PATTERN CAUSED BY VARIATION IN ANTENNA TILT ANGLE ARSR-3, LOWER BEAM RECEPTION



smooth areas such as .a calm sea, a flooded field, or a relatively flat snow-covered area, can cause a relatively large reflected signal. Insomeinstances the terrain can undergo seasonal variations which change the nature of the surface from rough to smooth. These changes can be due to snow, as mentioned, or due to natural vegetation changes, or due to agricultural activity. At any prospective radar site the extremes of reflection characteristics should be considered in assessing the terrain effects on vertical lobing.

2 As a criterion for the occurrence Of lobing effects it is convenient to assume a surface to be smooth(and consequentlya good reflector) if the height of surface irregularities, Ah, at the reflection point produces a net signal phase difference of less than 45 degrees, or one-eighth wavelength, between the waves reflected from the peaks and from the troughs of the irregular surface. This condition is satisfied when the terrain peak-to-trough height difference Ah is less than a critical height difference-Ah,, where Δh_c is-related to the grazing angle, ψ, as follows:

$$2 \Delta h_c \sin \psi = X/8 \ . \qquad (3\text{-}32)$$

3 For Δh 7 Δh_c the surface may be considered rough with no appreciable lobing effects. The parameter Ah, can be conveniently determined from figure 3-33. It should be noted that as radar antenna height increases, the angle, θ, of the first null, and therefore the grazing angle, ψ, decreases ($\theta = \psi$). Since, from figure 3-33 critical height increases with decreasing grazing angle, rougher terrain will be required to break up reflections using high antenna towers than is the case for low towers. This can be seen from the following condition for a rough surface, derived from the relationships given above:

$$\Delta h > \frac{\lambda/8}{2 \sin \psi} \ . \qquad (3\text{-}33)$$

(c) Location of Reflection Point.

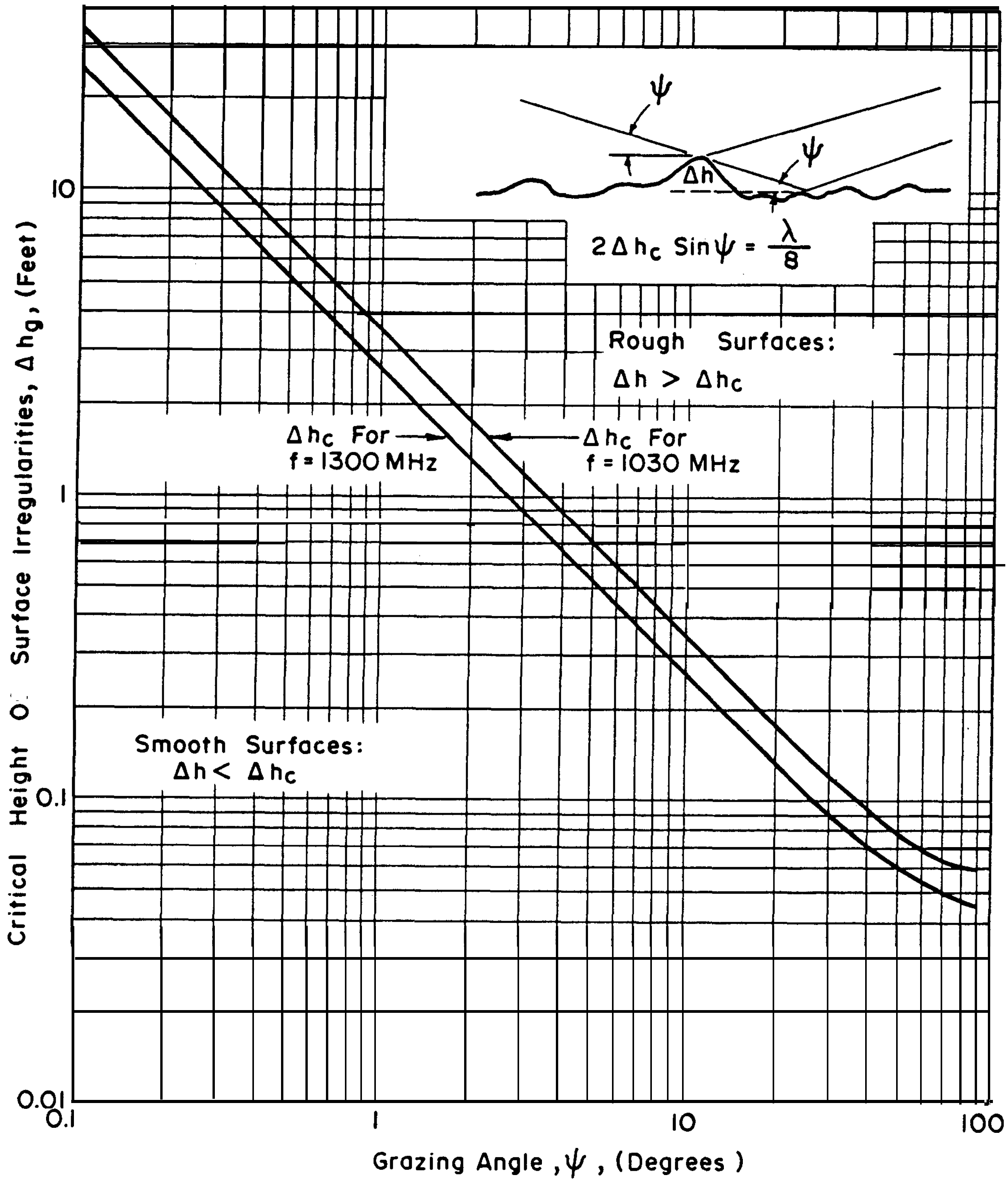
1 The distance, d_1, from the radar to the reflection point for each null in the vertical lobing pattern may be determined from the expression

$$d_1 = \frac{4 h_a^2}{n\lambda} \ , \qquad (3\text{-}34)$$

where h_a is the antenna height above the reflecting surface and n depends on the null number, for example n = 2 corresponds to the first null, n = 4 corresponds to the second null, and n = 6 corresponds to the third null.

2 This location is determined from simple image theory but is only rigorously correct for perfectly smooth reflectors. The reality of the reflected field at a given point in space is the sum of radiation from currents induced over a large surface region illuminated by the energy source.

Fig. 3 - 33 SURFACE ROUGHNESS CRITERION



Vertical lobing, nevertheless, will occur approximately as presented above for imperfect reflectors, if the surface is relatively smooth (as defined in the previous subparagraph) over the first Fresnel diffraction zone. The range limits, d_ℓ, of this region are given by

$$d_\ell = \left[\frac{1}{2n} + \frac{1}{n^2} \pm \frac{\sqrt{1+n}}{n^2}\right]\frac{8h_a^2}{\lambda} \tag{3-35}$$

For the first null n = 2, and

$$d\ell \begin{cases} \dfrac{0.536\ h_a^2}{\lambda} & \text{(near point)} \\ \\ \dfrac{7.464\ h_a^2}{\lambda} & \text{(far point)} \end{cases} \tag{3-36}$$

Similarly, the distances for the second null are given by 0.382 h_a^2/λ and 2.62 h_a^2/λ for the near and far points respectively, and, for the third null, by 0.301 h_a^2/λ and 1.48 h_a^2/λ. These distances are plotted in figures 3-34 through 3-39 for the first three nulls at ARSR-3 and ATCBI frequencies.

3 The use-of high towers affects lobing and coverage in several ways. First, as shown in figures 3-31 and 3-32, increasing the antenna height, h_a, can possibly cause the formation of more, but thinner, lobes and nulls compared with the lobe structure for lower antenna heights. Which condition is preferable-- fewer, wider lobes, or more but thinner lobes--will depend on the radar coverage required, including specific fixes at given altitudes. Higher values of h_a, of course, also provides somewhat longer range coverage at low altitudes. As a second consideration, larger values of h_a result in smaller values of grazing angle, ψ, at the ground reflection point corresponding to a given null. And, from figure 3-33, smaller values of ψ have larger values for the critical height of surface irregularities, and therefore require rougher terrain if reflections are to be broken up. A third effect of increasing tower height is that higher towers extend to a greater distance the required area of the Fresnel zones which must be considered in determining reflection characteristics.

4 As an example, consider a case where the surroundingterrain is relatively uniform with surface irregularities averaging 4 feet. Figure 3-33 indicates that at 1300 MHz this would be considered relatively smooth terrain for grazing angles of 0.65 degree or less and rough terrain for higher angles. Reference to figure 3-14 indicates that for antenna heights of 35 feet or less all null angles are greater than 0.65 degree. Therefore, for these larger angles, the terrain with 4-foot irregularities would be considered rough, and lobing effects would be weak. For a greater antenna height, for example, 75 feet, the first null could occur at a grazing angle of 0.3 degree. Therefore, at this small angle (i.e., less than 0.65 degree), the terrain would be

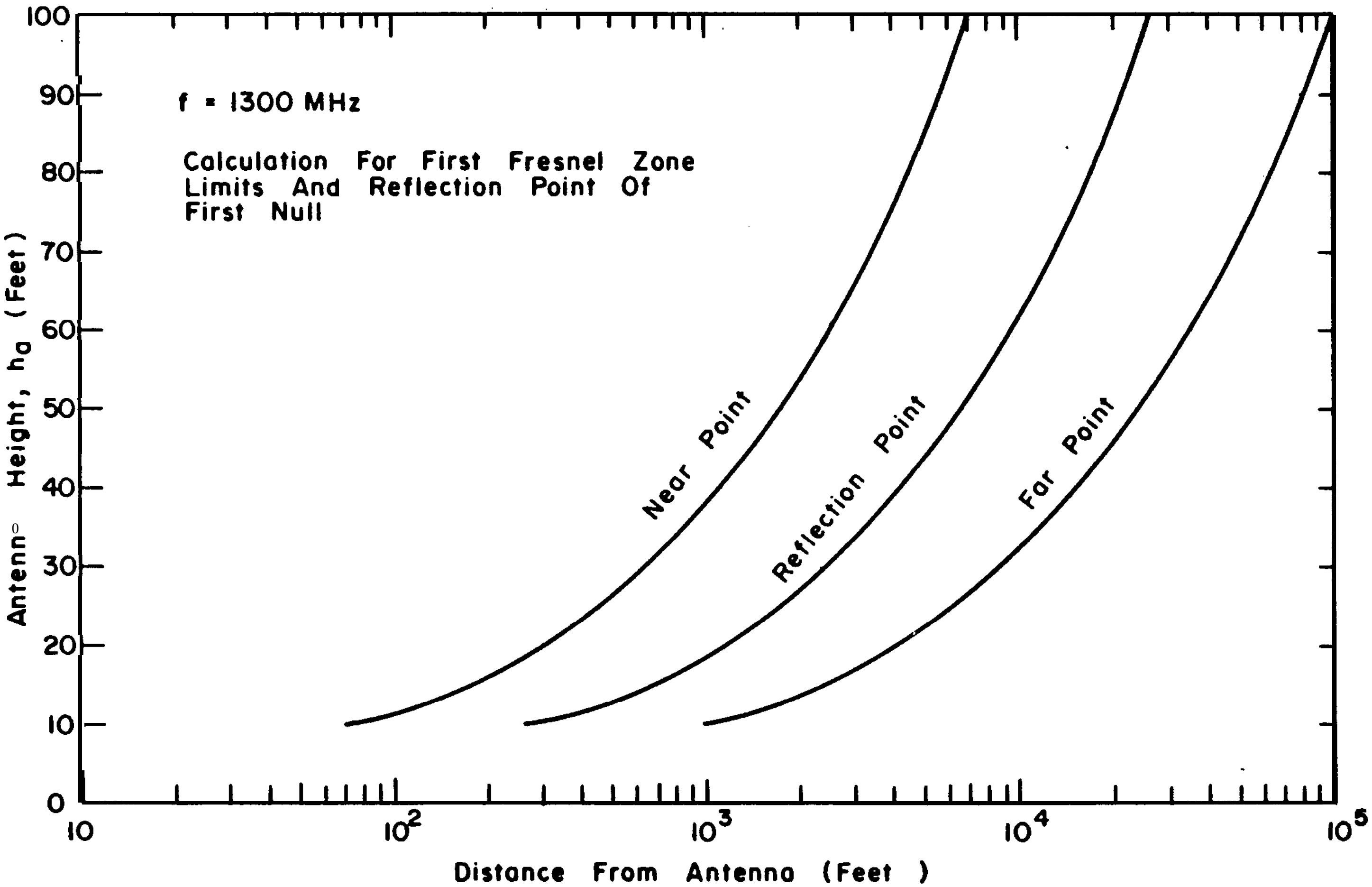


Fig. 3-34 FIRST NULL REFLECTION POINT LOCATION (ARSR EQUIPMENT)

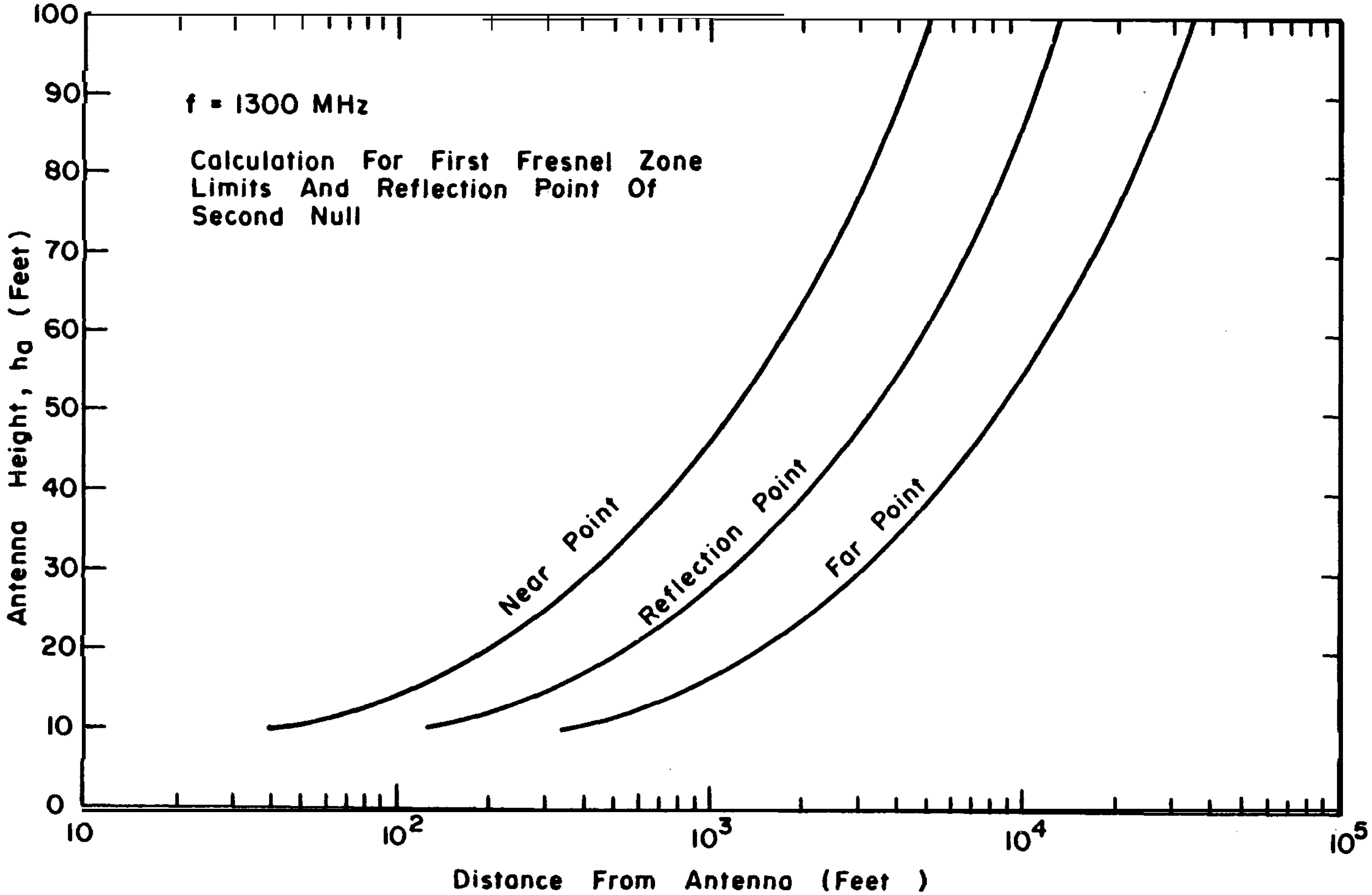


Fig. 3-35 SECOND NULL REFLECTION POINT LOCATION (ARSR EQUIPMENT)

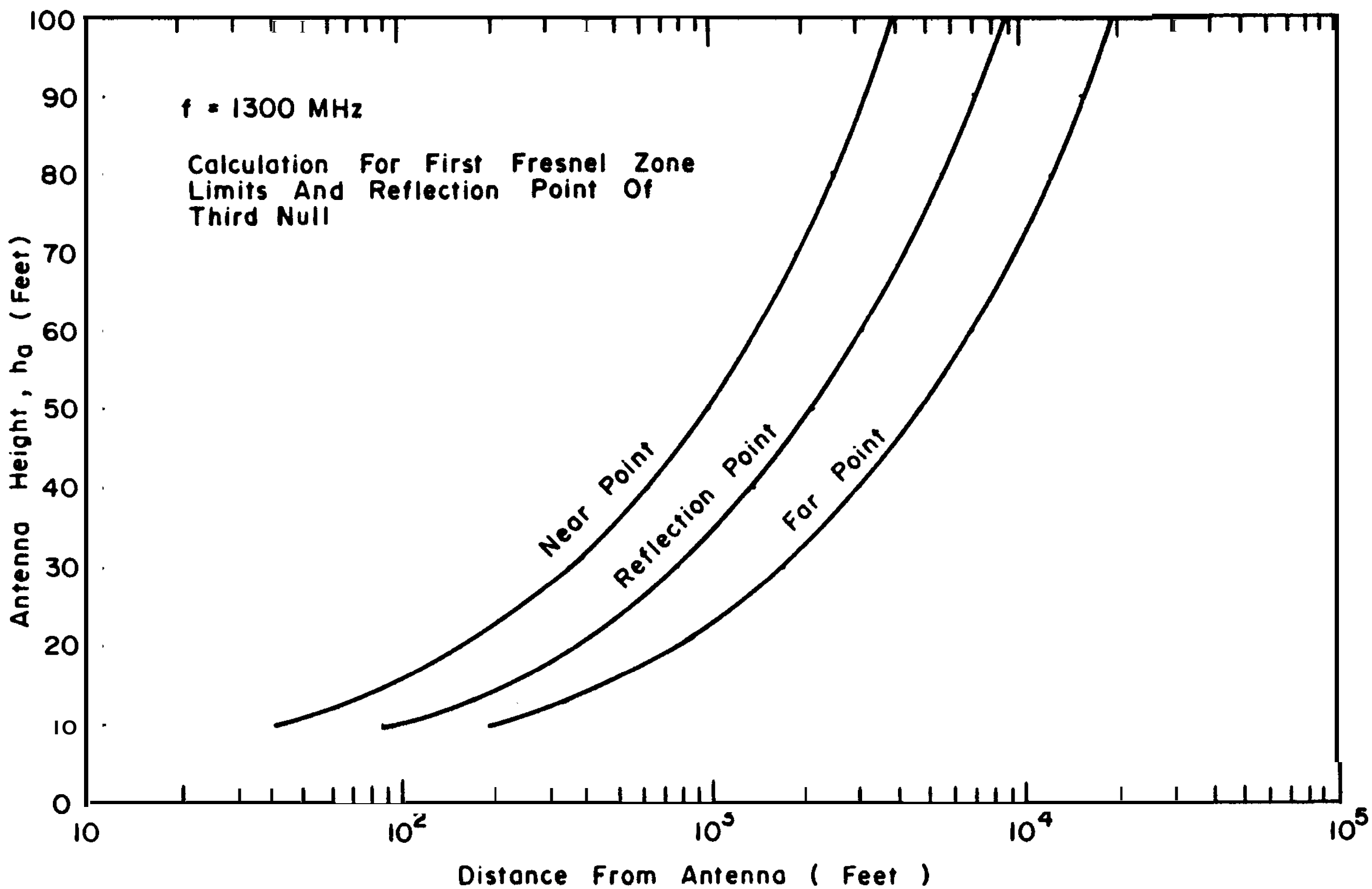


Fig. 3-36 THIRD NULL REFLECTION POINT LOCATION (ARSR EQUIPMENT)

Figure 3-37 FIRST NULL REFLECTION POINT LOCATION ATCBI EQUIPMENT

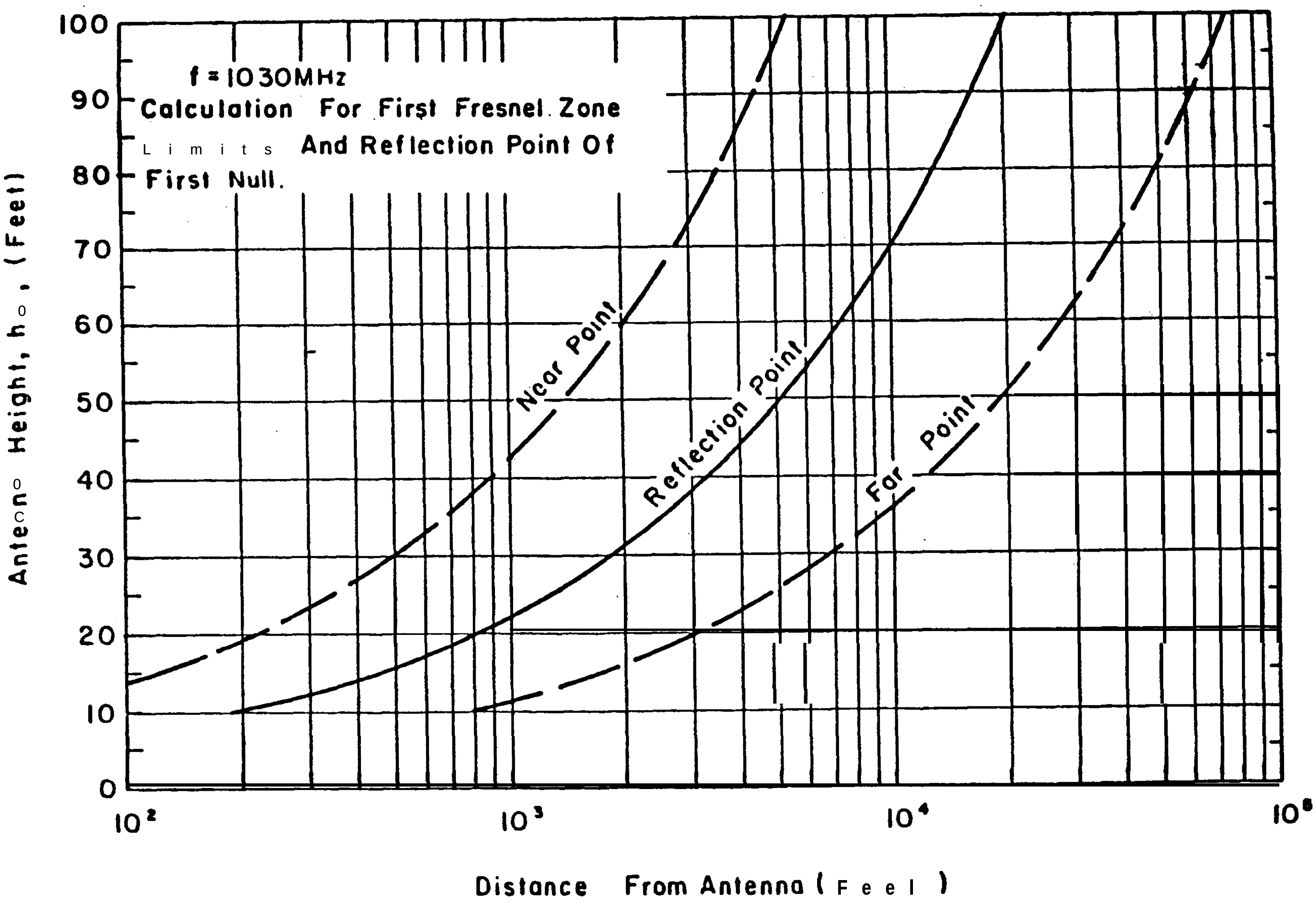


Figure 3-38 SECOND NULL REFLECTION POINT LOCATION - ATCBI EQUIPMENT

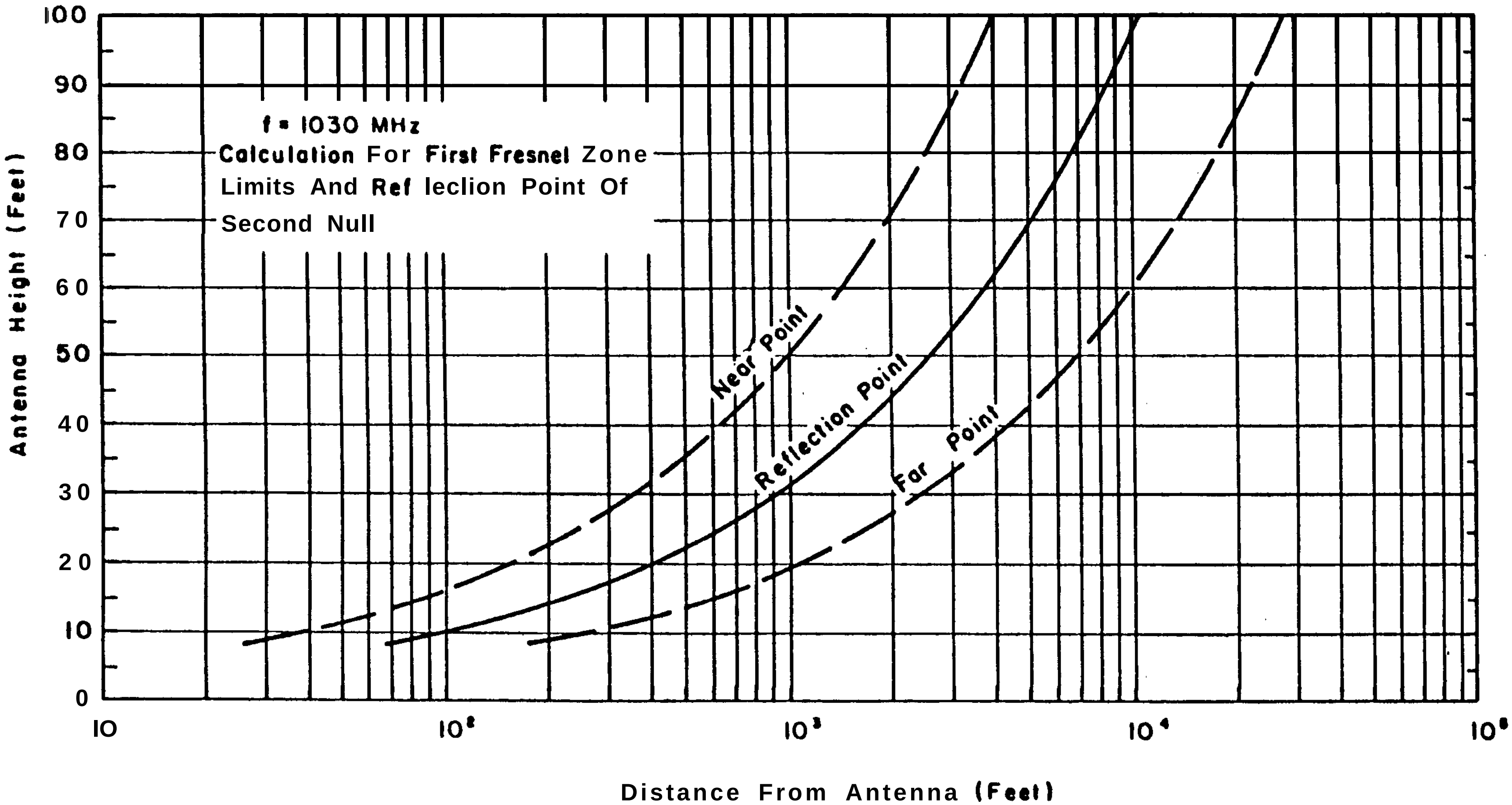
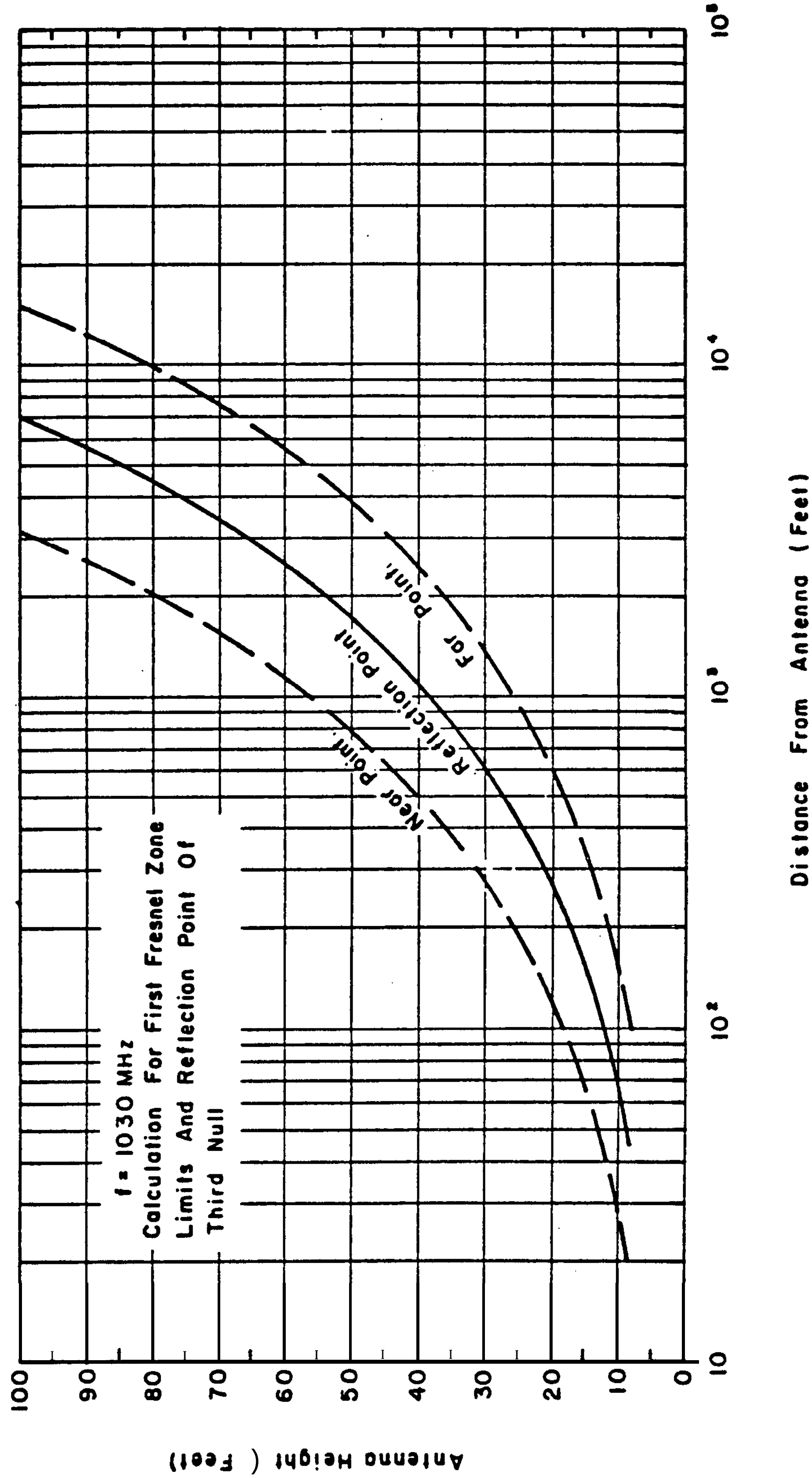


Figure 3-39 TH a D NULL REFLECTION POINT LOCATION-ATCBI EQUIPMENT



considered smooth, and reflection could occur, producing a first null. However, the highest order nulls would be weaker becasue of their required larger grazing angles, at which the terrain would be considered rough.

5 Where the terrain is not realtively uniform, the surface roughness criterion must be applied to the Fresnel zone corresponding to the null whose existence is being investigated. For example, figure 3-34 shows that for an antenna height of 45 feet, the first null reflection zone extends out to approximately 20, 000 feet or 3-3/4 nmi. Therefore, if the surface of relative smoothness extends out at least 3-3/4 nmi for the antenna, lobing will occur; if it does not, the presence of lobing is uncertain. Present theory does not cover the condition where the first Fresnel zone is only partially covered by smooth terrain, with the region near the reflection point being more heavily weighted. It should also be noted that the presence of vertical surfaces near the Fresnel zone may act to screen or otherwise break up vertical lobing effects.

(d) Reflection Coefficient Effects.

1 As indicated above, the vertical lobing relationships developed here assume the reflected wave undergoes no attenuation and a 180 degree phase reversal at the reflecting surface. This is not the case in general, but serves as a conservatively useful assumption. If greater accuracy is desired; the magnitude, p, and phase, ϕ_r, of the actual surface reflection coefficient must be included in the analysis.

2 The calculated amplitude and phase of the reflection coefficient are plotted in figures 3-40 and 3-41 for a smooth sea and dry soil as a function of the angle of reflection. Curves are give for horizontal and vertical polarization, and frequncies between 100 MHz to 3000MHz. For dry soil, the reflection coefficient is not sensitive to frequency changes, and the 100 MHz curve may also be used for 3000 MHz. It is seen that the reflection coefficient for vertical polarization is less than that for horizontal polarization.

3 The coefficient of reflection for vertical polarization varies rapidly with frequency and angle of reflection for sea water and more gradually for dry soil. The angle of reflection corresponding to the minimum point of the curves in figure 3-40 is known as the Brewster angle corresponding to a similar definition in optics. Cases of various other types of terrain not considered in figures 3-40 and 3-41 may be computed from the following equations.

Figure 3-40. MAGNITUDE OF REFLECTION COEFFICIENT

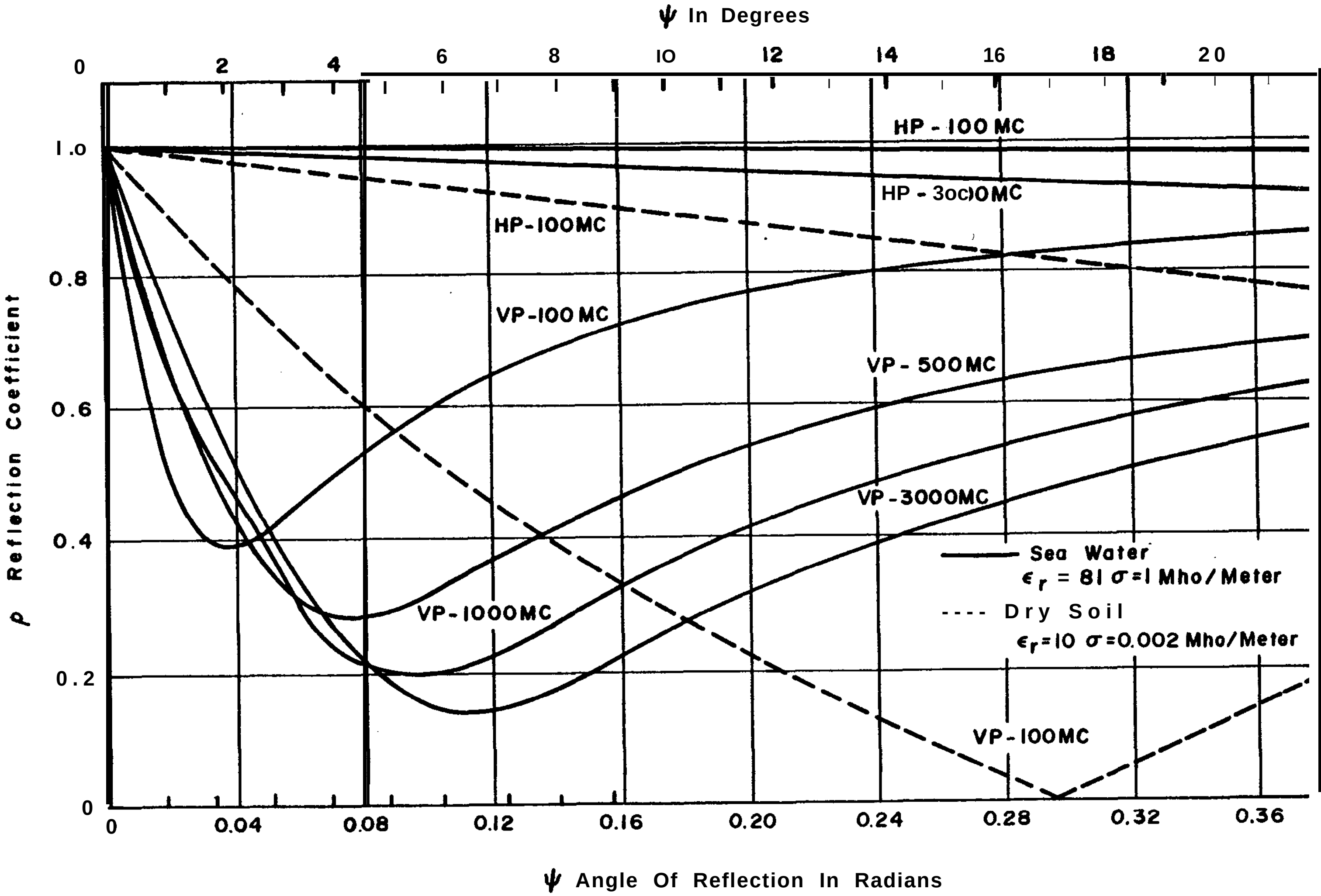
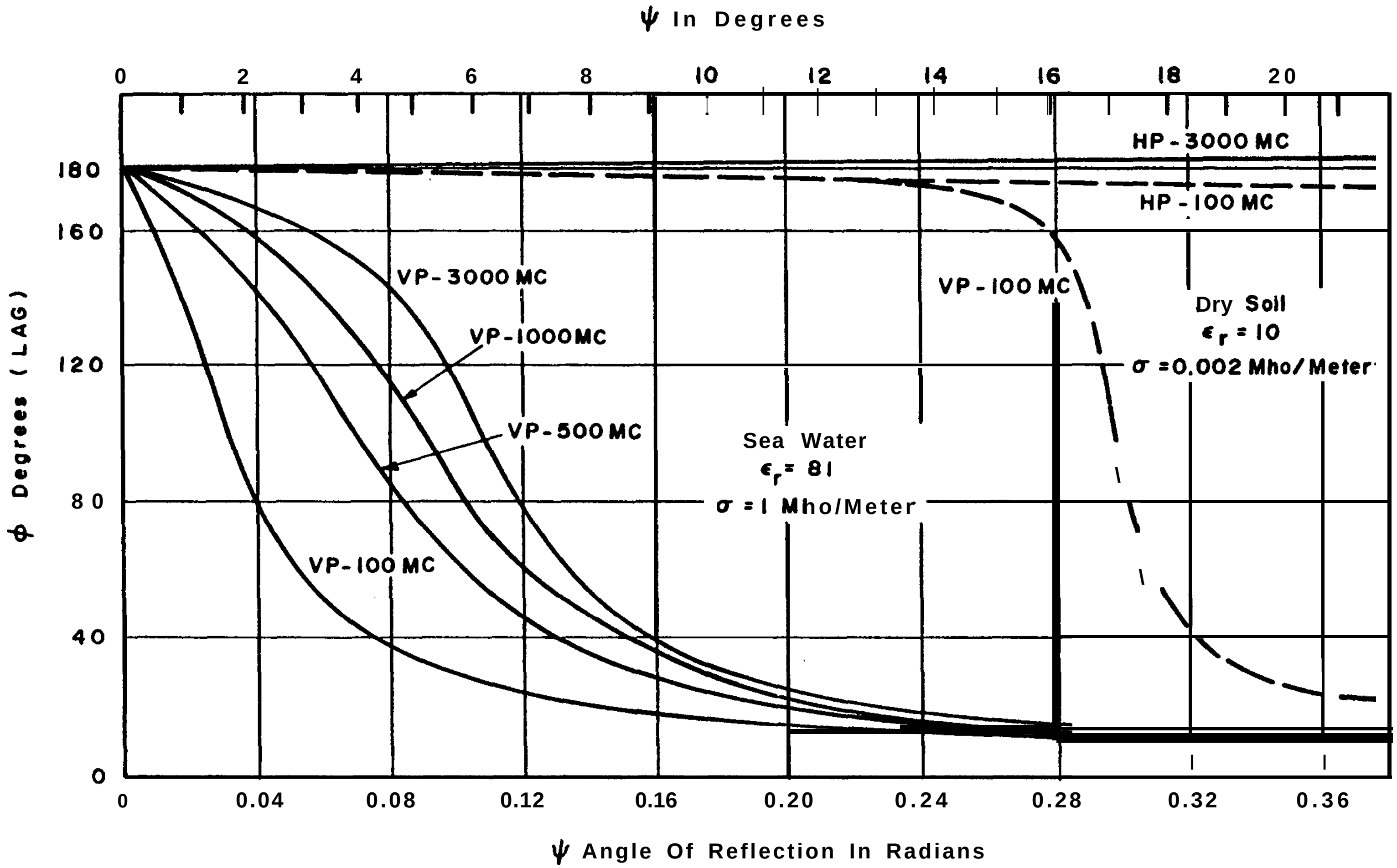


Figure 3-41. PHASE OF REFLECTION COEFFICIENT.

Note : Solid curve represents seawater.
Dot ted curve represents dry soil .



_ 4 For vertical polarization:

$$\rho \ \exp(-j\phi) = \frac{\epsilon_c \sin\psi - \sqrt{\epsilon_c - \cos^2\psi}}{\epsilon_c \sin\psi + \sqrt{\epsilon_c - \cos^2\psi}} \qquad (3\text{-}37)$$

5 For horizontal polarization:

$$\rho \ \exp(-j\phi) = \frac{\sin\psi - \sqrt{\epsilon_c - \cos^2\psi}}{\sin\psi + \sqrt{\epsilon_c - \cos^2\psi}} \qquad (3\text{-}38)$$

where

$\epsilon_c = \epsilon_r - j\,60\sigma\lambda$

ϵ_r = dielectric constant of the reflector relative to air

σ = conductivity of the reflector mhos/meter

λ = wavelength, in meters

ψ = phase angle, lagging.

Some typical ground constants are given in table 3-2.

c. Clutter.

(1) Definition. In the discussion of signal detectability given in section 3, it was assumed that only one echo signal is present withinthe range and angle sector being considered. If a few other targets are present within the total coverage volume of the radar, little or no harm is done. But if there are so many targets that they run together on the cathode-ray screen or other type of display, or if they overlap in time when time-gatedautomatic detection devices are employed, detection of a desired signalwillbeseriously affected. A profusion of echoes sufficient to produce this effect is called clutter or clutter echoes. Such echoes produced by an extended reflecting region such as the surface of the land or sea, by weather, or even by birds or insects, is called distributed clutter.

(2) Noiselike Characteristics. Distributed clutter, that is, clutter echoes from various types of terrain and from rain, have many characteristics in common with receiver noise. They are randomly fluctuating in amplitudeand phase, and in many cases they even have a probability density function like that of thermal noise. However, they differ in one important respect--their fluctuation rate is much slower, which means that their frequency spectrum is narrower.

Table 3-2

TERRAIN REFLECTION CHARACTERISTICS 3/

Type of Terrain	Relative Dielectric Constant εr	Conductivity σ, mhos/meter
Rich soil	20	3×10^{-2}
Heavy clay	13	4×10^{-3}
Rocky soil	14	2×10^{-3}
Sandy dry soil	10	2×10^{-3}
City industrial area	5	10^{-3}
Fresh water	81	10^{-3}
Sea water	81	1

3/ Reference 7

(3) Slow Fluctuation Rate. When the clutter level is much higher than the receive noise level, the detection problem is in terms of the **signal-**to-clutter ratio rather than signal-to-noise ratio. It has many properties in common with the problem of detecting a signal in thermal'noise. But, because of the slower fluctuation rate, integration of pulses is relatively ineffective; the clutter is usually correlated for time separations which may be of the order of pulse periods. Also, some clutter may be spiky in character, which means that its statistics are different from those of the receivernoise. But the basic problem of detection is the same: the signal power must,on the average, be great enough to produce a probability of detection substantially greater than the false-alarm probability.

(4) Signal Detection in Clutter. Radar detection capability, therefore, is analyzed by considering how the target echo and the clutter echoes vary with the range, so as to determine at what ranges the **target-to-clutter-**signal ratio necessary for detection is reached. In the absence of specific information on the clutter statistics, a reasonable assumption to make for the required signal-to-clutter ratio is that, for given detection probability and false-alarm probability, it corresponds to the required signal-to-noise ratio for single-pulse detection (no integration). This value, as determined from reference 5 for $P_{fa} = 10^{-6}$ is about 15.4 dB. This value, of course, must be modified by the mti improvement factor of 39 dB provided by radar signal processing. Therefore, the minimum required signal-to-clutterratio at the receiver input is 15.4 dB minus 39 dB, or -23.6 dB.

(5) Signal-to-Clutter Ratio. The signal-to-clutter (s/c) ratio is given by the ratio of the effective radar cross sections of the target and the clutter, σ_t and σ_c, if both target and clutter are subject' to the same propagation factors. However, the propagation factors may be different, because of antenna pattern effects. The criterion of detectability of the target therefore becomes

$$s/c = \frac{\sigma_t G_t G_r}{\sigma_c G_{tc} G_{rc}} \geq s/c(\min) \qquad (3\text{-}39)$$

where

G_t = radar transmit antenna gain in direction of target

G_r = radar receive antenna gain in direction of target

G_{tc} = radar transmit antenna gain in direction of clutter

G_{rc} = radar receive antenna gain in direction of clutter

$s/c(\min)$ = -23.6 dB.

As discussed in paragraph 16.a.(6), the ARSR-3 has two beams. Transmission always occurs with the lower beam. Reception can occur with either the upper or lower beam. For the shorter ranges where clutter is a problem, the upper beam would ordinarily be used.

(6) Land or Sea Clutter Cross-Section. The clutter cross-section, σ_c, is the product of the cross section per unit area, σ_o, and the area of the surface, A,, illuminated by the radar pulse. For a radar of horizontal beamwidth, θ_a radians and pulse length, τ, seconds viewing the surface at a grazing angle, ψ, this area is, for small values of ψ,

$$A_c = R\theta_a \frac{c\tau}{2} \sec \psi \qquad (3\text{-}40)$$

where R is the radar range to the surface and c is the velocityof propagation (3x 10^8 m/sec). This is shown diagrammatically in figure 3-42. Thus

$$\sigma_c = A_c \ \sigma_o \ , \qquad (3\text{-}41)$$

and once σ_o is known, both clutter cross section and s/c are readily determined for the target of interest.

(7) Clutter Cross-Section for ARSR-3. Expressing range, R, in nautical miles and using the ARSR-3 radar parameters indicated in table 2-1 gives

$$A_c = 11{,}000 \text{ R secant } \psi \quad \text{(sq. meters)} \qquad (3\text{-}42)$$

and hence

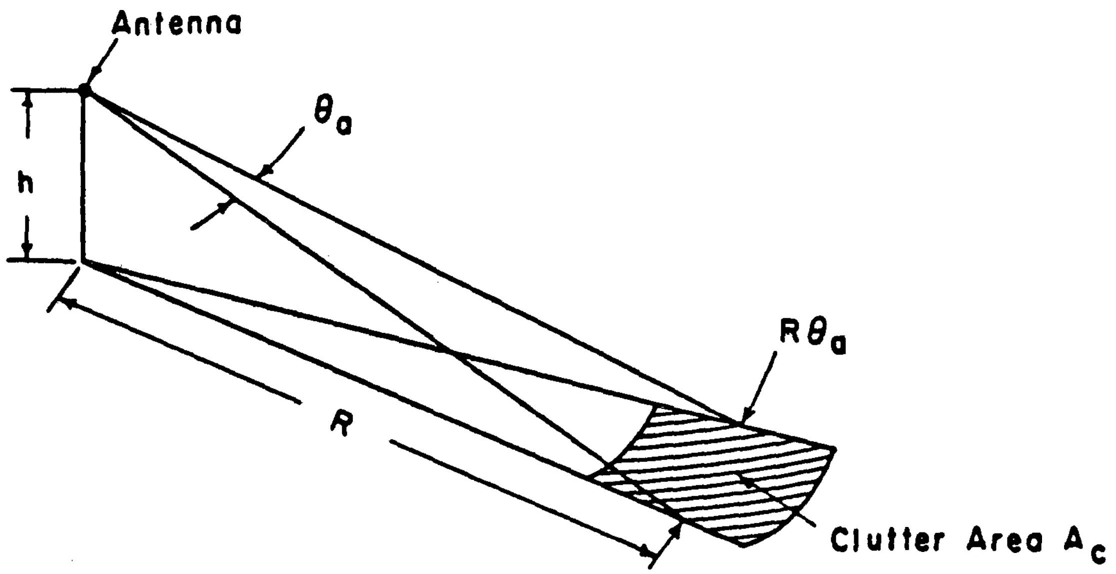
$$\sigma_c = 11{,}000 \text{ R}\sigma_o \text{ secant } \psi \text{ (sq. meters)} . \qquad (3\text{-}43)$$

σ_o in these equations has the dimensions of (m^2/m^2). It should be noted here that clutter extends outward in range only as far as the radar horizon. This distance depends upon earth curvature, atmospheric refraction, the terrain features, screening, etc. It is discussed in some detail in section 2.

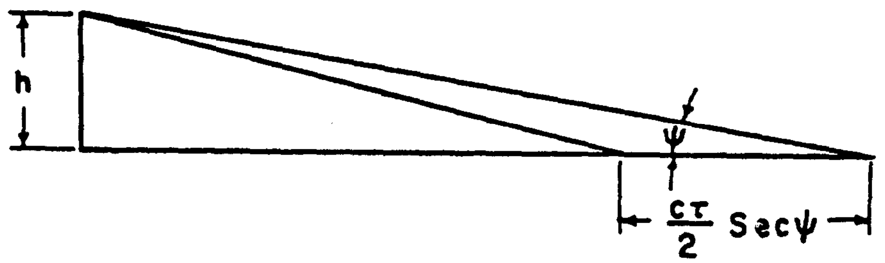
(8) Values of σ_o. The clutter cross-section per unit area, σ_o, is a parameter which exhibits considerable variation with terrain type, terrain condition (e.g., moisture content, snow cover, seasonal foliage cover, wave patterns, etc.), and grazing angle. In addition, σ_o for any given clutter cell will vary in time due to the effects of wind/wave motion and of radar beam scanning. The variable nature of clutter makes prediction of σ_o difficult and subject to considerable error. This should be borne in mind when performing clutter analyses so as to avoid elaborate computations not justified by clutter data accuracy. Simple clutter analyses may be carried out based on mean values of σ_o derived from measurement or theoretical models. Some useful σ_o data is presented in tables 3-3 and 3-4 for land and seaclutter. If the tabulated σ_o data is used, the mean clutter cross section can be computed with the aid of equation 3-41 above.

(9) Signal Detection Criterion for Clutter, Use of equation 3-39 will allow computation of the s/c ratio for a given target. It shouldbenoted here that antenna gain values used in the calculation must account for any antenna tilt employed. To a first approximation it can be assumed that the

Figure 3-42 CLUTTER PATH GEOMETRY



a) Surface Area Illuminated By Radar Pulse - Pictorial



b) Surface Area Illuminated By Radar Pulse - Profile

Table 3-3

LAND CLUTTER REFLECTIVITY

0-1° ANGLE OF INCIDENCE[4/]

Reflectivity in dB below 1 m^2/m^2
Pulse width = 1 μs, $\theta_a = 2^o$
σ_0 = median backscatter

Terrain	L-Band (1.2 Gc) σ_o	S-Band (3.0 Gc) σ_0	C-Band (5.6 Gc) σ_0
Desert	45	--	--
Cultivated Land	32 (V)	--	--
Open Woods	34 (H)	33	--
Wooded Hills	35 45	32 47	-- --
Small House Districts	--	35	35
Cities	30	--	--

4/ Reference 2

Table 3-4

NORMALIZED MEAN SEA BACRSCATTER COEFFICIENT, σ_o 5/

L-Band (1.25 Gc), 0.5-10 μs Pulse

Sea State	Pol	σ_o in dB below 1 m^2/m^2 — Grazing Angle (degrees) 0.1	0.3	1.0	3.0	10.0
0 Calm	V	---	---	68†	- - -	45†
	H	- -	---	80†	72†	60†
1 Smooth – < 1 ft Waves	V	---	---	65†	53†	- - -
	H	- -	- -	73†	62†	56†
2 Slight 1-3 ft Waves	V	87†	---	58†	53	37
	H	90†	- -	65+	59	53
3 Moderate 3-5 ft Waves	V	- -	- -	54†	43	34
	H	82†	- -	60†	55†	48
4 Rough – 5-8 ft Waves	V	- -	- -	45	38	31
	H	- -	---	52†	48†	45
5 **Very Rough** 8-12 ft Waves	**V**	- -	- -	43	38	28
	H	65†	- - -	50†	46	43†

5/ Reference 2.

† 5 dB error not unlikely.

target will be detected in the presence of clutter' if the computed value of s/c is greater than -23.6 dB, as explained in section 4 above. This occurs if

$$10 \log_{10} s/c \geq -23.6 \text{ dB} \qquad (3\text{-}44)$$

(10) Minimum Signal Detectable in Noise. The computational methods discussed here assume clutter power to be much greater than system noise. If this is not the case, achievement of the minimum required s/c ratio will not insure target detection since detection may be limited by receiver noise. Receiver noise level, N, is approximately $8(10)^{-15}$ watt, or $8(10)^{-12}$ milliwatt, or -111 dBm. With the radar operating in the diplex mode, detection of an aircraft requires that the individual received signal pulses be 5.2 dB greater than the receiver noise, or -105.8 dBm. Therefore,

$$S_{min} = -105.8 \text{ dBm} = -135.8 \text{ dBW} = 2\cdot 6(10)^{-14} \text{W} \qquad (3\text{-}45)$$

(11) Calculation of Signal Level. The expected aircraft echo signal power, S, can be estimated for comparison with both (1) the clutter power C, if clutter is measured directly with a mobile radar unit, or (2) the receiver noise level. Measured values of C must, of course, be corrected to account for differences in antenna gains between the test radar and the radar being sited. For free-space propagation, S can be determinedfromtheradar equation:

$$S = 4.29(10)^{-17} \frac{P_t G_t G_r \lambda^2 \sigma_t}{R^4} \qquad (3\text{-}46)$$

where

P_t = transmitter peak power (in watts)

G_t = transmitting antenna gain in target direction

G_r = receiving antenna gain in target direction

λ = wavelength = 0.231 meter at f = 1300 MHz

σ_t = target radar cross section (in sq. meters)

R = range to target (in nmi)

and values of the parameters are listed in table 2-1. Target detection in clutter can then be determined using equation 3-44, provided $S > S_{min}$, as given by equation 3-45.

(12) Discrete Clutter. In addition to the diffuse scattering and distributed clutter considered above, considerable radar clutter may also be generated by large buildings,water towers, powerlines and other stationary objects, and by vehicular traffic, birds and other slow moving objects.

Clutter return from these objects is usually treated separately, in much the same manner as targets. Where the resulting clutter is intolerably severe, attempts should be made to provide either (a) natural shielding of the clutter source, or (b) man-made shielding in the form of properly designed fences. The latter may be accomplished using the methods described in references 8or 9.

d. Angels.

(1) Definition. Clutter that is nonstationary and elusive is most commonly called angels. Angel echoes can be obtained from regions of the atmosphere where no reflecting objects apparently exist. They take many different forms and have been attributed to various causes, including birds, insects, and meteorological effects.

(2) Bird Echoes. Probably the most important source of angels is birds, especially for ground-based radars looking over the sea. Although the radar cross section of a single bird is small comparedwiththatof anordinary aircraft, bird echoes can be relatively strong, especially at the shorter ranges because of the inverse-fourth-power variation with range. For example, the radar cross section of a bird the size of a sea gull might be of the order of 0.01 m^2. A bird with this cross section at a range of 10 nmi will return an echo signal as large as that from a 100 m^2 radar cross section target at 100 nautical miles. When birds travel in flocks, the total cross section can be significantly greater than that of a single bird. Because the radar display collapses a relatively large volume of space into a small radar screen, 'the display can appear cluttered with bird echoes even though only a few birds can be seen by visual examination of the surrounding area. Birds can fly at speeds up to 50 knots (or higher if carried by the wind). This is probably too high a speed to be rejected by most mti radars. The small echoing area of birds means that they are primarily seen at relatively short ranges, 20 to 25 miles or less, for medium-power search radars.

(3) Insect Echoes. Insects, even'though small, may also be readily detected by radar. A direct correlation has been shown between nighttime angel echoes detected by radar and observations of insects within a search- , light beam illuminating the same volume as the radar. Insects are usually carried by the wind; therefore, angels due to insects might be expected to have the velocity of the wind. Both insect and bird echoes are more likely to be found at the lower altitudes, near dawn and twilight. Since themajority of insects are incapable of flight at temperatures below 40 degrees or above 90 degrees Fahrenheit, large concentrations of insect angel echoes would not be expected outside this temperature range.

(4) Anomalous Propagation. Radar waves directed at low angles can be reflected or refracted to the ground by (a) an atmospheric layer of considerable refractivity, (b) sharp refractive gradients over a local terrain feature such as intense moisture gradient over a river or lake, or (c) wind-carried refractive inhomogeneities. The echoes return to the radar by the same path. In essence, the radar sees the ground or some object on the ground as a target. For example, a very realistic target might be tracked by the

radar operator if the deflected radar beam happened to be illuminating a moving train. An apparent moving target might also be indicated even when the beam observes a stationary object on the ground provided the reflecting portion of the atmosphere is itself in motion. At a range of 50 miles, a horizontal reflecting layer rising 3 m/sec can cause an apparent echo to move at 300 mph.

(5) Control of Angels. In general, angels caused solely by meteorological effects are beyond the control of radar siting engineers and do not require unusual consideration when selecting a particular radar location within a limited region. Angels due to birds and insects, however, do merit some consideration insofar as their severity can be controlled by the radar stc characteristics.

e. False Targets.

(1) Beacon False Targets.

(a) Cause. As discussed in chapter 2, reflecting surfaces can constitute a severe problem to ATCRBS operation due to the generationof false targets. These most commonly occur when the main beam of the ATCRBS directional antenna successfully interrogates an airborne transponder via a reflected signal path. This will produce an apparent target at the azimuth of the reflector and at a range corresponding to that of the reflected path, which is always greater than the direct path range. This range difference is generally imperceptible on a normal display, however. The reflector and path geometry are illustrated in figure 2-20. The range and azimuth region over which false target effects may be observed are limited by (1) interrogation link power and sensitivity, and (2) reflector dimensions and aspect angle. This assumes that the ATCRBS interrogation link determines the maximum range of the system, as discussed in paragraph 22. Also discussed in chapter 2, sls and isls are employed in ATCRBS equipment to reduce the incidence of beacon false targets.

(b) Radar Cross Section of False Target. In order todetermine the amount of energy reflected by the reflecting object, its bistatic radar cross section, σ_b, can be determined from (reference 10):

$$\sigma_b = \frac{4\pi A_{eff}^2}{\lambda_i^2} , \qquad (3\text{-}47)$$

where Xi = interrogation wavelength (0.291 m), and A_{eff} = effective area of the reflector (m^2), which is equal its cross-sectional area, A, multiplied by the sine of the angle of incidence, α:

$$A_{eff} = A \sin\alpha \qquad (3\text{-}48)$$

(c) Flat Rectangular Reflector. For a flatrectangular reflector of height h and width w

$$A_{eff} = hw \sin\alpha \quad , \qquad (3\text{-}49)$$

where these relationships can be used except where the reflector width exceeds that of the ATCBI antenna beamwidth. In that case

$$w = \frac{\pi}{180} R_2 \theta_{ai} \qquad (3\text{-}50)$$

where

R_2 = range between antenna and reflector

θ_{ai} = azimuth beamwidth, in degrees, of interrogation antenna

and w and R2 are measured in the same units. For a flat lossless reflector, A_{eff} can be determined using the nomograph in figure 3-43a. The nomograph construction assumes θ_{ai} = 2 degrees, which is the beamwidth of the ATCBI directional antenna in conjunction with the ARSR-3.

(d) Maximum Range for False Interrogation. With A_{eff} known, the maximum range over which targets can be falsely interrogated can be determined from the bistatic radar equation

$$S_{min} = \frac{P_d G_i G_t A_{eff}^2}{(4\pi R_1 R_2)^2 L_s} \qquad (3\text{-}51)$$

where

P_d = ATCBI peak power output

G_i = interrogator antenna gain

G_t = transponder antenna gain

R_1 = range between reflector and target

R_2 = range between antenna and reflector

L_s = system losses, and

S_{min} = transponder minimum sensitivity

in consistent units. Rearranging gives

$$R_1 = \sqrt{\frac{P_d\ G_i\ G_t\ A^2_{eff}}{(4\pi R_2)^2\ S_{min}\ L_s}} \qquad (3\text{-}52)$$

(e) Example of Maximum Range. Equation 3-51 can be conveniently solved for R1 under the conditions

S_{min} = -74 dBm

L_s = 5.5 dB (see reference 8)

G_i = 22.5 dBir

G_t = 2 dBir

with the aid of the nomograph in figure 3-43b. A brief examination of the nomograph indicates that for transmitter power on the order of 200 watts, reflectors of 300 square feet effective area within 1000 feet of the interrogator can cause false targets to appear at ranges within 60 nmi of the ATCBI installation. With a transmitter power of only 50 watts, the same reflector can cause false targets to appear at any range out to 30 nmi.

(f) Angular Regions Affected by False Targets. The angular extent of the sectors affected by false targets is defined in figure 3-44. The incident rays are set 1° beyond the edges of the reflectors to account for scanning of the antenna beam across the reflecting surface, False targets are displayed at azimuth angles between δ_2 and 61. These occur due to targets in the angular sector between 52 and ζ_1. The false targets are displayed at ranges corresponding to R1 + R2.

(g) Characteristics of Beacon False Targets. Some of the characteristics of beacon false targets which are important in differentiating them from second-time-around returns, near synchronous fruit, etc., are:

1 The false target and the normal replies will generally appear in pairs. There is an exception to this, however, if the aircraft is in a screened region for direct interrogation, but can be interrogated via a reflected path.

2 The range of the reflection will, at all times, be greater than the ranges of the normal reply. If the range of the normal reply is increasing or decreasing the same change in range will apply to the reflection,

Equation: $A_{eff.} = hw \sin a$

SOLUTION.

1. DETERMINE WIDTH OF REFLECTOR AND RANGE FROM TRANSMITTER SITE. IF ACTUAL WIDTH OF REFLECTOR IS GREATER THAN INCIDENT BEAMWIDTH AT THAT RANGE AS DETERMINED FROM THE "A" SCALE USE RANGE SIDE OF SCALE, OTHERWISE USE WIDTH SIDE.

2. PLACE STRAIGHT EDGE BETWEEN ABOVE POINT ON "A" SCALE AND POINT ON "B" SCALE EQUAL TO HEIGHT OF REFLECTOR AND OBTAIN ACTUAL AREA ON "C" SCALE.

3. FROM THAT POINT ON THE "C" SCALE LAY THE STRAIGHT EDGE TO A POINT ON THE "D" SCALE CORRESPONDING TO ANGLE OF INCIDENCE. THE INTERSECTION ON THE "E" SCALE YIELDS THE EFFECTIVE AREA IN FT.²

4. IF WIDTH OF REFLECTOR IS GREATER THAN ANTENNA BEAMWIDTH AS PER STEP NO. 1, OMIT STEP NO. 3 AND USE ACTUAL AREA OBTAINED IN STEP NO. 2 TO COMPLETE THE SOLUTION.

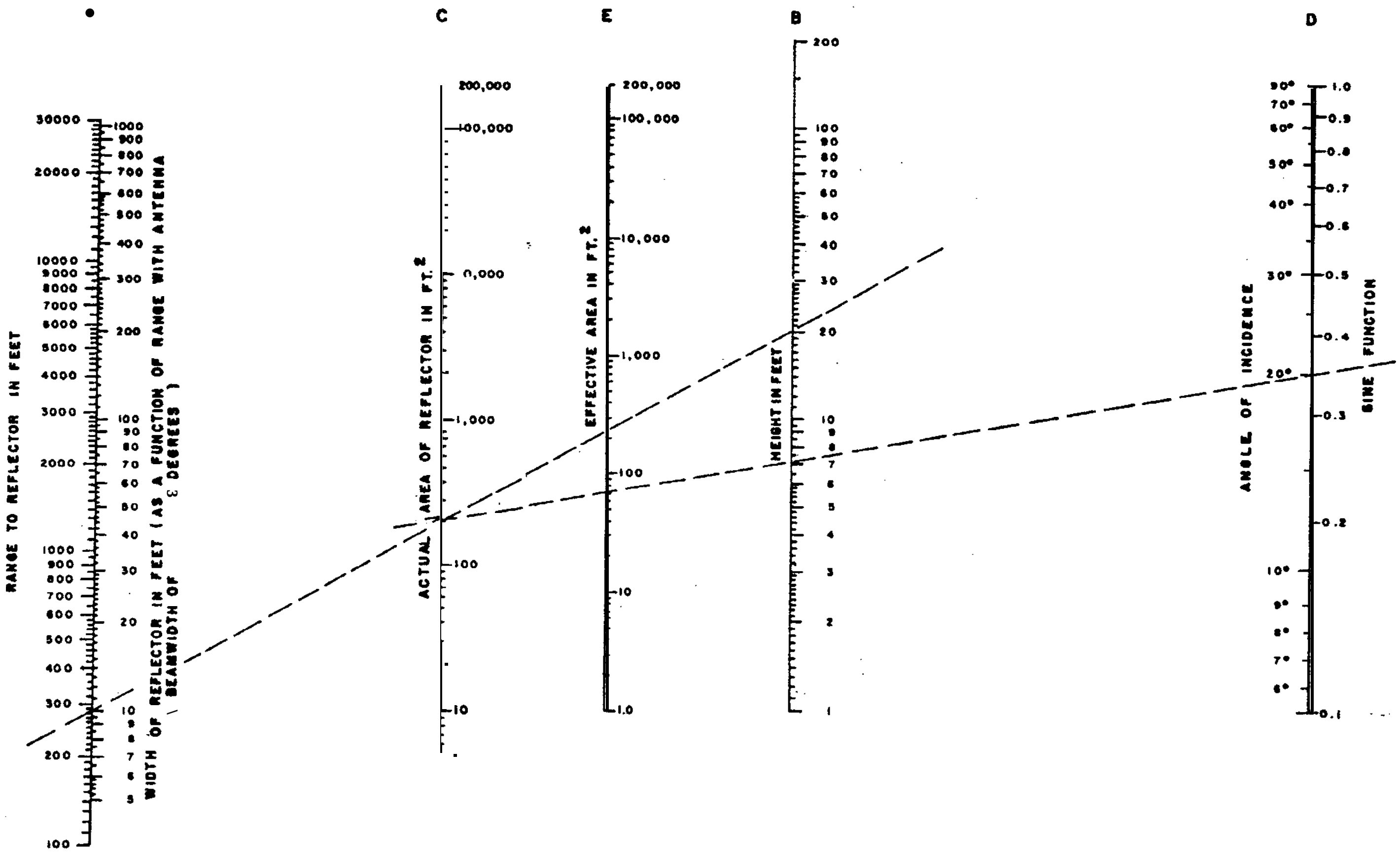


Fig. 3-43a BEACON REFLECTION NOMOGRAPH - EFFECTIVE AREA DETERMINATION

Equation : $R_2 = \sqrt{\dfrac{P_d G_i G_t A_{eff}^2}{(4\pi)^2 R_1^2 S_{min} L_s}}$

SOLUTION :

1. LAY STRAIGHT EDGE BETWEEN POINT ON "F" SCALE EQUAL TO RESULT OF STEP NO.2 OR NO.3 OF FIG.2-48A, AND A POINT ON THE "G" SCALE RELATING TO TRANSMITTER PEAK POWER, THUS LOCATING AN INTERSECTING POINT ON THE DIMENSIONLESS "H" SCALE.

2. PIVOT THE STRAIGHT EDGE AROUND THAT POINT ON THE "H" SCALE TO INTERSECT A POINT ON THE "J" SCALE CORRESPONDING TO RANGE FROM THE TRANSMITTER TO THE REFLECTOR. THE RESULTING INTERSECTION WITH THE "K" SCALE YIELDS THE MAXIMUM RANGE OF THE REFLECTION.

NOTES

1. MAXIMUM RANGE OF REFLECTION FOR AIRCRAFT TRANSPONDER WITH A MINIMUM TRIGGERING LEVEL OF - 74 dBm

2. ASSUMED VALUES FOR ANTENNA GAINS AND SYSTEM LOSSES ARE :

G_i = 22.5 dbir
G_t = 2 db
L_s = 5.5 db (Transmission Line Losses)

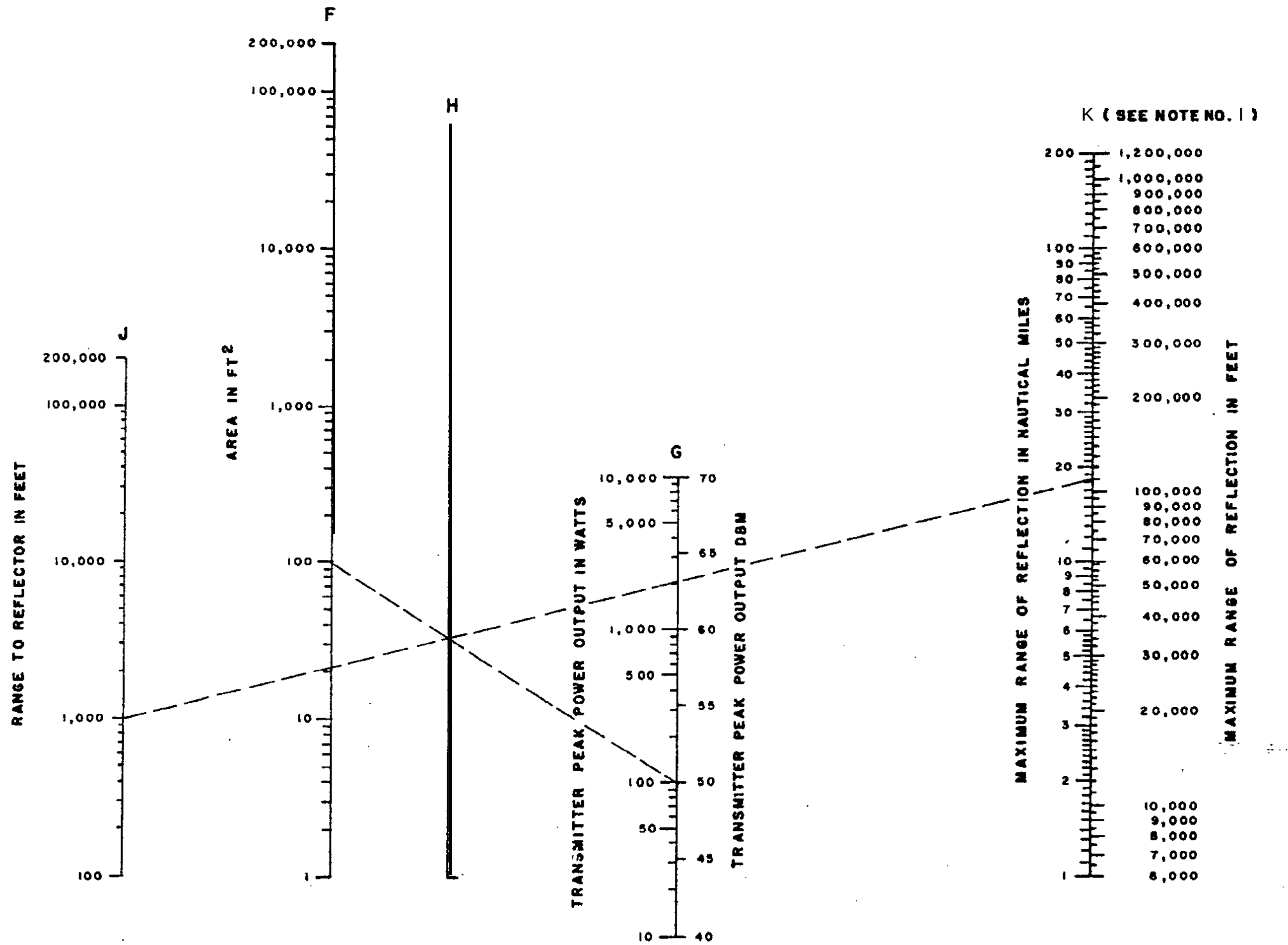
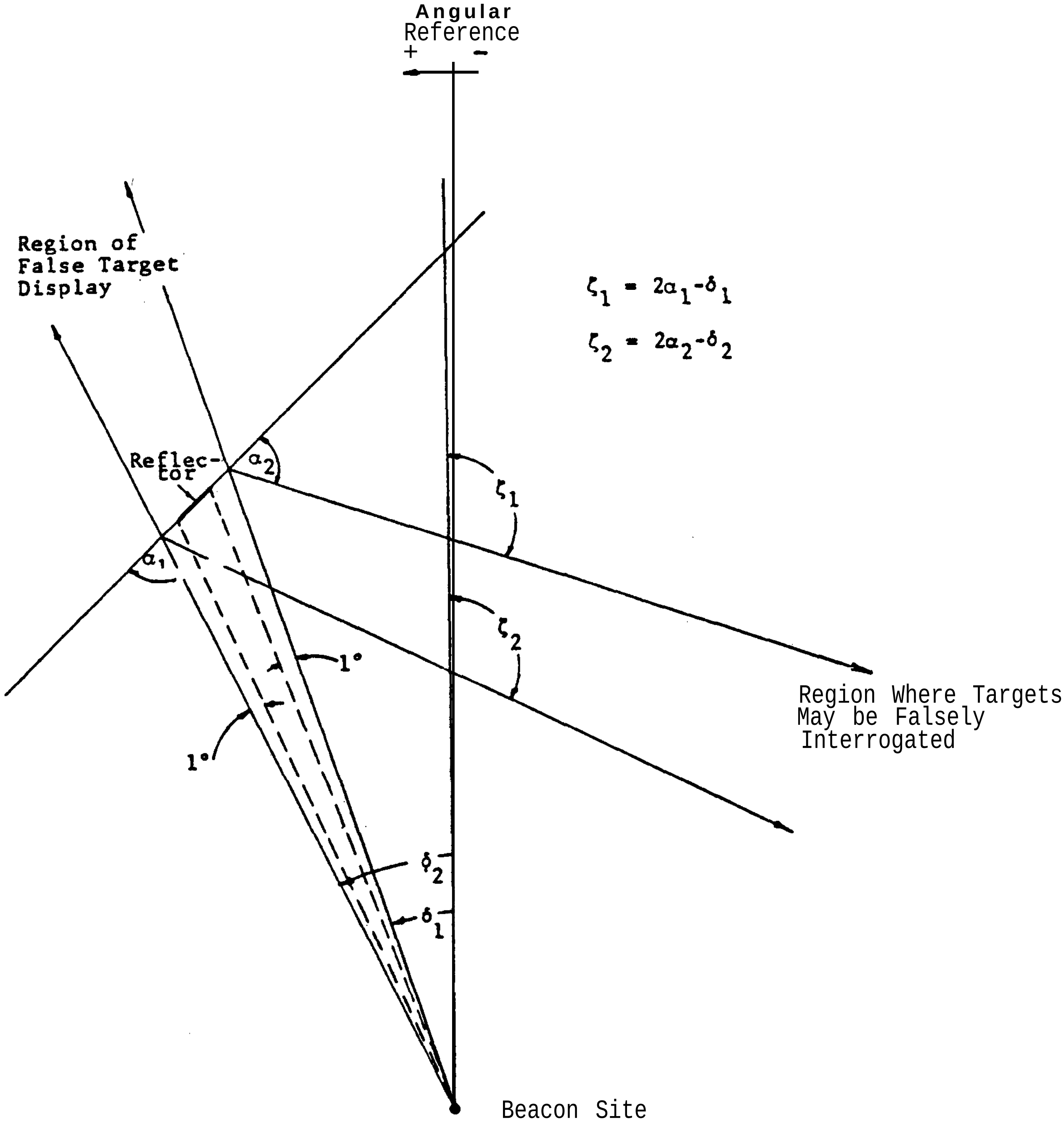


Fig . 3-43 b BEACON REFLECTION NOMOGRAPH-MAXIMUM RANGE DETERMINATION

Figure 3-44 BEACON FALSE -TARGET ANGULAR GEOMETRY



(h) Reflectors Likely to Cause False Targets. Because of the importance to air traffic control operations, all en route siting analyses should include an assessment of the locations where beacon false targets may be expected to determine the impact of overall ATC operations. Metal buildings or building roofs, water towers, fences, parked aircraft, etc., within 1 mile of the radar site should be considered as primary potential sources of reflected false targets. Large reflecting surfaces at even greater distances may also cause difficulties as can be seen from figures 3-43a and b.

(2) Radar False and Unwanted Targets.

(a) General. False targets may be generated in ARSR equipment by much the same reflection mechanism as described above. These will occur in the same areas as beacon false targets, but will generally be less severe in effect. As a consequence, it is usually acceptable to ignore reflected radar false target effects in favor of acarefulconsideration of beacon false targets.

(b) Various Moving Targets. Of more serious concern are unwanted radar targets caused by the detection of moving targets other than aircraft. These include automobiles, railroad trains, birds,etc. Thisoccurs since the undesired targets are of sufficient size that they can be detected, and since their velocity is outside the radar's mti rejection region. Some reduction in the direction of unwanted echoes may be achieved through the proper use of radar's stc or css capabilities, but efforts should be made to minimize this problem at the time of site selection. To do this,sites should be selected which provide natural shielding of the nearby highways and railroad lines. Where this is impossible, landscaping or other artificial means to provide the necessary screening should be considered. In addition, selection of sites where visible vehicular or rail traffic travels along a radar tangential path will minimize the false targets produced.

f. Tangential Course Problems.

(1) Cause. The ARSR mti receiver operates to reduce the appearance of stationary targets (clutter) on the radar ppi display. This is commonly done, as described in chapter 2, by using canceler networks with response characteristics dependent upon the observed target Doppler frequencies approaching zero. Even moving targets may be invisible to an mti radar if their direction of flight causes the radial component of their velocity to approach zero. This occurs as the target flight path becomes tangential to circles drawn about the ARSR site. As a consequence, ARSR site selection should include careful examination of airways which carry traffic on tangential flight paths for the potential loss of radar coverage.

(2) Significance of Coverage Loss. Loss of coverage is said to occur whenever signal dropoutcausesmissed detection for a period of three (or more) consecutive radar scans. Remembering that coverage loss due to tangential courses is a problem which affects only the radar's mti receiver, consideration can probably be limited in most cases to a region within 10 or 15 nmi of the radar site. Beyond this range, clutter is usually not a

factor and the normal or log radar receiver is employed. Exceptions occur where mountains or other terrain features cause clutter, and hence require mti usage to greater ranges.

(3) Critical Dropout Time. Missed detection on three consecutive scans can, in some cases, occur if signal dropout lasts over a time duration, TD, just exceeding, or equal to two radar scan periods,i.e., if TD $= 120/w_r$, where TD is the critical dropout time (sec) and w_r is the radar antenna scan rate (rpm). For the ARSR-3 with its 5 rpm scan rate, TD = 24 sec.

(4) Minimum Detectable Radial Velocity. The Doppler frequency, f_d, of the target signal is equal to 2 V_r/λ, where V_r is the target radial velocity component with respect to the radar, and λ is, wavelength. Due to the shape of the mti response curve (figure 2-9), targetshaving radialvelocity (range rate) below some minimum value, V,, will not be readily detectable. This minimum'detectable radial velocity is dependent upon several factors including: (a) the basic mti canceler response, (b) the particular form of velocity shaping employed, and (c) the radar prf jitter characteristics, and hence is not readily specified with accuracy at the time of siting. It is probably sufficient, however, for preliminary analyses, to assume a minimum detectable radial velocity of 15 knots. This is based on assuming target detectability is impaired where the response is 6 dB below the average response (figure 2-9).

(5) Tangential Path Geometry. In addition to the maximum signal dropout time, TD, another parameter of extreme importance is the maximum distance, L_{dm}, the aircraft travels during the dropout time. As can be seen from figure 3-45, Ldm = 2 d tan α, where d is the distance from the radar to the airway. In turn, a = sin" (V_{rm}/V_g), where V_g is the target ground speed. Combining these two relationships:

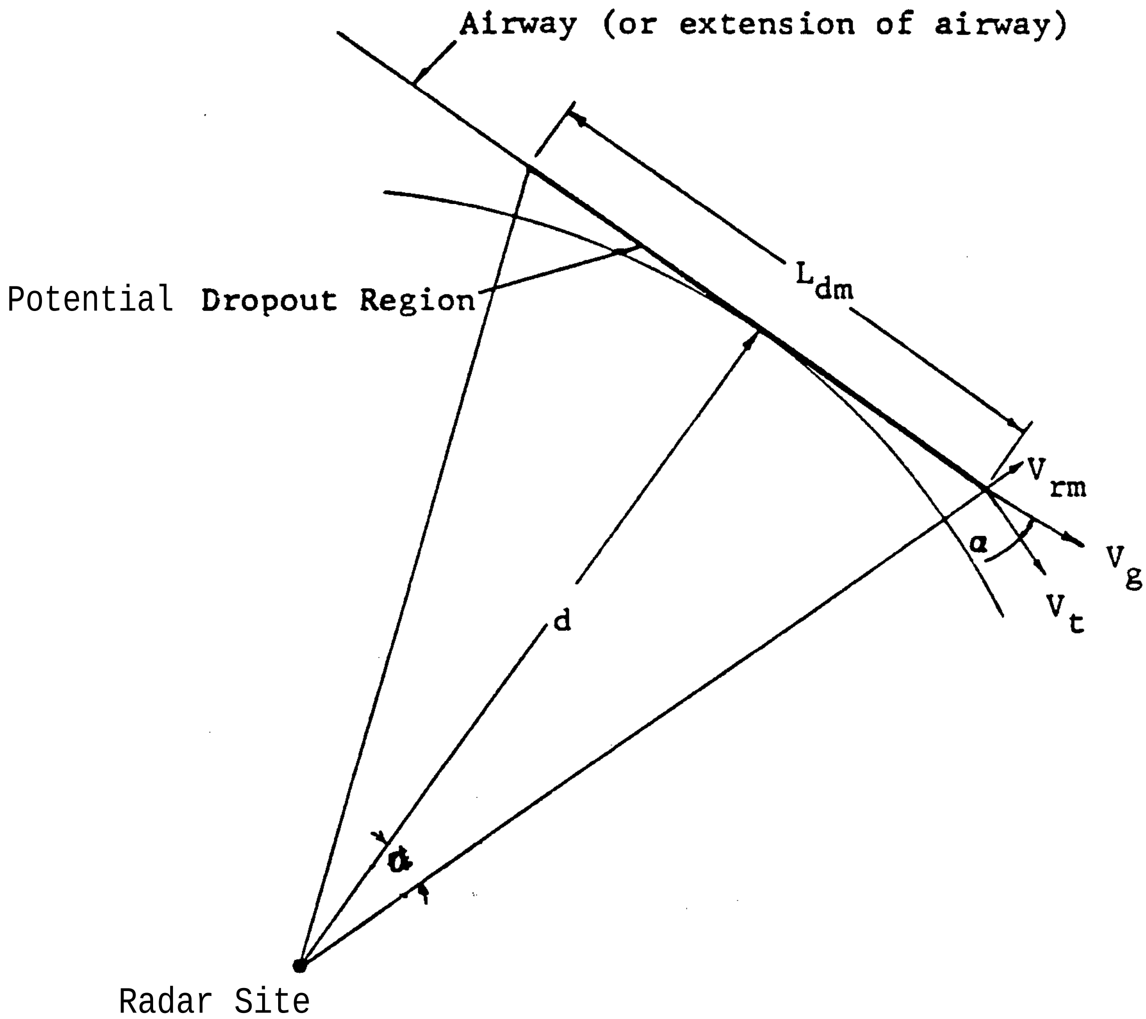
$$L_{dm} = 2d\tan \sin^{-1} \frac{V_{rm}}{V_g} \tag{3-53}$$

with the results graphed in figure 3-46.

(6) Coverage Dropout Region. As can be seen from figure 3-45, L_{dm} is centered on the point of tangency between-the airway, or its extension, and a circle about the ARSR site. The distance, L_d, of ACTUAL dropout corresponds to the region of overlap between the airway plan, and L_{dm}. This is illustrated in figure 3-47. As isreadily apparent, Ld may be considerably less than L_{dm}. For each airway where coverage dropout is possible, the distance Ldm can be determined from figure 3-46. Map study of the local air routes will then allow the actual dropout region, and L_d, to be determined.

(7) Dropout Time and Distance. Once known, Ld can be used together with the aircraft velocity to determine the duration, Td, of coverage dropout.

Figure 3-45 TANGENTIAL PATH GEOMETRY



d = Distance from Site to Airway at Tangent Point

L_{dm} = Maximum Distance of Coverage Dropout

V_{rm} = Minimum Radial Velocity Detectable by MTI

V_g = Target Ground Speed

V_t = Target Tangential Velocity

2α = Maximum Angular Extent of Dropout Region

Figure 3-46 MAXIMUM COVERAGE DROPOUT DUE TO TANGENTIAL TARGETS

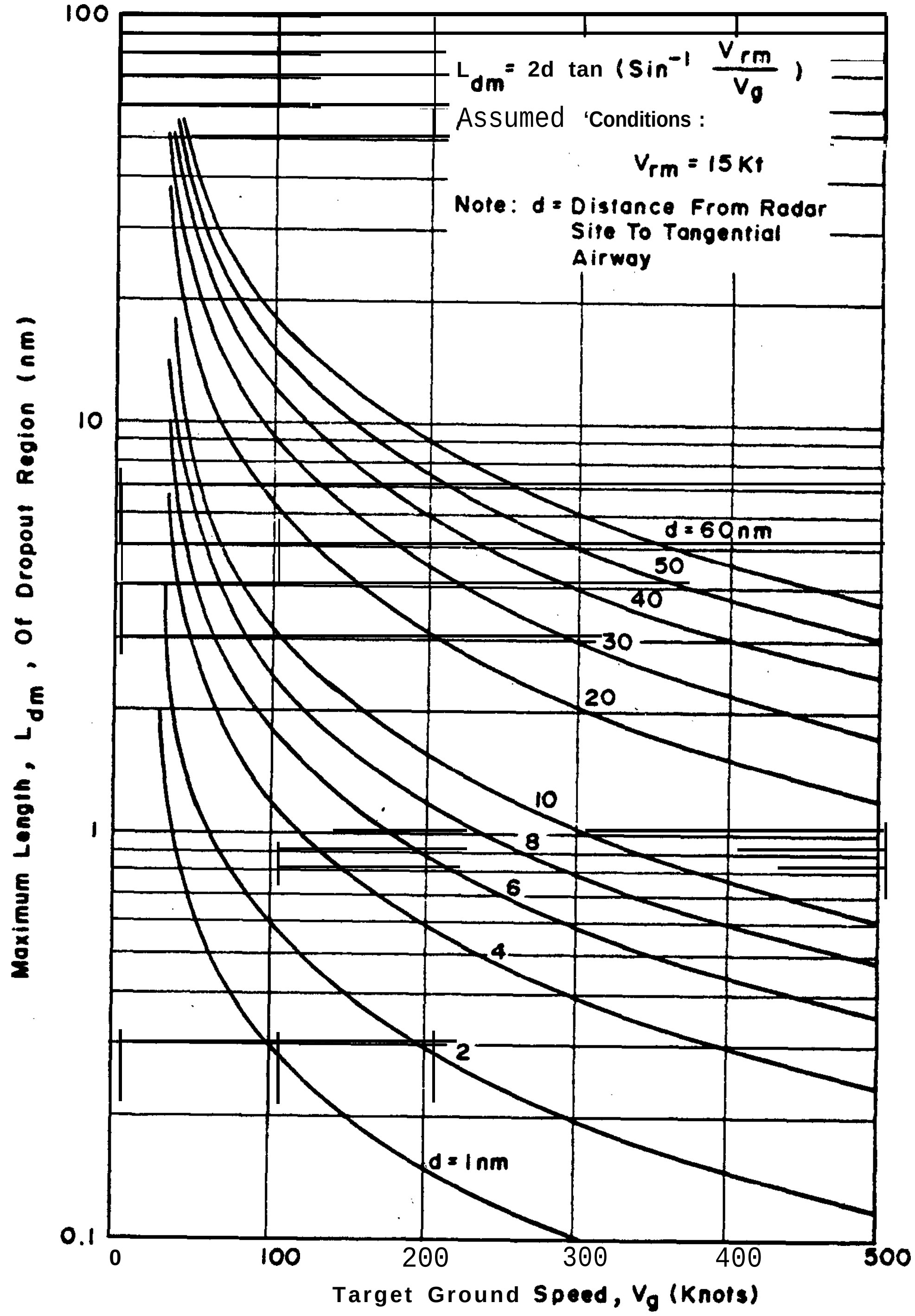
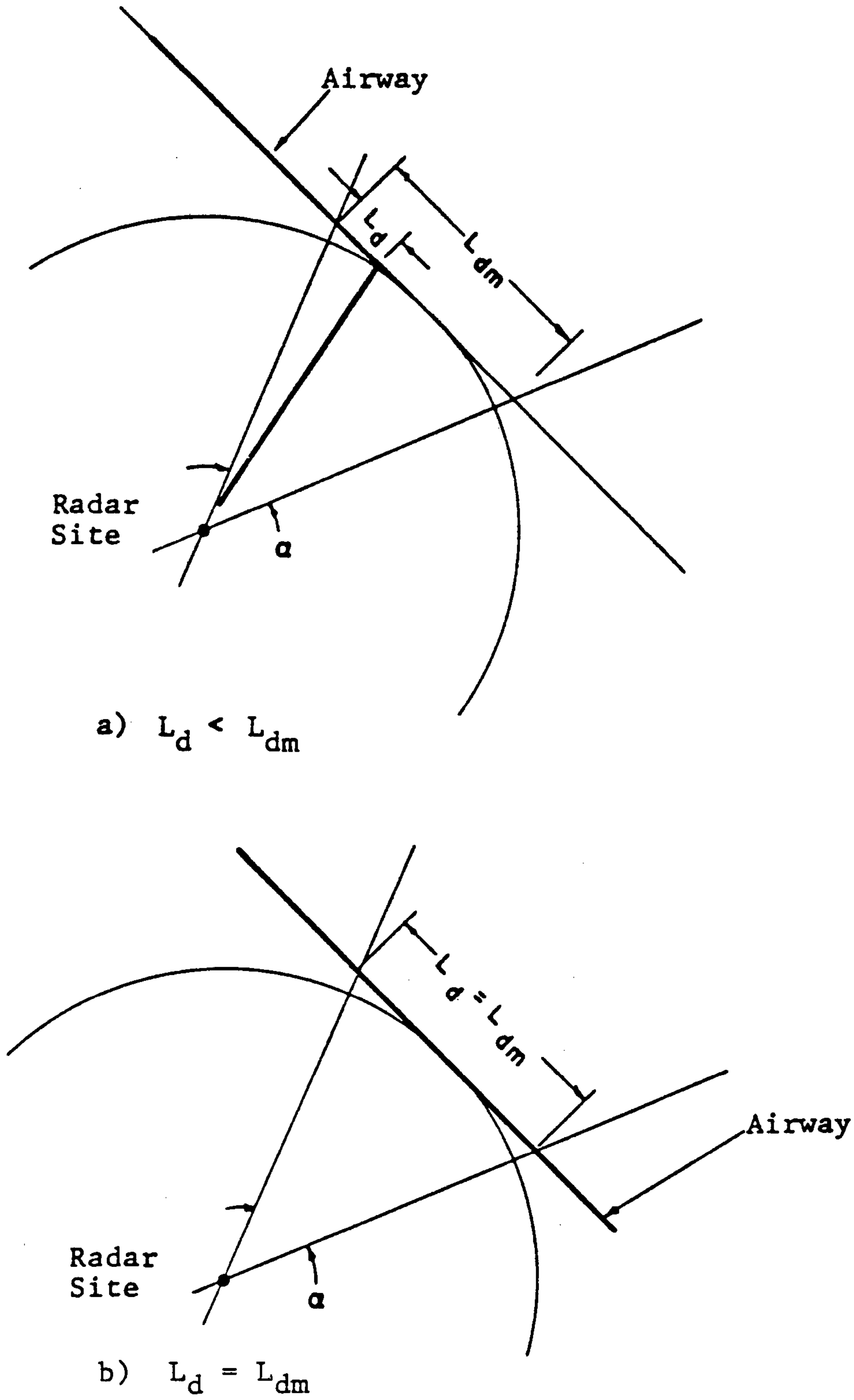


FIGURE 3-47. COVERAGE DROPOUT REGION



This is given by

$$T_d = 3600 \frac{L_d}{v_g} \qquad (3\text{-}54)$$

where Td is given in seconds, L_d in nautical miles, and v_g in knots. Equation 3-54 is plotted in figure 3-48. Tolerablecoverage dropout will beexperienced where the value of T_d so determined is less than 24 seconds, the value of T_d derived earlier. Further consideration of a site where T_d < TD, for any airway within the (usually 10 or 15 nmi) range region of mti receiver usage, should be given only after coordination with Air Traffic and Flight Standards Division representatives.

40. SOURCES/CAUSES OF DEGRADED PERFORMANCE.

a. Introduction. Radar performance is materially affected by the environment, and therefore the geographic location, in which the radar operates. The two most important factors which influence radar/beacon coverage are the earth's surface and its atmosphere.

(1) Earth's Surface. The earth's surface or terrain in the vicinity of the radar/beacon antenna can alter the free-space radiation pattern as well as produce unwanted signal returns. The extent of these earth-surface effects depend on the effective antenna height, surface roughness, terrain features, and the presence of natural or manmade obstacles about the site. The specific character of these surface-related parameters determines the radar/beacon coverage obtainable by virtue of the screening, lobing, false targets, and/or clutter they produce.

(2) Atmosphere. The earth's atmosphere within the geographical region of the site can also affect radar/beacon performance by (1) refraction caused by an inhomogeneous atmosphere, (2) attenuation due to severe weather conditions, and/or (3) chemical damage to thecomponents of the radar/beacon system from corrosive agents (or contaminants) in the atmosphere. These sources of system performance degradation are discussed below.

b. Site Eievation and Surface Roughness.

(1) Site Elevation Effects. The effect of site elevation on the radiation pattern and coverage of the radar/beacon antenna may be seen in figure 3-49. A comparison of radiation patterns between the high-sited and low-sited antenna in the figure shows that the high-sited antenna has the greater low-angle coverage. However, the extent of clutter (signal return from nearby land and sea surfaces) is increased for high-sited radars, and the high altitude coverage is correspondingly decreased.

(2) Effective Antenna Height. The effective height of an antenna is a significant factor in calculating the effect of the earth on the radiation pattern. It may or may not correspond to the site elevation. The effective height of anantenna --with the earth regardedas a smooth reflector-- is its

Figure 3-48 TIME VS DISTANCE FOR COVERAGE DROPOUT

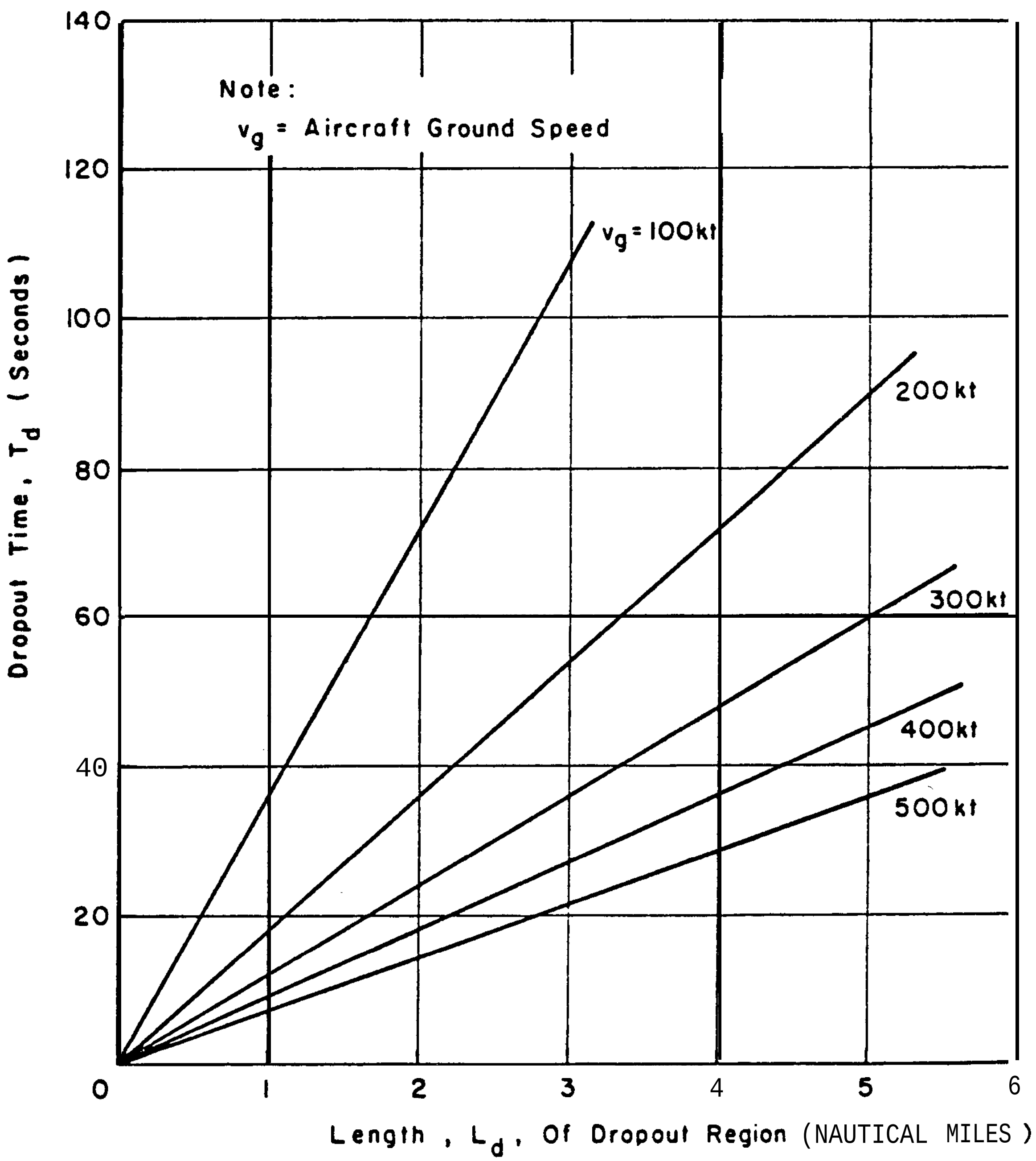
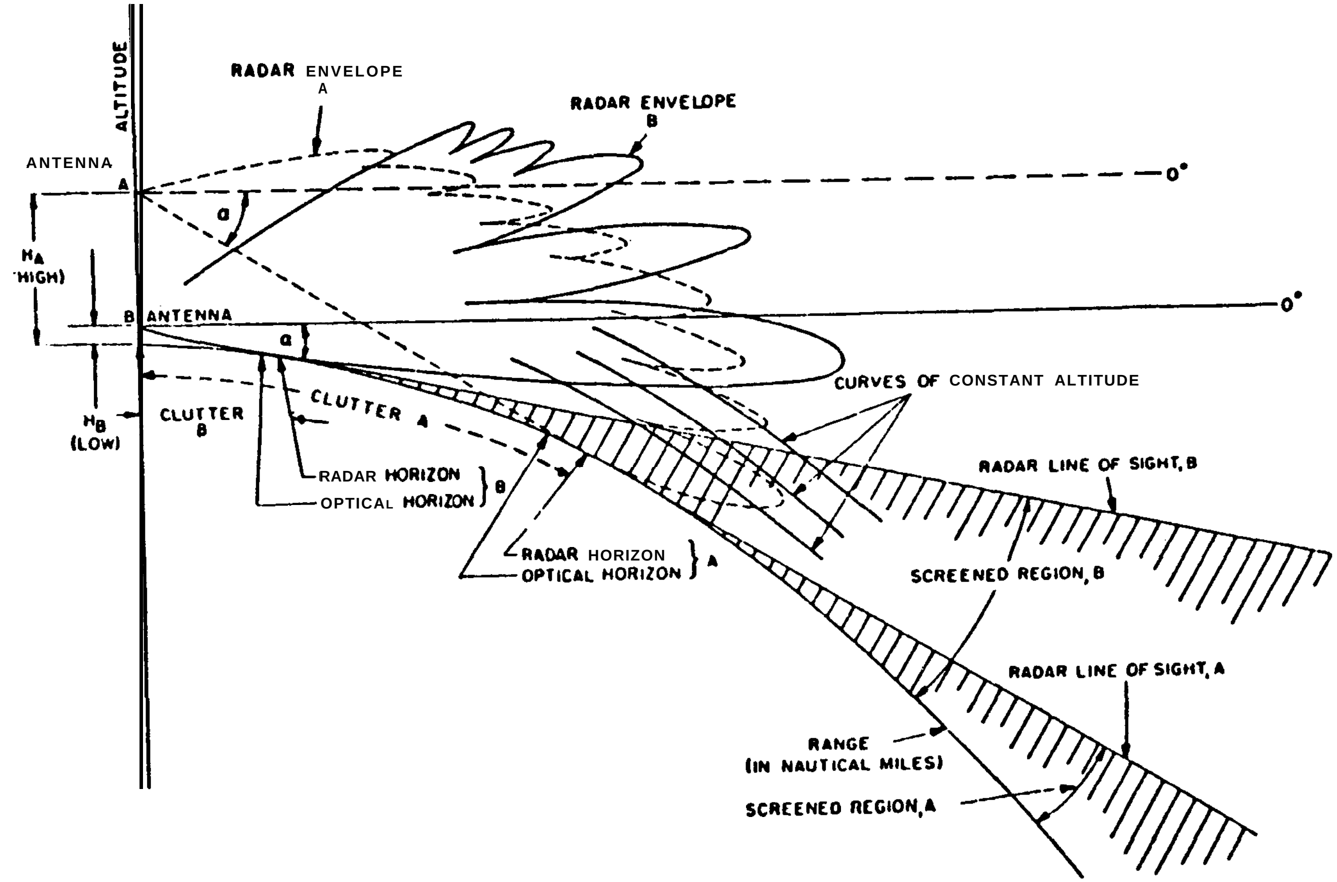


FIGURE 3-49. COMPARISON BETWEEN HIGH-SITED, LOW-SITED RADAR/BEACON



height above the local terrain or reflecting surface. Effective height can vary as the antenna rotates. This is especially true of a coastal cliff-sited antenna; its effective height is equal to its elevation on an over-water azimuth, but is much less when the antenna looks inland.

(3) Vertical Lobing. Groundreflection occurswhen thebeamradiated from the antenna strikes the surface of the earth and bounces upward. The vertical coverage of a radar can vary greatly because of ground reflections, as the reflected wave may arrive at the target in a manner that will either aid or oppose the direct wave. This effect of subtraction and addition between the reflected wave and the direct wave creates a vertical pattern of nulls and lobes as illustrated in figure 3-49. Lobing effects are discussed quantitatively in detail in paragraph 39.b. With low-sited antennasin smooth terrain terminal areas, beacon lobing null angles frequently occur for low-altitude aircraft, and may seriously compromise ATCBI coverage.

(4) Surface Roughness. The factor of effective antenna height has added significance where reflections from the earth'ssurfacemateriallyaffect the structure of the radiation pattern. Where theearthis smooth, relative to radar wavelength, ground reflections of the radar beam occur. Where the earth is rough, diffuse reflection (scattering) of the radar beam results, the radiation pattern is much less affected by ground reflection, and the factor of effective antenna height has reduced significance.

(5) Summary. In general, the selection of high versus low antenna elevations requires a tradeoff between the various performance degrading effects to achieve optimum coverage; An ideal antenna heightwillescludelobing null angles from important coverage altitudes while minimizing the clutter area and permitting adequate high and low altitude coverage.

c. Terrain Types. In general, radar sites are divided into three geographic categories: coastal, flat-earth, and mountainous. Since the terrain varies considerably with locality, a discussion of each category is included as background information for guidance in specific site selection.

(1) Coastal Sites.

(a) Line-of-Sight Coverage. When the area of primary search overlooks the sea, the site should be located to obtain a wide, unobstructed panorama of the sea. Low-angle, long-range coverage is best obtained with the antenna site at the highest practical elevation. Lowering the height of the antenna raises the radar los and resultsin areductioninrange coverage at the lower altitudes. Therefore, if the detection of target aircraft at low angles is a criterion in meeting operational requirements, the sacrifice in low-angle coverage that results from decreasing the antenna height must be carefully considered.

(b) Vertical Lobing. Theradiation patternfor a lower antenna height (see paragraph 39b), is characterizedby fewerlobes at higher elevation angles and greater spacing between the lobes. The consequent reduction in low-angle coverage is in addition to that imposed by changing the radar los.

The reduction of low-angle coverage and the greater gaps in vertical coverage are perhaps the most important characteristics of the low-sited coastal radar.

(c) Sea Clutter. An estimate of the extent of the sea return can be made by assuming various antenna elevations and by calculating the corresponding distances to the radar horizon. Under conditions of a disturbed sea, the sea return will tend to extend to the radar horizon. Tracking at ranges less than the horizon distance may be largely handicappedby seaclutter. The extent of sea clutter can be expected to diminish with decreased radar horizon distance as the elevation of the antenna is decreased. For the case of a radar sited relatively low over the sea, the problem is one of intensity of clutter rather than of extent of clutter relative to the maximum range of the radar.

(d) Radar Range. Radar range, as well as the extent of sea clutter, varies somewhat with the condition of the sea. When the sea is smooth, clutter is reduced and the vertical radiation pattern is characterized, in general, by a large number of closely spaced lobes in the pattern. As an approximation, the number of lobes will be equal to the number of half wavelengths contained in the height of the antenna above the sea. Some extension of the radar range can be expected as a result of lobing. This may be offset, however, by loss of tracking ability associated with the gaps of the interference pattern. Under conditions of a disturbed sea, it may be expected that the clutter will increase in extent and intensity, and that the radiation pattern will tend toward the free-space condition because of the effect of scattering. As a result, radar coverage or trackingbeyond the range of clutter may be expected to be more solid; however, because of the great intensity of the seareturn, tracking within the range of cluttermay begreatly diminished.

(e) Summary. If there is a choice between a site overlooking the open sea and one overlooking a large expanse of relatively protectedwater of comparable azimuth extent, the latter is to be preferred. This is because of the reduced sea clutter and, to some extent, the more nearly stable effect on the radiation pattern. The guiding factors, in any case, should be: (a) maximum unobstructed azimuthal coverage, and (b) sufficient antenna height for operational coverage of low altitude fixes.

(2) Overland Sites.

(a) In overland azimuth sectors of earth, particularly over rough terrain, ground clutter can be extensive up to the radar horizon. In addition, permanent echo returns from terrain featureslocated beyondtheradar horizon may be visible on the radar indicator because of their height and large reflecting areas. The primary difference, then, between a site overlooking the sea and one overlooking land, is the extent and intensity of the clutter. Land search imposes more severe clutter limitations on a givenradar. Again, the height of the antenna above the ground will have to be a compromise between the niaximumuseful range of a radar, for a given target aircraft, at medium or low altitudes and the amount of ground clutter that can reasonably be tolerated.

(b) Flat-Earth Sites.

1 In situations where the terrain in a given locality of a proposed radar site is relatively flat, particular regard should be given to: (a) the distant horizon should be visible from the antenna location over as great an azimuth sector as possible, particularly in the azimuth sector of interest for minimum screening; and (b) the ground in the vicinity of the antenna should be thoroughly rough, with trees, undergrowth, small buildings , and such obstructions that will break up reflections of the radar beam. (Care should be taken that this roughness does not increase clutter or permanent echoes unduly.)

2 In heavily forested regions, or in the presence of natural/manmade obstructions to visibility, the radar antenna should be tower-mounted at a height sufficient to clear the obstructions and permit visibility of the distant horizon.

3 Clutter may be reduced to some extent by adjusting the antenna tilt, by using mti devices, or by incorporating an allowable amount of local screening. The first two clutter control measures are associated with the radar equipment. In the latter method, the screening obstacle may be a ridge, a succession of ridges, or a series of hills in the vicinity of the site.

4 The location of the antenna, with respect to the screening obstacle, should be-such that the clutter is reduced to allowable limits and that the elevation of the line-of-site does not exceed operational limits. In an idealized case, the location of a radar antenna would be at the center of a large, shallow, saucer-shaped depression. The clutter would then be limited largely to the periphery of the depression. However, such depressions are not commonly found. The same effect can be created by trees or other types of vegetation completely surrounding the site. Deciduous vegetation will, of course, produce seasonal effects. Nonreflective man-made objects may also provide screening.

(c) Mountain Sites.

1 In mountainous regions the location of a search-radar antenna is determined, as a general rule, by the amount of screening that may be tolerated from adjacent mountain ranges or ridges, the extent and intensity of the cluter and permanent echo return, the accessibility of the site, and the economic limitations and special problems imposed by the topography of locality. With the relatively high elevation of an antenna site located on a mountain top, the problem of clutter is correspondingly greater.

2 The principal factors to be considered in selecting a mountain locat ion-are : (a) the elevation of the tentative site in relation to that of adjacent screening terrain; (b) the distance between the site and the screening terrain; and (c) the range of performance capability of the radar compared with the clutter.

3 The first two factors combine to determine the angular elevation of the los or screening angle. They should be of such as to yield a maximum depression of the los in the azimuth sectors of primary operational interest. The second, screen distance, affords an estimate of the extent of clutter to be expected -- clutter generally extends to the visible skyline. The choice of a mountain-top location as a radar site thus involves a compromise between screening and clutter limitations and radar performance capability.

4 Mountain top sites often introduce special problems of access, installation, operation, and maintenance. These concern access road construction; protection against wind, snow, and ice; and the availability of water and local fuel. These are items of particular interest to the construction engineers in a siting party. They are items, too, whose costs may rule out the use of otherwise desirable sites.

(d) Urban Sites.

1 Urban areas present widely varying conditions which can affect radar band beacon performance. Such sites are typified by variable skyline and surface conditions, and increased problems due to structures, vehicular traffic, rfi, and atmospheric contaminants. Frequently, cost-related factors are decisive in selecting site locations in urban areas. Land availability and the cost thereof, will, in many cases, severely limit the number of potentially acceptable site locations.

2 Once potential site locations are determine, selection should give special attention to screening and reflections due to structures, interference, potentially corrosive atmospheric pollutants, and clutter. Screening, clutter, and reflection problems can be examined with the aid of techniques presented in paragraphs 39a, b, and c. Interference and corrosion considerations are discussed in subsequent sub-paragraphs.

3 For typical housing developments and established urban communities, the compact arrangement of homes usually presents a surface of closely spaced rooftops interspersed with tree foliage. The type of reflecting surface, being highly irregular, will in general break up the impinging ARSR and beacon radiation to the extent that little lobing can be expected. However, ARSR clutter will increase in the azimuth sector and range over which this surface extends. Nevertheless, with use of mti and stc clutter reduction techniques, antenna heights and tilt angles can usually be found which afford an effective compromise between this type of clutter and the low-altitude coverage desired.

4 Highways, streets, or roads located near a site under consideration should be noted particularly when the road surface will be directly illuminiated by the ARSR and beacon. If the course of the thoroughfare is along a radial of the scanning ARSR or beacon interrogator, localized vertical lobing can be expected. Furthermore, moving vehicular traffic along a highway, road, or railroad will generate moving target indications on the ppi.

5. Becauseof theconstant constructionand renewal activities in and around urban areas, it is advisable to contact municipal officials to identify any planned construction in the vicinity of the site being considered which could degrade and/or compromise radar and/or beacon performance.

d. Anomalous Propagation.

(1) Definition. Electromagnetic waves propagating through the earth's atmosphere do not travel in straight lines, but are curved. This curvature is caused by the variation with altitude of the velocity of propagation in free space to that in the medium in question. For a standard atmosphere, the index of refraction decreases with altitude, causing the radar waves to bend downward. At times, however, changes in the standard conditions of the atmosphere brought about by moving air masses, rain, fog, temperature inversions, etc., can cause changes in the nominal index of refraction. When this occurs, abnormal propagation results where radar waves are bent either further downward, or in some cases, upward. This departure from the normal bending of the radar wave is called anomalous propagation.

(2) Types of Anomalous Propagations. The termanomalous propagation includes both super-refraction and subrefraction. Super-refraction results in an extreme downward bending of the radar waves and permits ground and near surface targets to be seen considerably beyond the normal radar horizon. The energy is propagated in a region called a duct which usually lies at or near the earth's surface. A duct is produced when the index of refractiondecreases with altitude at a rapid rate. Upward curvature of the radar waves occurs when the refraction index increases with increasing altitude. This is called subrefraction and leads to a decrease in radar range as compared with standard conditions.

(3) Index of Refraction, n. At ARSR and beacon frequencies, the index of refraction,n, forairwhichcontainswatervapor is (from reference 11)

$$n = 1 + \frac{77.6p \times 10^{-6}}{T} + \frac{0.373e}{T^2} \qquad (3\text{-}55)$$

where p = barometric pressure in millibars (1 mm Hg = 1.3332 millibars)

e = partial pressure of water vapor in millibars

T = absolute temperature, °K.

(4) Normal Variation of n With Altitude. The barometric pressure, p, and the water vapor content, e, decreases rapidly with altitude, while the temperature, T, decreases slowly. Hence, the index of refraction normally decreases with increasing altitude. A typical value of the index of refraction near the surface of the earth is 1.0003, and in a standard atmosphere it decreases at the rate of about 13.1 x 10^{-8} per foot of altitude.

(5) **Causes of Anomalous Propagation.** Theatmospheric conditions that can produce anomalous propagation are those where the pressure, temperature, and water vapor content gradients depart drastically from that of a standard atmosphere. As stated earlier, to,produce a duct, the index of refraction must decrease with altitude at a rapid rate (i.e., faster than normal). This can occur when (a) the temperature increases, and/or (2) the humidity (water vapor content) decreases abnormally with altitude. Anincreaseof temperature with altitude is called a temperature inversion and occurs when the temperature of the sea or land surface is appreciably less than that of the air. A temperature inversion, by itself, must be very pronounced to produce ducting. Water-vapor gradients are more effective than temperature gradients alone. Thus, super-refraction is usually more prominent over oceans, especially in warm climates.

(6) Super-Refraction. In general, super-refraction will occur when the air is exceptionally warm and dry in comparison with air at the surface. Over land masses, super-refraction is most noticeable on clear summer nights, especially when the ground is warm and moist, This leads to a temperature inversion at the ground and a sharp decrease in humidity with altitude. Such ducting will usually disappear during the warmest part of the day. Movement of large masses of warm dry air, from land, over cooler bodies of water produces temperature inversion. At the same time, moisture is added from the water to produce a moisture gradient. The resulting ducting tends to be more prominent on the leeward side of land masses and can last for long periods of time. Ground ducts can be produced by the diverging downdraftunder a thunderstorm that causes a temperature inversion and a decreasing moisture gradient over the lowest few thousand feet of altitude. In temperate climates, super-refraction is more common in summer than in winter. It does not occur when the atmosphere is well mixed, a condition generally accompanying poor weather. When it is cold, rough, stormy, rainy, or cloudy, the lower atmosphere is well stirred up and propagation is likely to be normal. Both rough terrain and high wind tend to increase the atmospheric mixing, consequently reducing the occurrence of ducting.

(7) Characteristics of Ducts. Atmospheric ducts are generally of the order of several tens of feet high, never more than perhaps 500 or600 feet. They are primarily limited to low angles of elevation, rarely affecting radar/beacon coverage at angles above 1.0 to 1.5 degrees. In general, low-sited radars are more susceptible to ducting than high-sited ones. The chief effect of ducting is to extend the surface coverage of the radar/beacon, while at the same time creating a large hole of poor coverage in the airspace above the extended surface coverage. In the case of the ARSR, this can be troublesome. Most of the long-range, low-altitude coverage will include clutter, making detection of aircraft more difficult. Also, the extended ranges within the duct may result in ambiguities and confusion because of interferenceof second-time-around echoes. Super-refraction is a phenomenon that cannot be depended upon. Its presence and magnitude are determined by meteorological conditions over which there is no control.

(8) Sub-Refraction, Sub-refraction phenomena occur less frequently than ducting. In certain cases, fog can lead to substandard propagation or sub-refraction. Fog forms when the water in the air changes from the gaseous to the liquid state, but the total water content remains unchanged. The effect of water in the liquid form on the index of refraction is negligible compared to the water vapor content (see equation 3-55). Therefore, the formation of fog near the surface results in a reduction in the water vapor contributing to the index of refraction at the surface. All other factors being equal, the net result is that the water vapor content increases with altitude, causing the index of refraction to increase with altitude. It should be pointed out that although fog can cause sub-refraction, the presence of fogisneither a necessary nor a sufficient condition for its occurrence.

(9) Implications for Siting. Since the meteorological conditions that support anomalous propagation may extend throughout and beyond the airspace of interest, the options for reducing its effect by selective siting are limited. As stated earlier, high-sited radar/beacon systems are less susceptible to the effects of ducting than low-sited ones. This dependence can sometimes be beneficial against potential ducting at coastal sites if the effective antenna height above the sea is 500 feet or more. Shielding or screening is another option. However, this is limited by the amount of low-altitude coverage that can be sacrificed within the airspace. Although the siting options with respect to anomalous propagation are limited, it is nevertheless important that the siting engineer understand and recognizethe causes and effects of anomalous propagation. Efforts should be made to collect the climatological data necessary to predict its occurrence and estimate its effect on ARSR/beacon performance, so that when the condition occurs it will be recognized and the radar/beacon output properly interpreted.

e. Weather

(1) Adverse Effects. Although one of radar's specific benefits is the ability to penetrate fog, rain, snow, etc., these weather conditions can have degrading effects on some radar systems. The most important effects are generally (a) signal attenuation, causing reduced signal detectability as a result of absorption or scattering of energy, and (b) signal backscatter, causing masking or confusion of legitimate targets due to the displayof echoes from the weather itself. These effects are usually more pronounced for rain than for other possible weather conditions, and are frequency dependent. The first effect, signal attenuation, is negligible for both the ARSR and ATCBI frequencies, even for heavy rainfall conditions. The second effect, backscatter, is discussed below.

(2) Radar Resolution Cell. A radar resolution cell is defined by the antenna azimuth and elevation beamwidths and by the radar pulse width:

$$v_r = R^2 \theta_a \theta_e \frac{c\tau}{2} \qquad (3\text{-}56)$$

where

R = range (meters)

θ_a = antenna azimuth beanwidth (radians)

θ_e = antenna elevation beamwidth (radians)

τ = pulse duration

c = velocity of light.

(3) Rain Equivalent Backscatter Cross Section. If rainiswidespread in the area, it may fill the entire resolution cell at short ranges. This can be seen by considering the following numerical examples derived from the ARSR-3 parameters. In range, the cell dimension is $c\tau/2$, or 300 m. In azimuth, the cell dimension is proportional to range, being 1 nmi at a range of 50 nmi, and 4 nmi at 200 nmi. In elevation, the cell dimension is again proportional to range, being 3 nmi at 50 nmi, and 12 nmi at 200 nmi. At the longer ranges the vertical dimension of the resolution cell obviously exceeds the possible extent of a rainstorm. As an estimate of a practical upper limit of rain cell dimensions, the following values will be assumed: range, 300m; azimuth,4 nmi; elevation, 3 nmi. The resultant volume is $12(10)^9 m^3$. As indicated in table 3-5, the rain backscatter cross section per unit volume is estimatedat $2(10)^{-9} m/m^3$ for heavy rain (16 mm/hr). Thus, the resultant equivalent backscatter cross section of the rain is 24 m^2. As can be seen from table 3-1, this is of the same order of magnitude as the radar cross sections of the larger aircraft, and an order of magnitude larger than that of the smaller aircraft.

(4) Use of Circular Polarization (CP). Successful detection of desired targets under severe rain conditions therefore requires rejection of precipitation echoes. This is done in ARSR systems primarily by a switch to cp operation. There are two types of cp, distinguished by the direction of rotation of the electric vector as viewed by an observer looking in the direction of propagation. A clockwise rotating electric field vector is known as right-hand cp, while a counterclockwise rotation is known as left-hand cp. If the radar radiates one sense of circular polarized energy, it cannotaccept the backscattered echo signal from a target such as a sphere since the sense of polarization is reversed on reflection. That is, if right-hand cp is transmitted, spherical raindrops reflect the energy as left-hand cp, just as the mirror-reflected image of a right-hand screw thread appears to be left-hand. Since the same antenna is used for both transmitting and receiving, and the radar antenna is not responsive to the opposite sense of rotation, the receiver does not receive echo energy from the spherical reflector.

(5) Aircraft Echo Characteristics. An aircrafttargetwillreturn some energy with the correct polarization as well as energy with the incorrect polarization. Energy incident on the aircraft may be returned afteronebounce, as trom a plane sheet or a spherical surface; or it might make two or more bounces between various portions of the aircraft before being returned to the radar. On each bounce the sense of polarization is reversed. Signals which make single reflections (or any odd number) will be rejected by the cp antenna, but those signals which make two reflections (or any even number) will be

Table 3-5

RAIN BACKSCATTER AT 1250 MHz

Weather Condition	Rain Backscatter Cross Section Per Unit Vol. m^2/m^3
Drizzle (0.25 mm/hr)	2×10^{-12} (1)
Light Rain (1 mm/hr)	2×10^{-11} (2)
Moderate Rain (4 mm/hr)	2×10^{-10} (2)
Heavy Rain (16 mm/hr)	2×10^{-9} (1)

(1) Estimated.

(2) Data from reference 2.

accepted. The radar cross section of aircraft targets is, in general, less with circularly polarized radiation than with linear polarization. The difference in echo signal level with cp and lp will depend upon aspect angle, but it has been reported (reference 2) that on the average cross section with cp is about 5 dB less than with lp for the ARSR frequency region.

(6) Effect of CP on Maximum Detection Range. If itcanbeassumed that the combined effects of cp operation and mti improvement will allow a target to be detected against a rain clutter echo background, it is useful to determine the range of such detection, relative to free space operation. This is determined from the loss in signal strength due to cp (5 dB). This corresponds to a range coverage which is 75 percent of the free-space range.

(7) Weather Information From ARSR-3. The use of a polarization diplexer in the ARSR-3 provides weather information when using cp. The cp weather returns are not cancelled, but are shifted to an orthogonal polarization after passing back through the polarizer. Normally the waveguide system rejects the orthogonally polarized weather returns, but in the ARSR-3 these returns are accepted in the opposite channel because of the polarization diplexing arrangement. For example, if frequency f_1 is radiated in channel 1, the weather returns at f2 are accepted by channel 2. Thus, weather informa-. tion is made available (reference 11).

f. Environmental Damage.

(1) Sources. Chemical constituents and/or sand and dust in the atmosphere are potential sources of corrosionor damage to radar/beacon equipment or components. Protection against natural concentrations of' these agents within a geographical region is best accomplished by specific design of the ARSR/ATCRBS systems. However, within a given region,certainlocales(centered about chemical processing plants,sewage disposal facilities, ocean shorelines, mining operations, or industrial parks) may exhibit unusually high concentrations of such contaminants. In siting, these areas should be avoided.

(2) Atmospheric Contaminants, Some of the most importantatmospheric constituents with respect to corrosion include chlorides,sulphates, nitrates, hydrogen ions, sand and dust. Table 3-6 shows the source, location, and concentration of these contaminants. Along ocean or sea coasts, salt spray is a corrosive factor for installations located less than 1000 feet inland. This minimum distance should be even greater in coastal areas where unusual high wind conditions are known to prevail. Ozone at the earth's surface created by photochemical reduction of organic pollutants (smog) will deteriorate rubber materials. Sand and dust from storms in desert regions, or in and around stone quarries or mining operations can have serious effects on moving parts (i.e., bearings, gears) of the radar/beacon antenna systems. Areas of high sand and dust concentration should be avoided, if possible.

Table 3-6

ATMOSPHERIC CONTAMINANTS

Concentration (in rain water), Source, and Location
of the Most Important Constituents with Respect to Corrosion/Wear 6/

Contaminant	Source	Location	Concentration in Rain Water, mg/liter
Chloride (Cl^-)	Sea Spray	Over sea or near the coast	2-20 average. In extreme winds up to 100
Sulphate (SO_4^{--})	Industrial Areas	Large cities, industrialareas	10-50 average. Higher under extreme conditions (e.g., smog)
Nitrate (NO_3^-)		Over land	l-5
Hydrogenions		Overland, near industrialareas	Avg. 5
Sand/Dust	Miningoperations. Desertwind storms.	Overland. Deserl areas.	

6/ Reference 13.

g. Structures.

(1) Effects of Structures. Structures such as buildings, metallic fences, towers, etc., in the vicinity of an ARSR-beacon site can result in 'unsatisfactory radar/beaconcoveragebyvirtue of the reflections they produce. This situation is most serious with respect to beacon operation where such reflections cause the radar beacon reply from an aircraft to appear at false azimuth and range positions (see paragraph 23.b.(4)). In the case of the ARSR, similar type false targets are possible in theory. However, because of the two-way propagation path involved, ARSR false targets of this type are not considered a significant problem. Themoreimportant effect of structures upon ARSR performance are the permanent echo returns they produce. This, however, is a potential problem for very large structures located within 2000 feet of the radar because of the recovery time limitations of the ARSR. Such radar returns are generally considered as falling within the general clutter environment of the radar (see paragraph 39.c) and may be treated as such in selecting the ARSR/beacon site. Hence,from a siting standpoint, the more significant concern with structures within the immediate site vicinity (i.e., less than 2000 feet)is their effect in producing beacon false targets.

(2) Fences. Among the most prominent sources of beaconfalse targets are chain-link fences. Reflections from such fences can cause beacon false targets over a large azimuth sector due to the variable angle of reflection that develops as the beacon interrogator beam sweeps along the fence. Fences as far as six miles from the transmitter site have been found to cause false target replies. The nomograph of figures 3-43a and b may be used to predict the range extent of beacon false targets for a given fence within view of the ARSR/beacon site. If a site cannot be located which is free of possiblefalse target reflections due to fences, consideration should be given to a site which is directly adjacent to the fence, thereby greatly reducing the effective reflecting area. Other alternatives, such as substituting wood fencing or tilting the fence to produce Brewster angle reflections should also be considered.

(3) Buildings. Large buildings within the vicinity of a site can produce beacon false targets and/or permanent radar echoes at the ARSR display depending on their size,-distance,and orientation relative to the direction of illumination, surface roughness, and material. Buildings with metal framework or metal siding or roofing are especially troublesomeand should be avoided in the siting of the ATCRBS antennas. The site should be free from such reflectors out to a minimum of 2000 feet from the antenna, preferably to a distance of one mile. Where no site is available with sufficient separation from nearby buildings to reduce the occurrence of false target reflections, an attempt should be made to locate a site for which the radar energy angle of incidence upon the reflector is as small as possible, thereby minimizing the effective reflecting area. Other alternatives include shielddfencing or architectural treatment of the buildings for minimum reflections.

(4) Towers and Backup Facilities. Towers withinthe immediate vicinity of the ARSR/ATCRBS site to support RML transmitters or backupradar/beacon systems, in all likelihood, will produce beacon false targets, and/or beacon

splitting. Beacon false targets are frequently produced by reflections from the steel framework of towers. In the case of backup radar/beacon facilities located nearby, the antenna of the backup system presents an excellent reflecting surface for beacon false target replies to the primary system. Furthermore, any slightly different rotation rate of an operative backup dish relative to the primary system rotation can cause false target replies from almost all azimuths about the site. Towers erected near the ATCRBS site are also believed to produce splitting of beacon replies, and hence the reporting of false targets on automated display equipment. Studies of this phenomenon (references 13 and 14) have indicated that no radar/beacon site should be established within 1200 feet of RML or other towers, in order to minimize beam split effects.

(5) Siting Guidelines with Respect to Structures.

(a) Clear Area. In the selection of a site for an ARSR/ATCRBS installation, the area should be free from potential reflectorsoutto a minimum of 2000 feet from the antenna, preferablyto one mile. Potential reflectors such as metal buildings (metal frame, siding, or such as metal buildings (metal frame, siding, or roofing), chain link fences, metal towers, etc., that are not removed should be either shielded from direct illumination by the radar beacon or modified to minimize their effects. Exact predictions as to the severity of reflections from particular structure(s) are not possible since few reflecting surfaces are ideal lossless flat-plate surfaces, and the amount of reflection varies from object to object. Worst-case estimates can be made, however, with the aid of figures 3-43a and b. In so doing, consideration should also be given to second-bounce reflection paths.

(b) Modification of Reflector. Tilting of a reflecting fence, or other flat reflectors, can be aneffectivemeansof reducingthe intensity of reflected signals and, therefore, of eliminating false beacon replies. Application of a smoothly curved surface over a flat reflector results in divergent scattering and, therefore, elimination of false beacon'replies.

(c) Placement of False Target Returns. When screeningor other techniques are not practical means of reducing false targets, an attempt should be made to locate the site in such a manner that the resulting false targets will fall in the least critical coverage area.

(d) Additional Guidance. For more detailed discussions of siting guidelines, reference 8 should be consulted.

h. Interference to ARSR/ATCRBS.

(1) General. The problems of mutual interference which might exist between an ARSR/ATCRBS facility and-various other types of electronic equipment operating in the general area of the proposed siteshould not be overlooked when considering a particular site location. Data should be gathered regarding the location and types of nearby radiation sources. If considered necessary, an evaluation can then be made to determine the extent of interference prevailing. This may influence the selection of a site location.

(2) Potential Interfering Transmitters. Commercial installations that may cause interference include television stations, fm broadcast stations, and microwave links. The latter are frequently used by railroads, and by pipeline, power, and utility companies. A complete listing of all commercial, as well as FAA installations and their operating frequencies, may be obtained from the nearest regional office of the Federal Communications Commission (FCC). In addition to these sources, arc-welding equipment and improperly grounded or shielded industrial and/or diathermy equipment operated by industrial concerns or by local medical facilities will frequently radiate sufficient rf energy to cause objectionable interference.

(3) Effects of Nearby Conductors. The proximity of the ARSR/ATCRBS site to electrical power installationsof all types shouldalso beinvestigated as a likely source of interference. The presence of nearby power lines, telephone and telegraph lines, electric fences, electric railways, and the like may represent sources which conduct and reradiate rf interference that has been transmitted to the lines from a noise source by direct radiation, conduction, or induction. Strong interference levels may thus be conducted over long distances by power or telephone and telegraph lines which, in turn, may radiate throughout their entire length. For this reason, isolation,noise suppression, or attenuation by means of natural or fabricated shielding must be considered where such conditions are likely to exist.

(4) Meteorological Effects. Interference due to meteorological disturbances may include heavy rain, snow storms,'deep snow on the ground, thunderstorms, etc. From a siting standpoint, very little can be done about such sources of interference. However, information regardingweather conditions at the site should be obtained so as to recognize the conditions and limitations imposed on ARSR/ATCRBS operation at a specific site.

i. ARSR/ATCRBS Generated Interference.

(1) To Microwave Communications. ARSR and ATCRBS outputs generally have some degree of harmonic and spurious signal output. The FAA has agreed to take steps to minimize these unwanted portions of the output, and also to cooperate with microwave common carrier companies in an effort to reduce interference in the siting of radar/beacon systems. Interference has been experienced in a commercial microwave link that was traced to an en route radar 70 miles away. The ARSR/ATCRBS should be sited at least 10 degrees off the microwave path, and shielding of the radar or link using existing obstructions or obstacles should be attempted.

(2) To Television Receivers. The spuriousoutput from the ARSR/ATCRBS may cause interference to television reception in the immediate vicinity of the site. Although a built-up area is generally an excellent site to break up lobing of the ARSR/ATCRBS radiation patterns, residential and other areas where there are likely to be many tv‘receivers should be avoided if possible. If radar sites are established near residential areas, every consideration and effort should be made to minimize if not eliminate interference to the tv receivers in the vicinity.

(3) To Personnel. Powerdensities in excess of the generallyaccepted radiation hazards criterion can be exceeded out to 375 feet from the ARSR-3 antenna in the direction of the main beam. This level would not be exceeded at ground level with the lower 3 dB point of the main beam at 0 degree elevation due to minimum 37-foot AGL position and the sharp fall-off of the gain below the beam. However, consideration must be given in site layout to preclude illumination by the main beam of personnel within 375 feet of the antenna. This could be caused by lowering the beam angle or having occupied areas within 375 feet at a height high enough (37-foot AGL) to be in the main beam.

SECTION 5. SITE REQUIREMENTS/LIMITATIONS

41. INTRODUCTION. A basic prerequisite prior toconsideration of any property for use as an ARSR/ATCRBS site is that the land is available and can be acquired through purchase or long-term lease. In addition, the land or parcel of property must be adequateto theextent that the construction, installation, and operational requirements of the ARSR/ATCRBS facility can be met with reasonable cost and without undue environmental impact.

42. ENVIRONMENTAL IMPACT ASSESSMENT. Any location considered for an enroute radar site must receive a careful assessment of the overall environmental impact which will be produced by establishment and operation of an ARSR/ATCBI site at the location. This assessment is to be carried out in accordance with the latest edition of Order 1050.1, Policies and Procedures for Considering Environmental Impacts.

43. COMPONENTS OF AVERAGE FACILITY. A site would be considered adequate and reasonable in cost if the construction, installation, and logistics requirements approximate those of an average ARSR/ATCRBS facility. The principal components of an average facility are:

a. A plot of land (minimum) 300 feet x 300 feet including a 6-foot chain-link security fence surrounding the portion on which the building, tower, and equipment are installed.

b. Easements to preclude constructionof anystructurewhichwould project above a level 25 feet below the antenna platform level or which would be built of reflective materials within a one-half mile radius of the site property. Existing or planned easements affecting this clearance zone must be examined and their impact on site costs evaluated.

c. An access road not more than 1/4 mile long.

d. A standard transmitter/receiver building including air conditioning and engine generator units.

e. ARSR/ATCRBS antenna on an antenna tower 25 to 75 feet high.

f. A standard transformer substation.

g. Utility lines (power, water, telephone) or installations no more than 1/4 mile long.

44. LAND ACQUISITION.

a. Procedures. The process of land acquisition must be accomplished by the cognizant FAA offices. Once theparticular **parcel of land has** been selected as an acceptable site location, action should be taken by these offices together with members of the siting team to:

(1) Reaffirm that the land is available and that no municipal or local government restrictions, zoning laws, or other legal restrictions exist on the property that would prohibit its use as an **ARSR/ATCRBS** site.

(2) File Environmental Impact Statement and obtain **DOT** approval or Finding of No Significant Impact (FONSI) before proceeding with acquisition.

(3) Provide or secure competent legal representation with respect to the legal aspects of property surveys, buying or leasing of land, and easements for access roads and utilities.

(4) Obtain permission for right of entry to private lands by survey personnel, and arrange for reasonable compensation to property owners'for damage to property resulting from survey operations.

(5) Secure deed descriptions and copies of filed plans or maps covering the property and initiate title searches to determine the validity of title or easements.

(6) Provide or secure the services of personnel licensed to practice land surveys in the territory of jurisdiction.

(7) Review environmental impact factors.

b. Confidential Information. Throughout the period of siting investigations and negotiations, and until such time as a real **estate directive** is issued for procurement of land, all negotiations with the owner and/or agent must be handled by the proper authorities of FAA, and all information must remain confidential to prevent the possible increase of property acquisition costs.

45. ACCESS ROAD. In order to satisfy coverage requirements, **ARSR/ATCRBS** sites will often be located in outlying or rural areas. Where existing roads provide all or part of the access necessary to the proposed site, a survey should be made to determine their adequacy for thevehicular traffic expected to utilize such roadways. Some of the important factors to be considered in the evaluation of existing access roads are (a) maximum load limit of roads, bridges, culverts, etc., (b) maximum clearance height of underpasses, (c) maximum grade, road, and shoulder width and minimum turn radius of road, (d) road surfaces-- weather and seasonal considerations, **(e)** volume and **class of** traffic handled, and (f) adequacy of and responsibility for road maintenance (including snow removal. Useful data of this type can often be obtained by contacting state, county, or local highway department officials or, in the case of airport roads, cognizant airport officials.

46. ROAD CONSTRUCTION.

a. Determination of Requirements. Itcanbeexpected that an ARSR/ATCRBS facility will often need to be located at a site remote from existing roadways. When the construction of a new access road is required, a study of the construction cost, annual maintenance, traffic handling capacity, and the salvage value at time of replacement must be considered in determining the relative economic merit of different surfaces for a given geographic area. It should be remembered that no FAA improvements can be made to roads on which the FAA does not have a lease, easement, or similar legal arrangement. Some of the important factors to be considered when new construction is required are as follows:

(1) The length of road required from the point of entry to the site.

(2) The climatic and geological variables having an effect on snow depth, rain, frost heavings, load bearing capacity, and sub-grade soil.

(3) The requirements for grading and filling.

(4) Need for the construction of bridges, culverts, etc.

(5) Availability of labor and materials locally.

b. Design Standards. The detailed design standard for new road construction will vary because of the diversity of available materials, and various climates and geographic locations. In the reconstruction of existing roads, it is often economical and advantageous to utilize the existing roadbed as a base for the new construction. In this manner, advantage can be taken not only of the old paving materials, but also of the compaction afforded by previous traffic loadings.

47. CLEARING/GRADING/LANDSCAPING. The need for clearing, grading, and/or landscaping of the site property represents an additional cost above those nominally required for an average site facility. Clearing costs would include the cost of such items as the removalof trees,shrubbery, rocks,debris, etc. Grading may sometimes be necessary to improve drainage on or about the site, or to provide screening in a particular azimuth sector, The prevention of soil erosion about the site, esthetics from a public relations viewpoint, reduction of reflection from the surrounding security fences, etc., all add factors that could require special landscaping of the site. This landscaping should be in the form of sodding, planting of shrubbery, trees, etc.

48. SITE SECURITY. Consideration must be given to the action necessary to prevent intrusion,and toprotect theARSR/ATCRBS installation from vandalism or other damage. For the most part, a 6-foot chain-link security fence is adequate for these purposes. In general, all sites will require a fence and additional anti-intrusion and protective devices provided as required.

49. UTILITIES.

a. Electrical Power. The principalutility requirement for an ARSR/ATCRBS site is the need for three-phase 120/208-volt electrical power. Two independent sources of such power are required to minimize the loss of ARSR/ATCRBS operation due to power failure. The primary source of electrical power shall be from commercially available power within the vicinity of the site. In cases where power lines are a great distance from a substation, problems such as brown-outs, loss of a single phase, and transients can occur more often. These problems can cause the.equipment to experience a failure rate that is higher than normal. During the siting phase, the quality of commercial power should be evaluated for each site. If power quality for a particular site is viewed as a potential problem, then recommendations should be made for a power conditioning system. The second source or standby power shall be provided by an engine generator at the ARSR site.

b. Water and Sanitation. Water and sanitary facilities will usually be required as most sites will not be close to existing FAA sanitary facilities. A check should be made of the location of existing municipalwater andsanitary sewer lines and utilized if feasible; otherwise, a well and septic tank with drain field will be established. Check local ordinances to determine design requirements and with local well driller for probable depth of potable water. supply.

50 REMOTE SITE LIMITATIONS. The long-term costs increase dramatically when the site is located in an isolated location. Further, long outage time can occur because of increased travel time of maintenance crews. These items should be examined closely before a particular site is recommended.

CHAPTER 4. SITING PROCEDURES

SECTION 1. INTRODUCTION

51. MAJOR TASKS. The procedures to be used for site selection of en route **ARSR/ATCBI** facilities are described in this chapter in terms of eight major tasks as listed below. The tasks, shown diagrammatically in figure 4-1, are to be undertaken with respect to the equipments being sited in accordance with the matrix shown in figure 4-2. The major siting tasks are:

a. Preliminary Data Acquisition.

b. Preliminary Site Selection.

c. Site Survey.

d. Site Performance Analysis.

e. Site Environmental Analysis.

f. Site Cost Analysis.

g. Preparation of Siting Report.

h. Final Site Selection.

52. SPECIFIC ACTIVITIES. The specific work activities associated with each of these major tasks are described in this chapter along with detailed discussion of the procedures recommended for carrying out the work. Each major task area is covered in a separate section, with sample siting analyses included. For purposes of planning and scheduling the various siting activities, a typical Siting Management Plan is shown in figure 4-3.

SECTION 2. PRELIMINARY DATA ACQUISITION

53. GENERAL.

a. Basic Data Sources. Following receipt of an assignment to establish an **ARSR/ATCBI** site for a given geographical area, the first task will be to acquire specific working data and information regarding the operations, coverage requirements, and constraints associated with the area of interest. These data, which will be used throughout the various work phases of the siting effort, should include as a minimum airspace coverage requirements, applicable maps and charts, and local climatological data.

b. Additional Data Sources. The latest edition of the following documents and computer programs are also considered part of the data base necessary for siting operations, and should be available for reference as needed.

(1) Order OA P 8200.1, United States Standard Flight Inspection Manual.

FIGURE 4-1 MAJOR SITING TASKS

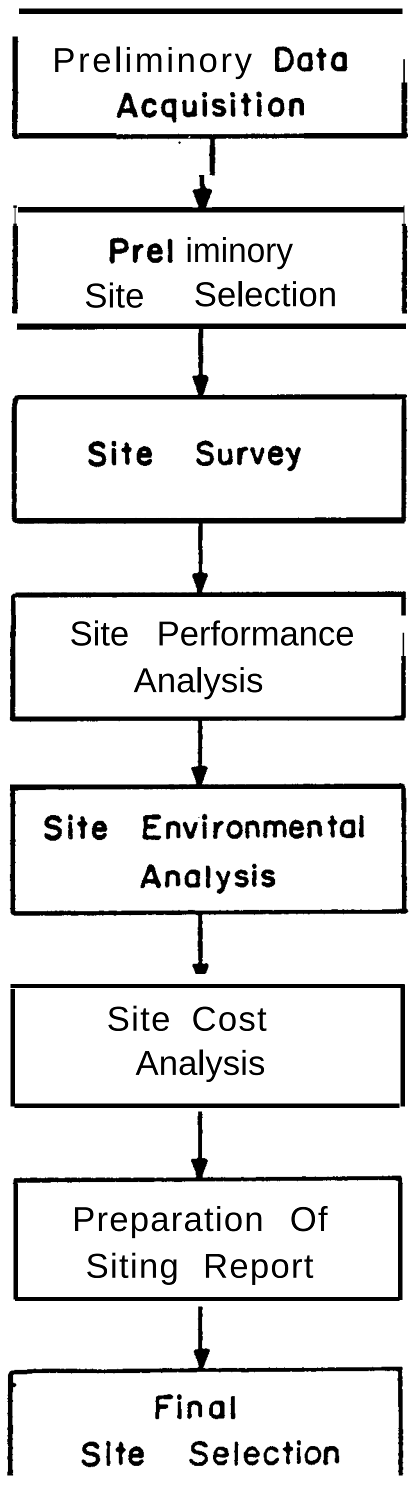
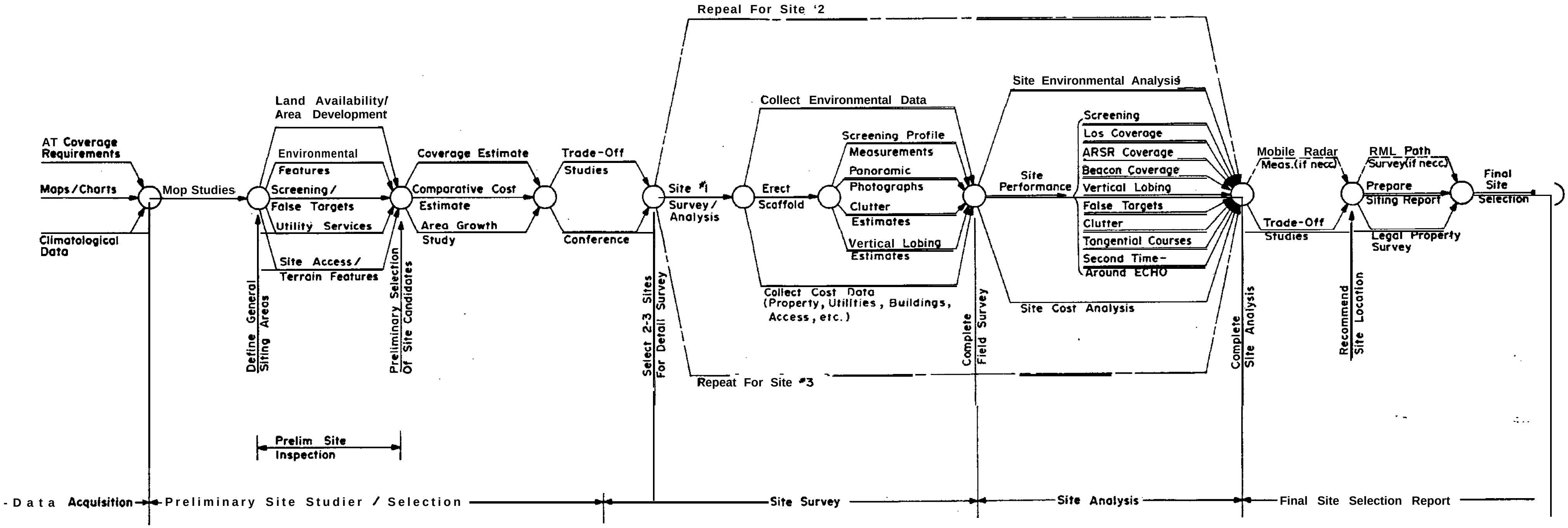


FIGURE 4-2 SITING TASK MATRIX

Reference Sec.	Reference Par.	Tasks To Be Performed	ARSR-3	ARSR (MTD)-4	ATCBI-5	DABS
2	53	Preliminary Data Acquisition				
	54	Airspace Coverage Requirements	●		●	
	55	Maps/Charts / Drawings...etc	●		●	
3	58	Preliminary Site Selection				
	59	Area Boundary Determination	●		●	
	60	Preliminary Site inspection	●		●	
	61	Preliminary Site Analysis	●		●	
	62	Selection Of Sites For Survey	●		●	
4	63	Site Survey				
	67	Screening Prof iie Measurements	●		●	
	69	Panoramic Photographs	●		●	
	70	Clutter Estimates	●			
	70	Vertical Lobing Estimates	●		●	
	70	Reflector Estimates			●	
	71	Environmental Data	●		●	
	72	Cost Data	●		●	
5	73	Site Performonce Analysis				
	75	Screening Analysis	●		●	
	76	Los Coverage Analysis	●		●	
	77	ARSR Coverage Analysis	●			
	78	Beacon Coverage Analysis			●	
	79	Vertical Lobing Analysis	●		●	
	80	False Target Analysis			●	
	81	Clutter Analysis	●			
	82	Tangential Course Analysis	●			
	03	Second Time- Around Analysis	●			
6	04	Site Environmental Analysis	●		●	
7	09	Site Cost Analysis	●		●	
8	92	Siting Report	●		●	
9	95	Site Selection /Coordination	●		●	

FIGURE 4-3 ARSR / ATCBI SITING MANAGEMENT PLAN



(2) Federal Aviation Regulations, Vol. XI, FAA, October 1969.

(3) Map overlays showing line-of-sight contour and contours showing target acquisition distance at specified altitudes for a designated radar location and antenna height can be obtained from the Electromagnetic Compatibility Analysis Center (ECAC) by request through FAA headquarters, AES-500, Spectrum Engineering Mvision, Systems Engineering Service.

(4) Computer Program for Radar/Communications Line-of-Sight Calculations (see appendix 3).

(5) Computer Program for Radar Coverage Calculations (see appendix 3).

54. AIRSPACE COVERAGE REQUIREMENTS.

a. Requirements. Specific ARSR/ATCBI coverage requirements for the -area to be served are obtained from the cognizant regional Air Traffic (AT) division and should include the following as a minimum:

(1) Area Positive Control. The volume of airspace about the radar site for which area positive control is required should be clearly defined. This is most generally done by defining the range and altitude levels which bound the area positive control region.

(2) Jet Routes. The jet routes or route segments for which coverage is required from the planned site should be identified.

(3) Airways. Airways or airway segments for which coverage is required from the planned site should be identified explicitly, usually by giving the airway number and identifying the bounding end points. The required altitude coverage for each designated airway should also be explicitly defined.

(4) Navaids. All navigational aid sites for which coverage is required from the planned site should be explicitly identified together with the corresponding altitude coverage requirements.

(5) Other. Any other airspace region requiring special coverage considerationshouldbesuitably identifiedboth as to areaextent andaltitude.

b. Approval/Coordination. All dataidentifying coveragerequirements for the planned site shall beapproved andsigned by an appropriate AT officer. Usually this will be the Chief of the regional Air Traffic division, or his designated representative. In addition, it is recommended that full knowledge and concurrence with these coverage requirements be obtained by AT from the Chiefs of both the Airway Facilities and Flight Standards divisions.

55. MAPS AND CHARTS.

a. Basic Sources. Once the geographicalarea to be considered has been established, applicable maps and/or charts should be obtained for subsequent siting studies. Although all sources of pertinent map data should be investigated, the following is considered the minimum working set:

(1) Aeronautical Charts. En Route Low Altitude, En Route High Altitude, World, and other available aeronautical charts should be secured for the vicinity of the proposed radar site. The designated charts provide invaluable information for establishment of radar coverage requirements and capabilities. Aeronautical charts may be obtained from:

Distribution Division, C-44
National Ocean Survey, NOAA
Riverdale, Maryland 20840.

(2) Minimum Enroute IFR Altitude (MEA)-Charts. MEA charts covering the airspace of interest can be obtained from the regional Air Traffic Division Chief. These charts should be reviewed with cognizant representatives to confirm airspace coverage requirements.

(3) U.S. Geological Survey Maps. USGS quadrangle maps in various scales, e.g., 1:24,000 (7½ minute), 1:62,500 (15 minute), and 1:250,000 are available and cover virtually all of the United States. These maps provide important topographical and cultural.information to aid in site selection. USGS maps may be obtained from the U.S. Geological Survey, Washington D.C. 20242, and from commercial map agencies in various communities. When maps are obtained from a commercial source the date of the survey should be noted, since older maps may lack certain details of importance.

b. Additional Sources.

(1) Topographic Maps. For certain areas, the Corps of Engineers and/or U.S. Air Force have made topographic maps containing details similar to U.S. Geological Survey quadrangle maps. Liaisonwiththe appropriate regional office of the U.S. Air Force Installations Representative or the.District Engineer, Corps of Engineers, may produce additional maps of a particular site area which are based on more recent surveys than USGS maps.

(2) Municipal, County and State Maps. Municipal, county and state maps may be obtained from the civil offices of the respective divisions of government. These maps may provide additional information regarding vehicular traffic (highways, railroads, etc.) of significance, or industrial areas which could give rise to a corrosive or rfi environment.

(3) Supplemental Maps/Charts/Photographs. Many other maps which may provide important pre-siting information are available from the Superintendent of Documents, U.S. Government Printing Office. These maps are listed in GPO price list PL-53 (Maps, Surveying, Engineering). Aerial photographs of the general area for site locations are also sometimes useful for the location and general evaluation of candidate areas. Such photographs can sometimes be obtained from local commercial enterprises or the U.S. Geological Survey.

56. LOCAL CLIMATOLOGICAL DATA. Seasonal weather, climatological, and seismic data of possible significance to radar siting may be obtained for the locality of the proposed ARSR/ATCBI installation. These data are published as Annual Climatological Summaries by the National Weather Service (NWS) for each locale in which a weatjer station is maintained. The Annual Survey may be obtained from the local NWS office or from: National Climatic Center, Federal Building, Asheville, North Carolina 28801. The local Weather Service or Environmental Protection Agency offices may, in some areas, also be able to provide records regarding the occurrence and altitude of temperature inversions in the proposed site area. This information may be significant in determining the seriousness and frequency of radar coverage changes due to anomalous propagation effects.

57. STANDARD DRAWINGS AND SPECIFICATIONS, AND WORKSHEET FORMS. Worksheet forms for site evaluation are shown in appendix 2. Reproducible copies are included in the envelope inside the back cover along with overlay charts for evaluating fix coverage. Copies of standard FAA drawings and specifications applicable to the siting effort should also be obtained for reference and future use. They include site construction drawings (D-5981-J-00 to D-5981-J-19 for ARSR-3); site construction Specification (FAA-C-2673 for ARSR-3); access roadway specification drawing (D-5980-1,2); 4/3 earth radius coverage chart (e.g., FAA Drawing C6202); polar coverage chart (e.g., FAA Drawing E6201.).

SECTION 3. PRELIMINARY SITE SELECTION

58. INTRODUCTION.

a. General. The preliminary selection of candidate site locations is essentially a real estate elimination process that takes into account as many of the factors described in chapter 3 as is practical without the benefit of precise survey data. The objective of this process is to converge. to a small number (two or three) of potential site locations which represent the best of all factors considered.

b. Basic Steps. The preliminary site selection procedures make use of maps of the types described in section 2 above. These are assumed to be on hand. The several Preliminary Site Selection activities are described in detail in the following paragraphs. They include, as basic components, determination of site area boundaries, preliminary site inspection, preliminary site analysis, and selection of sites for survey.

59. DETERMINE SITING AREA BOUNDARIES.

a. Coverage Area Boundaries. The boundaries of the general area in which a site may be located shall be determined on the basis of the distribution of fixes and air routes whose coverage is required from the site, together with the range, altitude, and cone-of-silence limitations of the ARSR (ATCBI coverage is not considered as the limiting factor in this investigation). If coverage 'requirements are alternatively defined in terms of a volume of airspace, the siting engineer will select a set of critical points whose coverage will insure radar coverage of the required airspace volume. Once these critical coverage points are defined, subsequent analyses proceed treating the points in the same manner as navigational fixes.

b. Range Coverage Limitations. The objective of this investigation is to determine the permissible land area within the required coverage region on which an ARSR can be located and still meet the range coverage limitations imposed by specific aircraft when located at each of the required navigational fixes or coverage points defining the coverage region. This investigation is of particular value when the required fixes/critical coverage points are distributed over a wide volume of airspace (e.g., 65-150 nmi from the radar site) and the detection of small aircraft (e.g., Cessna 180, Piper Comanche) is a necessity. An outline of the procedures recommended for conducting this investigation is given below as well as an illustrative example. For purposes of this analysis, it is sufficient to assume that slant range to all fixes is identical to the ground range to those fixes.

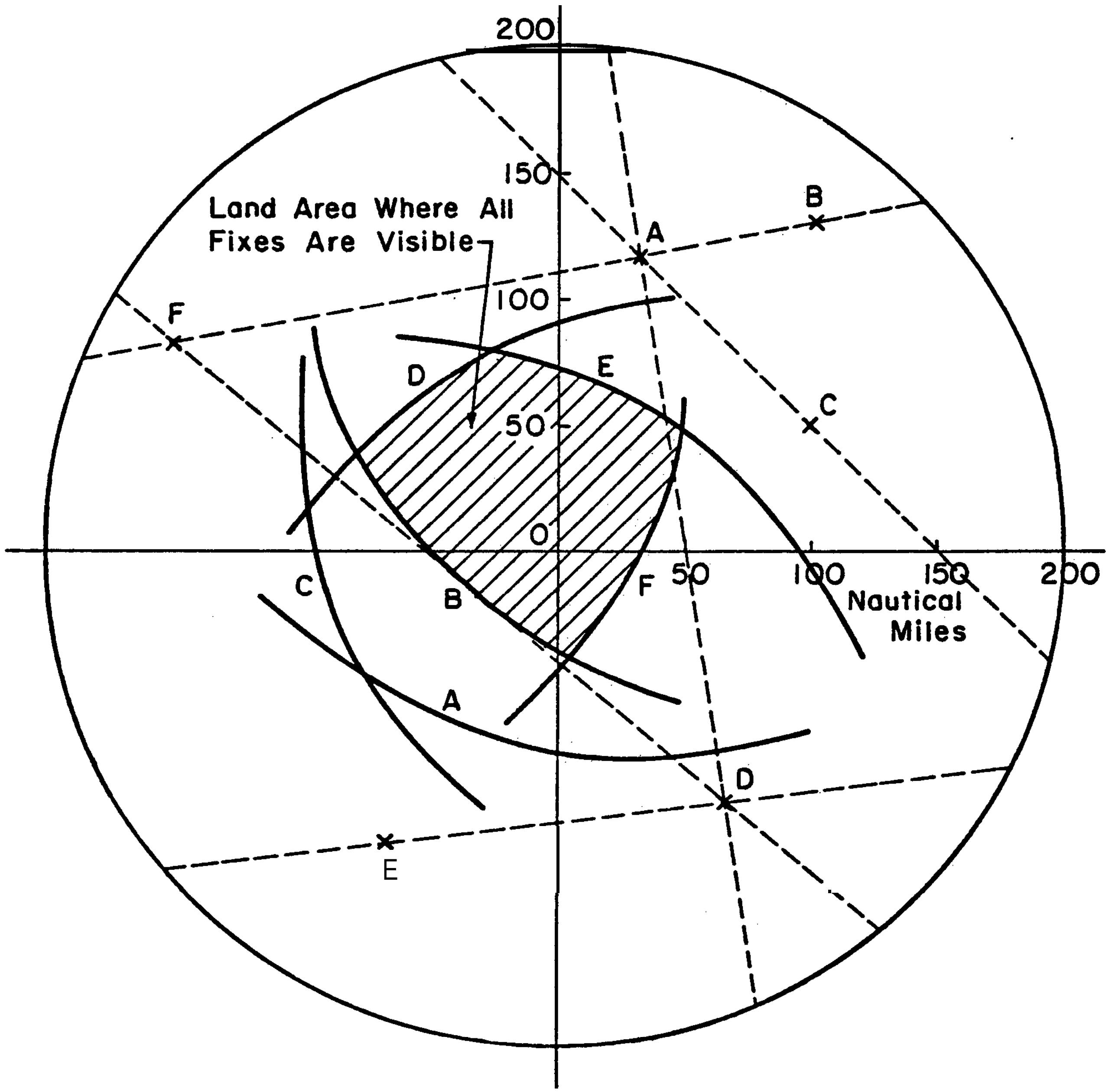
(1) Fix Location. Locateand identifyallgivennavigational fixes and/or critical coverage points on an appropriately sized quadrangle map or aeronautical chart. World Aeronautical Charts (scaled 1:1,000,000) are recommended for this purpose, although 1:250,000 survey maps may be used. In the latter case where fixes are specified relative to VORTAC or VOR locations, it is suggested that each such location be found by triangulation taking measurements from the aeronautical chart and transferring them to the quadrangle map.

(2) Construction. Using the location of each fix as a center, draw circles whose radii correspond to the maximum detection range of the ARSR for the smallest target size of interest. To obtain these maximum ranges, refer to the ARSR vertical coverage charts (using a nominal 0-degreetilt angle)and aircraft cross sections given in chapter 3 of this handbook. As a first approximation, the.maximum detection range selected from these coverage charts should represent that range obtainable on the nose of the ARSR coverage pattern. A technique for accounting for detection range variations as a function of fix altitude is discussed subsequently.

(3) Area Identification. Identify and mark the area common to all circles. This area identifies the region containing ARSR sites which satisfy the theoretical range coverage limitations of a given aircraft at each navigational fix. The best ARSR site locations would be at the centroid of this area, all other factors being equal.

(4) Illustration. To illustrate the above outlined procedures, consider the distribution of navigational fixes marked A, B, . ..F. as shown in figure 4-4. The grid reference point shown is arbitrary and is shown near the centroid of the potential site area. If a 200 nmi range capability is assumed for the ARSR (typical of coverage on the nose of ARSR-3 for small

FIGURE 4-4 DETERMINATION OF SITING LAND AREA AS A FUNCTION OF ARSR/ ATCBI COVERAGE AND FIX DISTRIBUTION



aircraft of the T-33 class), the allowable area for site locations can be determined by drawing 200 nmi circles centered about each of the fixes. The allowable siting area is that region common to all circles drawn about the fixes. The boundary of this area is shown as darkened arc lengths in the center of the figure. The letter shown alongside each arc segment identifies the fix that establishes that segment of the boundary.

c. Altitude Coverage Limitations. The land area defined in the above analysis is based on the assumption that all fixes are illuminated by the beam center or nose of the ARSR (lower beam) vertical radiation pattern. The purpose of this investigation is to refine the boundaries of the allowable siting land area by taking into account the fact that all fixes are not illuminated by the nose of the radiation pattern.

(1) Basic Technique and Assumptions. The techniques for carrying out this investigation are essentially an extension of those outlined in paragraph 59b above. The principal difference here is that the radii of the circles drawn from each fix are reduced in direct proportion to the reduction in range coverage that occurs at altitudes above or below the nose of the lower beam ARSR vertical radiation pattern. To determine these range reductions, it is convenient to make the following assumptions:

(a) Tower. The base of the antenna tower is assumed to be located at an msl elevation corresponding to the average msl elevation of the ground surface of the land area defined in paragraph 59b.

(b) Antenna Height. The effective height of the antenna phase center is initially assumed to be 37 feet above the antenna tower base; (i.e., a tower height of 25 feet is assumed; ARSR-3 antenna phase center is 12 feet above top of tower).

(c) Tilt. The vertical coverage pattern of interest is assumed to be the free-space pattern obtained for a 0-degree tilt angle of the antenna lower 3 dB point.

(d) Range. Optical and radar range and LOS are assumed equivalent.

(e) Operational Limitations. It is assumed that lobing, clutter, and/or other operational limitations brought about by surface reflections or screening may be neglected in this preliminary investigation.

(2) Procedure. The following procedures should then be followed. For ease of analysis, a worksheet similar to that shown in figure 4-5 may be used to record the derived values. For illustrative purposes sample data from reference 16, the siting report for the Beach North Dakota Long Range Radar is entered on the work sheet. Subsequent sample data entries for sample calculations are also selected from the same reference.

(a) Average Site Elevation. From topographic maps, determine the average msl elevation of the terrain within the boundaries of the general area established in paragraph 59b above.

FIGURE 4-5 WORKSHEET FOR PRELIMINARY RADAR COVERAGE ESTIMATION

Assumed Antenna Height 75' Radar Type ARSR-3

MSL Elevation Of Antenna Center 2500 Aicraft Type T-33

Fix Identification	MSL Altitude Of Fix (Feet)	Difference Between Fix & Antenna Altitude (Feet)	Maximum Coverage Range To Fix (From Coverage Diagram, nmi)
(BIS) VORTAC	10,000	7,425	145
10 nmi N BIS VORTAC	12,000	10,425	152
(DIK) VORTAC	6,000	3,425	135
(GCW) VORTAC	12,500	10,925	154
(MLS) VORTAC	10,000	7,425	145
(MOT) VORTAC	12,000	10,425	152
(ISN) VORTAC	12,500	10,925	154
OLF INTXN	12,500	10,925	154

FAA Form

(b) Fix Altitudes. Subtract this average msl elevation plus the assumed antenna height (75 feet) from the msl altitudes of each required fix. Enter these values in the third column of the worksheet of figure 4-5.

(c) Range Coverage. Determine the range coverage obtainable for each of the required fixes as a function of their altitude above or below the nose of the ARSR radiation pattern. The procedure for determining this range is illustrated in figure 4-6. In the figure, the ARSR-3 lower beam coverage contour for a small aircraft is shown. From thiscontour themaximum range coverage at the nose of the pattern is 237 nmi at an altitude of about 90,000 feet. This point is designated by the letter A in the figure. For fixes located above or below point A, the range coverage capability will be reduced in proportion to the drop in antenna gain as we move off the nose of the pattern. This reduction is determined by locating the fix at point B as shown in the figure, at an altitude, 10,425, corresponding to the altitude difference computed in (b) above for mot Vortac. The intersection, C, of the constant altitude line through B with the pattern contour defines the range, R, (shown as 152 nmi in the figure) of interest. This range should be entered in the last column of the worksheet and the process repeated for each of the specified navigational fixes.

(d) Area Adjustment. Make the necessary revisions to the area found in the investigations of paragraph 59b by drawing arcs about each fix using radii corresponding to the adjusted range values found in (c) above. Care should be taken to consider all fixes in this investigation even though they were not originally found to be critical in establishing the site area boundaries. Some of these fixes could become important on the basis of the altitude coverage considerations.

d. Cone-of-Silence Limitations. Further refinement of the aboveanalysis should be made by taking into account the coverage limitations of the ARSR due to its so-called cone-of-silence. To do this, it is recommended that the adjusted area determined above be redrawn on an appropriately sized chart which is marked to show those fixes, and airways which lie within the area, together with the corresponding altitudes for each. The real estate to be avoided beneath fixes and airways is determined by an area swept out along the ground surface by the base of a right circular cone as its apex travels along all air routes traversing the region. The apex angle of the cone is 130 degrees and its height equals the AGL (above ground level) altitude of the fix or point along the airway. The 130-degree apex angle assumes an R^4STC curve is to be used. Higher values of STC attenuation will require the use of larger apex angles. An illustration of the results obtained using this procedure is given in figure 4-7. Similar consideration for the airways plotted on the polar coverage diagram in a subsequent section shows no cone-of-silence limitation to airways coverage.

e. Summary. The area defined by the above procedure determines the general area in which the ARSR/ATCBI system must be sited to provide effective detection and tracking of aircraft over each fix and airway. Once determined, the area should be carefully replotted on an appropriate topographic quadrangle map to aid in selection of candidate sites. Generally, the area found

Figure 4-6. ILLUSTRATION OF REDUCTION IN RANGE COVERAGE CAPABILITY AS A FUNCTION OF FIX ALTITUDE.

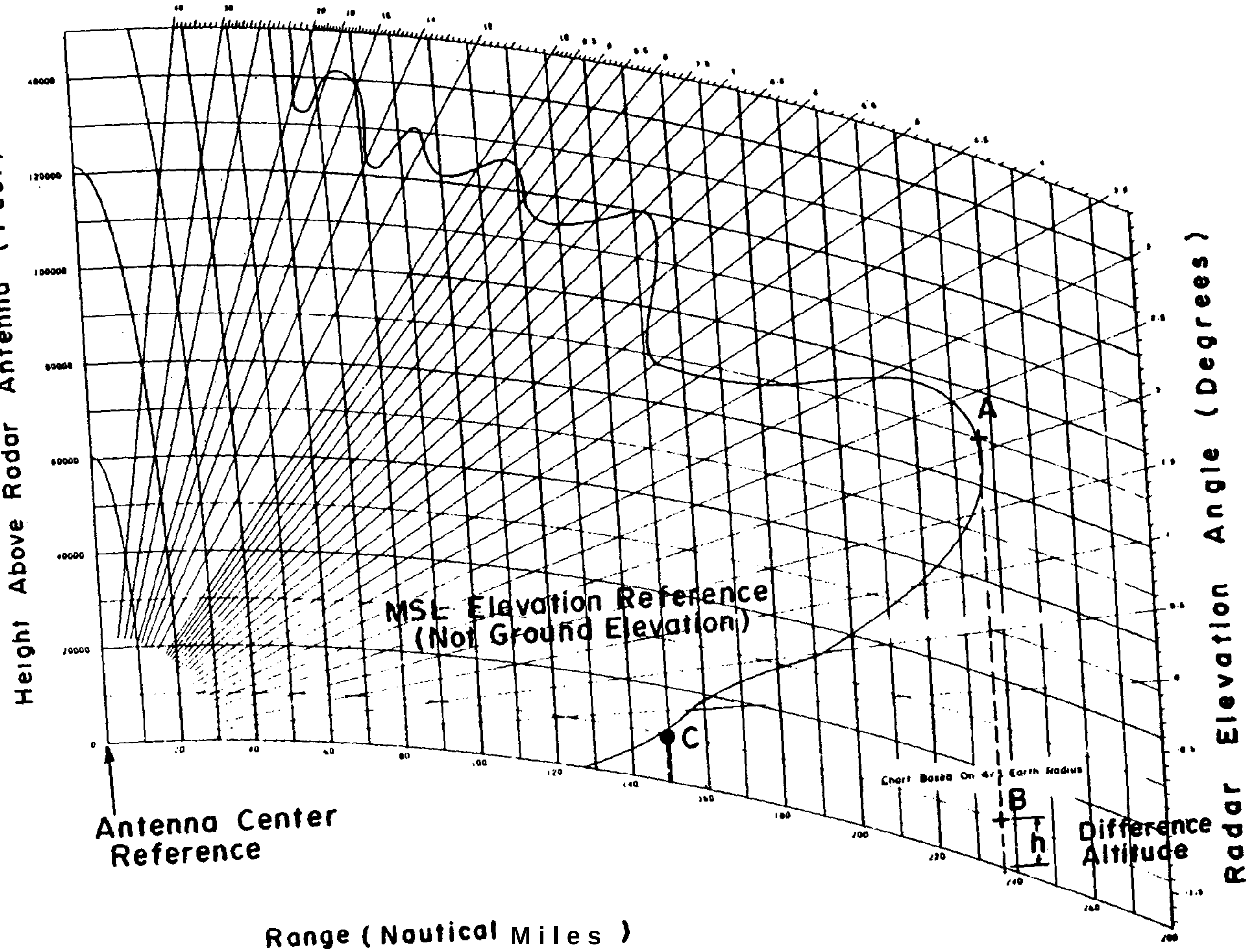
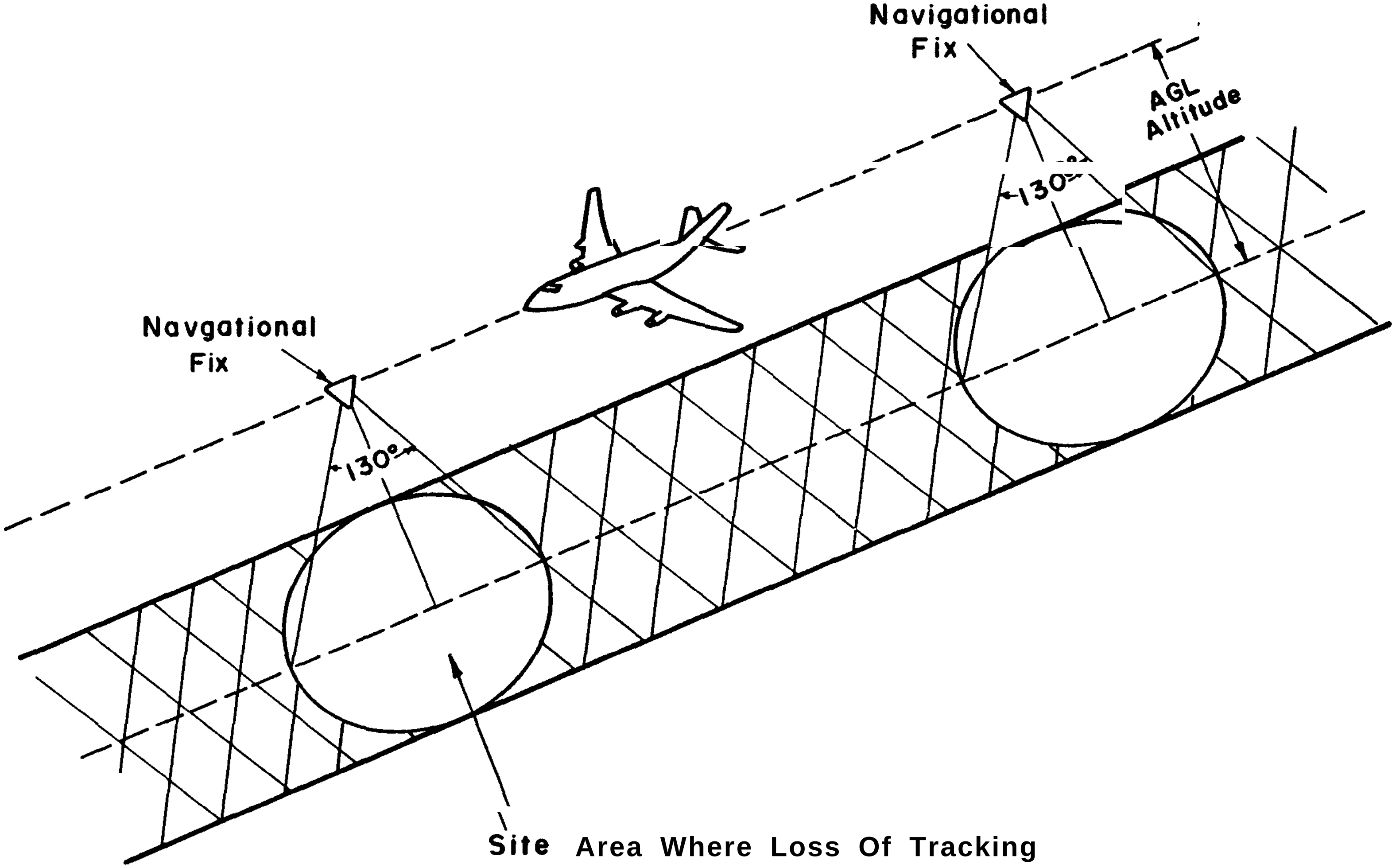


Figure 4-7. ILLUSTRATION OF LAND ELIMINATION TECHNIQUE BASED ON CONE-OF-SILENCE



will be sufficiently large to contain many site possibilities. However, if the area found using this procedure is unduly restrictive, leaving little or no choice for site location, discussions with AT personnel are advised to consider whether any relaxation or modification of the restrictive airway/fix requirements are tolerable.

60. PRELIMINARY SITE INSPECTION. The objectives of this investigation and inspection are to locate and identify available siting property within the general land areas established in the previous determination, and to select from these properties a small set of preferred site locations for in-depth survey and analysis. The preliminary investigation will include map studies, visits, and some analysis to ascertain the availability and suitability of the particular properties as site locations, taking into account the many criteria for good siting.

a. General Considerations.

(1) Land Availability. An important concern in locating potential enroute radar sites is to find property that is available through purchase or long-term lease. This property should be at an elevation which overlooks the surrounding terrain such that it can provide the desired coverage and is more or less isolated from above-ground obstructions which may interfere or cause reflections in radar/beacon operation.

(2) Initial Selection. State, county, municipal and other topographic maps, together with aerial photographs and/or inspection where appropriate, should be used to identify and locate the suitable property. Within the limits of these data, studies should concentrate on properties which meet the following criteria:

(a) Thoroughfares. The property should not overlook any sizeable number of busy thoroughfares (e.g., highways, expressways, railways, etc.).

(b) Structures. The property should not be located in an area zoned for commercial buildings or high-rise apartments.

(c) Area Development. The property should not be located in an area where expected future development could either degrade radar performance or require radar relocation due to environmental factors.

(d) Interference. The property should not be located closer than 2,500 feet from any local broadcast radio/television stations, or any industrial facility. Further, the site shall not be less than one-half mile from Weather Service radars and radiosonde equipment. Violation of the latter criteria requires a Washington waiver,.

(e) Access Facilities. Effort should be made to select properties for which road access and utility service are either already available or can be made available without major cost.

(f) Environmental. Every effort should be made to avoid selection of any property which includes wetlands, endangered species (flora or fauna), or other features which require special environmental protection. Environmental considerations will be weighed as heavily as coverage in final site decisions.

b. Preliminary Site Inspection. Having established the necessary legal permission, visits to each of the candidate site locations should be made and discussions with local government or business officials should be held as necessary to obtain the following information: A form such as the checklist shown in figure 4-8 may be used to record the data obtained.

(1) Screening Characteristics. Visual inspection of the environment and terrain surroundingthe propertyusing handlevelandmagnetic compass should be made to ascertain the quality and extent of screening objects(i.e., hills, buildings, tree growth, horizon, etc.) should be identified over the entire 360 azimuth sector. Estimates of the range and heights of the screen objects relative to the property elevation should also be made. Snapshot photographs may serve as a helpful aid in recording/documenting many of these features for future reference.

(2) False Target Sources. Potential sources of beacon reflections such as fences, metal structures,towers, etc. within 1 nmi of the property should be identified. The size and/or extent of these reflecting surfaces should be obtained along with an estimate of their range from the site.

(3) Terrain Features. Terrain characteristics should be documented by noting soil type, surface roughness, hilly areas, bodies of water, swamps, farmland, forests, urban areas, mountains, etc., on or near the propertyunder consideration. On the basis of this data, a qualitative estimate of the extent and/or severity of the radar clutter to be expected should be attempted along with the identification of land sectors which may support lobing.

(4) Environmental Features. Environmentally noteworthy features such as historical sites, antiquities, wetlands, endangered species, parks, recreational areas, etc., should be noted for later use in preparing the required environmental assessments.

(5) Accessibility. The existence of or need for roads to gainaccess to the property should be determined. Where road construction or improvement is necessary, estimates delineating the extent and type of construction or improvement shall be made.

(6) Electrical Power. Nearby access to three-phase electrical power should be established. Estimate the nature and extent of the construction or installations necessary to provide power at the site. Identify the power company having the franchise for the area.

Figure 4-8.

PRELIMINARY SITE INSPECTION CHECKLIST

SITE INSPECTED :	PAGE I OF 2
DATE :	PERSONNEL :

SITE ACCESSIBILITY : (note roads or improvements req'd, with est. of cost)

DAtALiNE/ RML REQUIREMENTS : (availability of commercial telephone data service and suppliers ; - as applicable)

ELECTRICAL POWER PROVISIONS : (avail. of comml. pwr. and loc.of nearest access pt.)

SANITATION : (note any sewer, water connections req'd. ; est. cost)

TERRAIN TYPE : (note gen. char. of terrain near site)

DRAINAGE : (note any special grading/leveling req'ts.; est cost)

ENVIRONMENT : (note nearby natural or other sources of harmful radiation, shock , vibration , corrosive atmospheres, recreational or historic site, environmentally sensitive areas, etc)

Figure 4-8. (continued)

SITE INSPECTED :	PAGE 2 OF 2
SURFACE TRAFFIC : (est. length, dir. , dist. of visible roadways & R.R. lines)	
SCREENING CHARACTERISTICS : (est. range, ht. of close - in and distant screening objects for oil azimuths)	
AREA DEVELOPMENTS : (est. nature , extent of future deveiopement in the site area)	
CLUTTER / LOBING ASSESSMENT ; (est. severity of clutter in unscreened areas , note regions of poss. iobing)	
REFLECTORS : (note size, range of potentially harmful reflectors)	

(7) Data Line/RML Requirements. The requirements for leased communications utility service to connect the potential site to its ARTCC's should be established. Identify the utility companies capable of providing the required service and note the approximate new cable requirements. For sites where an RML installation is indicated, estimate the los distance between the radar and indicator sites.

(8) Nearby Processing/Mining Industries. Chemical,sewagetreatment, mining or quarry operations located near or within the vicinity of the candidate site should be identified. Investigations should then be carried out to determine if any corrosive discharges, dust, chemical pollutants, shock or vibrations produced by these individual operations are serious enough to cause mechanical or electrical failures in an ARSR/ATCBI system.

(9) Surface Traffic. Estimates of the length and direction of highways, expressways, railways, or roads that are visible from the propertyshould be noted.

(10) Drainage. The soilconditions, relief,and gradingof the property terrain should be assessed from a drainage standpoint. Special note should be made of any leveling or grading necessary to improvedrainage of the property.

(11) Sanitation. The location of a well and septic tank and drainage field should be determined and recorded.

(12) Area Development. Plans for localarea development,area zoning and community growth patterns, as related to the candidate sites, should be determined from local officials.

61. PRELIMINARY SITE ANALYSIS.

a. General. A preliminary analysis is carriedout todetermine a small number of promising candidate site locations which will later receivein-depth survey and investigation. Since the data available for the preliminary analysis is only semi-quantitative at best, it should be recognized that absolute or precise results are not obtainable at this stage. Hence, in the procedure suggested below, the effort expended should reflect the need for relative comparisons rather than an elaborate or laborious preliminary assessment of the candidate sites.

b. Analysis. The analyses necessary to support preliminary site selection include but are not limited to: a determination of approximate coverage which can be achieved from a candidate site,and anestimate of any extraordinary installation, operational and/or maintenance costs required for each candidate. The analyses are described below.

(1) LOS Visibility. The purpose of this analysis is to estimate the los visibility of each of the required navigational fixes from each site under consideration, and to tentatively determine the antenna height required for full coverage. The principal factors to be considered in this analysis are the screening objects (close-in and distant) surrounding the candidate site.

Coverage plots machine generated from an automated digital terrain data file can be obtained from ECAC through the Systems Engineering Service, Spectrum Engineering Division, AES-500. Plots showing coverage contours for specified altitudes can be prepared for each site and proposed antenna height. These coverage plots can be supplemented with topographical maps and the screening data recorded during preliminary inspections as needed. Antenna heights necessary to obtain los visibility to each fix should be recorded.

(2) Cost Estimates. In addition to the anticipated cost for acquisition or lease of the property, cost estimates relating to extraordinary site improvements, system operations, and life cycle maintenance requirements should be made and tabulated for each site. Among the items which should receive special consideration are:

(a) Extensive and/or unusual road construction or improvements.

(b) Special installations to provide sanitary, water, and electrical power.

(c) Requirements for leased communications services and/or remoting.

(d) Unusual grading, landscaping or other property improvements.

(e) Tree removal or maintenance.

(f) All weather access for maintenance.

(g) Travel time and expense for maintenance.

(3) Tangential Course Situations. The location of all tangential course problems associated with each of the candidate site locations should be determined. This can be done by marking all primary and secondary flight paths in the controlled airspace on a scaled map or los chart, and identifying the portions of any flight paths which are tangent or nearly tangent to circles about the site in question.

(4) Area Growth Study. A study should be conducted, estimating the nature and extent of local area development anticipated in the vicinity of each candidate-site location for a period of ten years.

62. SELECTION OF SITES FOR SURVEY. The set of sites selected for in-depth survey should represent the most promising among those candidate sites investigated. To provide some assistance in making these choices, the following guidelines are submitted to facilitate trade-offs, comparison, and compromise among the various factors considered.

a. Coverage. Maximum preference is given to those sites having the best potential for meeting the radar coverage requirements. This potential should be evaluated by comparing or assessing the following factors for each candidate site with respect to coverage requirements.

(1) Range Coverage. For the smallest aircraft of interest, specify/describe the extent to which an ARSR at the site is not expected to meet basic range coverage requirements.

(2) LOS Visibility. Determine the number of fixes which are not visible from each site due to screening obstructions.

(3) False Targets. The number of potential false target reflecting surfaces surrounding each site should be determined and the extent of possible beacon false target replies should be estimated.

(4) Lobing. The azimuth sector(s) in which ARSR/ATCBI lobing may occur should be estimated and related to possible coverage problems,

(5) Clutter. The azimuth and range extent of expected clutter should be estimated and related to radar coverage,

(6) Surface Traffic, The extent of surface vehicular traffic visible to the ARSR/ATCBI location should be determined and the potential for producing unwanted radar targets assessed.

(7) Cone-of-Silence. All airways passing through and navigational fixes within the ARSR/ATCBI cone-of-silence should be identified for each site location.

(8) Tangential Course Problems. The locations of tangential course problems associated with each site should be identified with respect to the basic radar coverage requirements.

b. Interference. Sites should not be located near industrial operations whereby the ARSR/ATCBI system may be exposed to corrosive discharges, electrical interference, shock and/or excessive vibrations.

c. Site Surroundings. Sites surrounded by undeveloped and/or natural areas are preferred over those in heavily congested urban areas, business districts, etc. This preference, however, is predicated on the knowledge that no plans for future development exist in the undeveloped areas. Site areas where anticipated community growth may cause radar performance problems or may cause the radar site itself to become controversial on environmental grounds, should be avoided.

d. Close-In Screening. Site locations which provide a good deal of low-angle, close-in natural screening against clutter, lobing, and false target sources are desirable.

e. Required Improvements. Sites which require excessive improvements for the purpose of screening, utility service installation, and access, drainage, weather protection, tree removal, etc., should be avoided if at all possible due to the high cost associated with these improvements.

f. Maintenance. Sites requiring extensive annual maintenance such as grading, drainage, road repairs, trimming of trees, etc., should be avoided.

SECTION 4. SITE SURVEY

63. INTRODUCTION

a. General. The data and information to be obtained during the in-depth survey of each site may be separated into three principal categories: (1) communications-electronics, (2) environmental, and (3) engineering and construction.

b. Communications-Electronics Data. The communications-electronics data relates primarily to the location of the ARSR/ATCBI antenna and to the environmental factors that affect the performance of the radar/beacon system. These include the effective height of the antennas,. screening angles about the site, earth surface characteristics related to radar propagation, and manmade reflecting objects or surfaces near the site. Secondary communications-electronics data also relates to the location, orientation and space requirements for all RML antenna towers or landline facilities required for communication between the ARSR/ATCBI site and the ARTCC indicator site(s).

c. Environmental Data, Environmental data to be collected during the in-depth site survey includes information on the impact on air and water quality, noise, radio interference and radhaz, as well as recreational areas, historic sites, antiquities, wetlands, endangered species, and economic impact.

d. Engineering-Construction Data. The engineering and construction data that will be obtained relate to making the site operational, This includes surveys and investigations to determine the requirements for water, electrical power, sanitation, road access, grading, drainage, landscaping and other special features.

e. Site Survey. The above factors were all considered in a qualitative and/or semi-quantitative manner during preliminary investigations aimed at identifying a small number of potentially acceptable sites. The candidate sites chosen by that process must then be studied in considerably greater detail/accuracy to provide the quantitative information necessary to support selection of a single optimum site. The sitesurvey discussedhere isconducted to provide data for these detailed studies and analyses. The tasks and procedures recommended for the site survey are given below.

64. PRB-SURVEY COORDINATION. After the sites co besurveyed have been selected, a field siting team consisting of at least one radar/electrical engineer, a civil engineer and one technician should be designated to coordinate and carry out the survey effort, One of the first responsibilities of the engineers will be to contact and/or convene the necessary conferences and meetings with cognizant individuals/representatives/agencies to expedite the following:

a. Review preliminary investigations and confirm results obtained for each of the sites selected for in-depth survey.

b. Select heights above ground level (agl) at which the detailed survey shall be made for each site.

c. Establish the order in which the site will be surveyed.

d. Set a date and tentative time schedule for conducting the survey at each site.

e. Obtain the necessary legal approvalsto conduct the survey at eachsite.

f. Review, assign and schedule all tasks to be performed at each site.

g. Schedule and make arrangements for the transportation of personnel and equipment to the various site locations.

65. EQUIPMENT NEEDS. The following items represent typical technical equipments which are recommended to accomplish the site survey:

a. Adjustable scaffolding to provide a surveying platform at the height levels (spaced 12½ feet apart) of interest at each of the sites.

b. Surveyor's Transit capable of one minute resolution or better.

c. Stadia rods, level, and surveyor's tape.

d. 35mm (or larger) reflex camera with lens of 85 to 90 mm minimumfocal length and special lens reticle to produce calibrated azimuth and elevation scales (in degrees) on each photograph,

e. Camera mounting assembly to hold and align camera with transit vertical and horizontal reference planes.

f. Photographic film, exposure meter, cable release, and lens filters.

g. 6x to 8x binoculars with a 35 mm to 56 mm objective lens.

h. Abney Hand Level.

i. Pocket Transit.

j. Tapes, 5 feet and 100 feet.

k. Drafting equipment.

1. 10-inch protractor.

m. Triangles.

n. 24-inch straight edge.

o. Data sheets, worksheets, logbooks, etc.

66. SCAFFOLD ASSEMBLY.

a. Scaffold Assembly. It will be necessaryto erect a scaffold assembly at each of the sites under investigation to provide a surveying platform at the antenna height of interest. Since the antenna height selected in previous studies is based on preliminary studies only, it is advised, although not always necessary, that the survey be made at three levels, corresponding to (1) the nominal height selected, and (2) $\pm$ 12½ feet above and below this height. This will require that the scaffolding be adjustable. In erecting this scaffolding, special precautions should be taken to assure adequate footing and guy wire supports for stability and personnel safety. The scaffolding tower should be guyed at all corners and every30 feet or less. It is important that the platform deck be firm and rigid to eliminate unwanted instrument movement.

b. Alternative. An alternative to the use of scaffolding is the crane-mounted bucket or Cherry Picker. When this is a feasible alternative, it is generally less expensive and time consuming than the use of scaffolding. Guy wires are still required for stability.

67. SCREENING PROFILE MEASUREMENTS.

a. Purpose. The purpose of the screening profile measurement is to collect precise screen angle data from which line-of-sight (los) visibility contour diagrams can be constructed. Data contained in the los diagram is used to determine the los coverage capability that can be expected for the ARSR/Beacon system at the antenna height and sitelocation underconsideration.

b. Basic Procedure. The screeningangles aremeasured using a surveyor's transit instrument to determine the elevation angle of all screening objects through 360 degrees in azimuth as viewed from each of the prospective antenna heights. These antenna heights correspond to the height(s) selected on the basis of preliminary investigations. As many observations of the vertical angles to the successive screening objects are taken as is necessaryto define the 360 degree profile. Where the profile is highly irregular such as in mountain regions, readings of the vertical angle should be made to significant points on the skyline or close-in profiie; that is, to successive peaks and valleys that describe the profile. Azimuth intervals will, therefore, vary but should not be made smaller than 1 degree except for cases of unusual or rare profile irregularities. Vertical angies [illegible] and below the local horizontal should be read to the nearest (1.0 foot) minute or 0.02 degree.

c. Skyline/Close-In Profiles. For the most part, the screening profile of concern will be the skyline profile about the site location. However, where an appreciable amount of navigable airspace exists beneath this skyline los in the region between the site location and skyline object, it is required that this airspace be accounted for by making the appropriate survey. This condition, which is principally found in mountainous regions, is illustrated in the examples shown in figures 4-9 and 4-10. Figure 4-9 illustrates a situation where a considerable sector of navigable airspace exists' between

Figure 4-9. ILLUSTRATION OF CLOSE-IN AND DISTANT OR SKYLINE SCREEN PROFILES

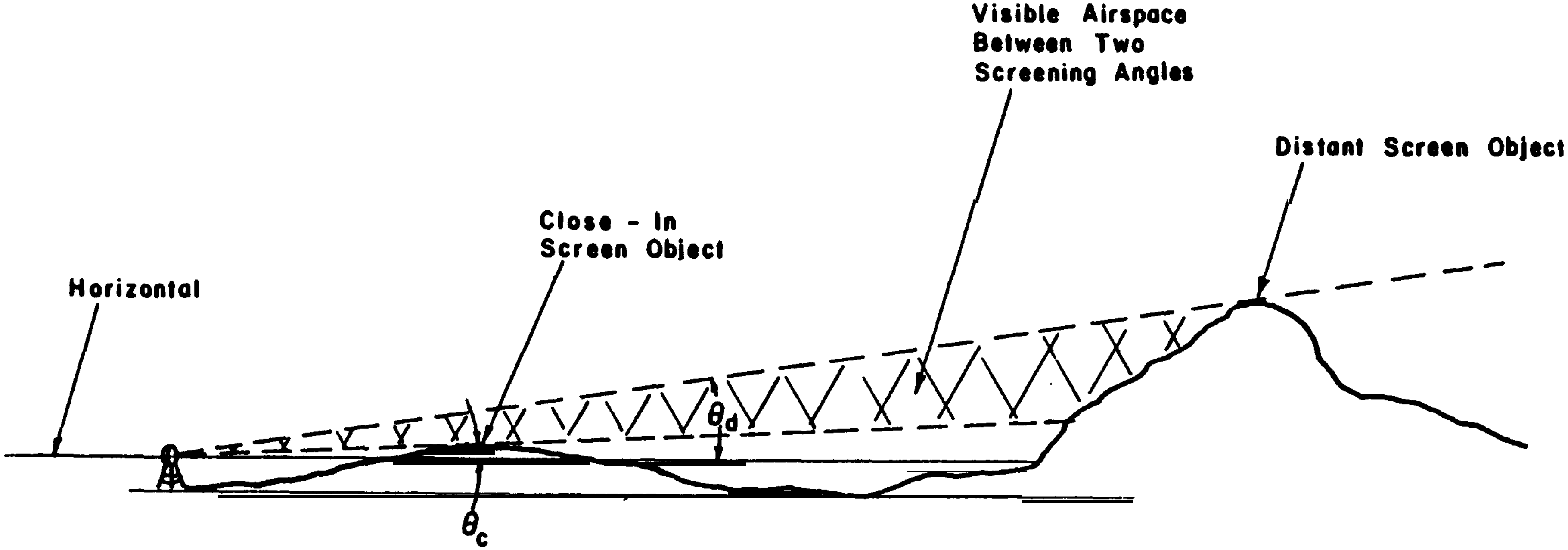
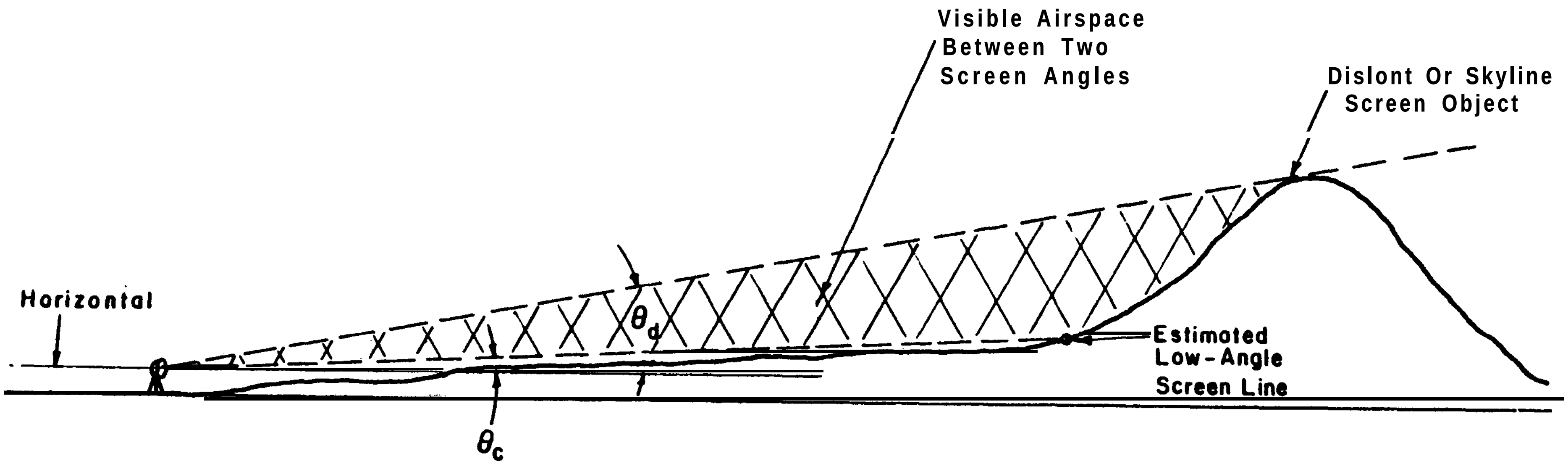


Figure 4 - 10 ILLUSTRATION OF DIFFERENCE BETWEEN LOW-ANGLE AND DISTANT OR SKYLINE SCREEN PROFILES



the two lines-of-sight established by the close-in hill and distant mountain skyline. The size of this sector is dependent on the distance between the mountain and site location and the site location and the size of the line-of-sight angle difference, $(\theta_d - \theta_c)$ shown in the figure. To determine the close-in screen profile about the site location, it should be recognized in figure 4-9, that the close-in los passes over the intervening hills, building, or other objects between the close-in screening objects and the distant mountain.

d. Low-Angle Screening. Figure 4-10 illustrates a case where the low-angle screening profile may be somewhat more difficult to establish when surveying. Here, no distinct and/or contiguous screening objects exist between the site location and the base or foothills of the mountain. Under these circumstances, a virtual screening profile along the base of the mountain should be established by lowering the surveying instrument until visually encountering any object between the site and mountain slope. The recorded low-angle los should pass over all intervening terrain,buildings, objects,etc.

68. SURVEY PROCEDURES.

a. Set-Up. Set up and level the transit at the location and height selected for the antenna. Make the necessary calibrations/adjustments to orient the transit with respect to magnetic north and correct for compass reading distortions caused by steel scaffolding. Select atruenorthreference and record for future reference and data conversion. A stake or suitable distant object will serve equally well. Set a marker at the center of the tower for future reference. Number and mark each tripod leg extension as well as each tripod leg and plumb bob point on the deck. This will permit resetting the transit at the same location and elevation with sufficient accuracy to continue the horizon profile work, should an interruption occur.

b. Initial Data Recording. Enter pertinent data identifying the site by name, number or other designation, anddescribing the site location, ground elevation, survey height, etc., on the Screen Angle Survey Data Sheet (figure 4-11). Care should be taken to include the height of the transit tripod as well as that of the scaffold platform in determination of surveyheight. Specify whether the data is for the close-in or skylineprofile and proceed as in steps c through g. Screen angle data derived from reference 16 is entered on the Screen Angle Survey Data Sheet as an example.

c. Instrument Alignment. Sight the instrument on the screening object, using the vertical circle tangent screw for alignment of the intersection of the vertical and middle horizontal crosshairs with the profile of the screening object,

d. Azimuth Angle Data. Enter the azimuth angle (to the nearest minute) of the screen object in the azimuth column marked TO and in the column marked FROM on the next line.

e. Vertical Angle Data. Enter the vertical angle(to thenearestminute) in the optical screen angle column. Care should be taken in reading the vernier correctly for plus and minus angles.

Figure 4-11

SCREEN ANGLE SURVEY DATA SHEET

Site Identification Beach N. Dak. Site "A"
Site Location { Longitude 103° 46' 45" W
Latitude 47° 40' 42" N
Survey Elevation (AGL) 75'
Site Elevation (MSL) 2500'

Close -In / Low Angle Screen
Skyline / Distant Screen
Recorder
Dot.

AZIMUTH (Mag. North)		AZIMUTH (True North)		SCREEN ANGLE	SCREEN DISTANCE (Nautical Miles)		SCREEN ANGLE	DESCRIPTION OF SCREEN OBJECT
From	To	From	To	(Optical)	Estimated	Measured	(Radar)	
		0	50	-0.3	37		-0.27	Distant Horizon
		50	80	-0.15	26		-0.13	"
		80	90	-0.4	30		-0.38	"
		90	100	-0.2	24		-0.18	"
		100	108	-0.3	30		-0.27	"
		108	120	0.0	24		+0.02	"
		120	124	-0.3	26		-0.27	"
		124	140	0.0	24		+0.02	"
		140	169	-0.1	27		-0.08	"
		169	176	+0.2	18		+0.22	Plateau
		176	180	-0.2	28		-0.18	Distant Horizon
		180	186	+0.2	20		+0.22	"
		186	191	-0.3	31		-0.28	"
		191	195	+0.3	18		+0.32	"
		195	295	-0.2	30		-0.18	"
		295	320	-0.3	33		-0.28	"
		320	330	-0.2	30		-0.18	"
		330	360	-0.3	36		-0.28	"

FAA Form 6310-S (12-73)

f. Screening Distance. Intheappropriate columnsenter the estimated or measured distance to the screening object and identify the screen object as distant horizon, buildings, nearby trees, etc. Distance estimates can be made by reference to known landmarks or by study of accurate site vicinity topographical maps.

g. Continuation. Repeat steps c, d, e, and f until data are obtained through 360 degrees in azimuth. Frequent checks should be made to see that the instrument remains level as screening measurements progress. Particular attention should be given to the bubble whose axis is parallel to the axis of the telescope, and any necessary readjustments of the leveling screws should be made.

69. PANORAMIC PHOTOGRAPHS.

a. Description. The panoramic photograph is intended to provide a pictorial representation of the visible skyline as viewed from the radar site and, also, to show the character of the surrounding terrain, buildings,fences, etc., comprising the reflection surfaces for the ARSR/ATCBI. It also serves to supplement the measured screen angle data by emphasizing significant points of merit when assessing and comparing the various site locations. The panoramic photograph may be used as a source of screening profile data in lieu of the transit survey if the photographs can be read to comparable accuracy (i.e., one minute, or 0.02 degree).

b. Procedures. The process of obtaining .a panoramic view of .the site surroundings consists of successive takes of as many separate exposures as are required to photograph the 360 degree azimuth about the site. It is recommended that each photograph extend over a maximum of 40 degrees in azimuth, requiring a total of nine or more photographs to obtain the full 360 degree panoramic. Panoramics should be taken at each of the antenna heights from which the screen angle measurements were taken. The following procedures may be used as a guide in taking the panoramic photographs:

(1) Camera Preparation. Load thecamera. Black-and-whiteor (preferably) daylight color print film of fine grain, moderate speed (ASA 125 for black-and&white, ASA 64 for color) is recommended.

(2) Camera Setup. Mount the camera on the tripod at the antenna height used in making the screen angle measurements. Bring the camera to a fine focus on the horizon using the focus adjust. Scan the camera 360 degrees in azimuth to assure that the distant screening profile falls within the field of view.

(3) Camera Filters. Select an appropriate filter to compensate for any haze, glare, shadow, or overcast conditions that may prevail.

(a) Black-and-White Photography. For black-and-white panchromatic film, yellow (K2, No. 8), deep yellow (G, No.15) and red filters (A, No. 25) gives progressively greater haze penetration in that order. In addition, these filters provide progressively sharper contrast between clouds and the sky, buildings and the foliage, etc.

(b) Color Photography. In color photography, the effect of atmospheric haze is to reflect invisible ultraviolet radiation which, in turn, causes an excessive bluishness. These effects can be cut down or eliminated by using a skylite (1A) or ultraviolet (uv) filter.

(c) Polarizing Filters. Polarizing filters are extremely useful in either black-and-white or color photography. They do not alter any of the colors in the scene, but intensify them by removing glare from tiny reflections that are largely invisible to the naked eye. They are all useful in controlling reflections from non-metallic surfaces such as glass, plastic, stone, painted structures, etc. Polarizing filters also darken blue sky and generally intensify sharp detail.

(4) Initial Camera Orientation. Orient the camera with respect to true north or with respect to some known reference point in azimuth. Record the azimuth reference point.

(5) Exposure Control. From the light-meter reading select the values for shutter speed and aperture (f-stop). Select the highest aperture (larger than f/8) possible for a 1/125 second or faster shutter speed. The higher the f-number, the greater the depth of field obtained. A new speed and aperture setting is usually required about four times in 360 degrees unless the sun is directly overhead and there are no clouds. If a filter is used for better definition, contrast, etc., the f-number or shutter speed should be corrected in accordance with the filter manufacturer's instructions.

(6) Photographs. Make as many exposures as may be required to obtain the complete panoramic. Each frame should include about a degree of overlap between successive frames to minimize end distortion and allow for waste in the printing process and later assembly of the complete panoramic. Since each frame will cover approximately 40 degrees in azimuth, approximately nine exposures will be needed to photograph the full 360-degree azimuth.

(7) Other Data and Notes. Make such notes as may be required to identify the separate takes. Azimuth references to prominent skyline features are especially worthwhile. A simple record of each photo taken will eliminate taking two shots of one azimuth or double exposure. It is recommended that the film for any one level be processed and inspected prior to removing or lowering the scaffold tower.

70. ADDITIONAL DATA FOR ELECTRONIC ASSESSMENT. In addition to photographs and screen angle measurements. observations made at the time of preliminary site inspection, and recorded-on the Site Inspection Worksheet (figure 4-8), should be verified and refined where necessary during the site survey. In particular, careful examination of the surroundings for sources of clutter,

vertical lobing, and reflecting surfaces should be made for each site surveyed. Data recorded should include:

a. Clutter Estimates.

(1) General terrain type(s).

(2) Range and azimuth dimensions of areas where severe clutter is expected.

(3) Range and azimuth of potentially large permanent echoes.

b. Vertical Lobing Estimates.

(1) Location of relatively smooth, horizontal surfaces within the radar field of view.

(2) Maximum height of surface irregularities in each area.

(3) Range and azimuth dimensions of each area.

c. Reflector Estimates..

(1) Location, orientation of moderate to large reflecting surfaces within 2500 feet of site.

(2) Location, orientation of large reflectors within 5000 feet of site.

(3) Estimated lengths, direction, location of visible roadways, railroad lines, and runways.

71. ENVIRONMENTAL DATA. Environmental considerations weigh heavily in the selection of ARSR/ATCBI sites, and FAA policy requiresan Environmental Assessment followed by either an Environmental Impact Statement (EIS) or Finding Of No Significant Impact (FONSI) in each site established. To provide input material for the Environmental Assessment, relevant data must be collected at the time of site survey. The data requirements are defined in detail in the latest edition of Order 1050.1, Policies and Procedures for Considering Environmental Impacts. Included among the requirements are the following:

a. Noise. Unless data or accepted estimates are otherwise obtainable, perform measurements of the ambient noise levels existing at each candidate site. Measurements shall include maximum sould level in dB(A) (single event measure), duration in time above a reference sound level, and a cumulative noise measure (e.g., Composite Noise Rating, Noise Exposure Forecast, Day/Night Level, or Equivalent Noise Level). Measurements may be made with commercial equipment such as:

(1) GenRan Inc., Concord Mass.
Model GR-1945, Community Noise Analyzer.

(2) B&K Instruments, Inc., Cleveland Ohio
Type 2218, Precision Integrating Sound Level Meter.

b. Air Quality. Estimate existing air pollutant concentrations at each candidate site location. This may be done by consultation with area EPA representatives.

c. Water Quality, Determine available water resources and facilities for waste treatment and disposal. This may be accomplished by conferring with the appropriate local agency responsible for water quality monitoring, or EPA.

d. Social and Socio-Economic Impacts. In consultation with local officials or planning organizations, estimate any impact of establishing ARSR/ATCBI sites at the candidate locations on population, neighborhood housing development and/or stability, vehicular traffic, or business development.

e. Special Use Areas. Using available source material and consultation as necessary, identify all existing and planned special use areas within or near the candidate site areas. The special use areas include public parks, recreation areas, and wildlife and waterfowl refuges.

f. Historical and Archaeological Sites. Using the National Register of Historic Places, identify all historical and archaeological sites within or near the candidate site locations.

g. Flood Hazards. In consultation with local area officials and/or EPA representatives, determine if the sites under consideration lie in or near any flood plain.

h. Wetlands, In consultation with cognizant local officials (e.g., EPA, Dept. of Interior, Dept. of Commerce) identify the location, types, and extent of wetland areas in the vicinity of each site candidate.

i. Coastal Zone Management. Determine if any of the site candidates lie in or near areas covered by a state coastal zone management program. This may be done by discussion with the appropriate state agency. In cases where site candidates are in or near such areas, obtain information on the nature of the state's program for the area.

j. Energy Supply and Natural Resources Development. Identify any energy production or consumption impacts which could occur due to development of the radar sites.

i. Construction Impacts. After studying the candidate site locations, identify any unusual or special environmental impacts which would occur as a result of site development. Factors to be considered include noise, air pollution, water quality, land use, etc.

l. Endangered Species. Consultation should be carried out with local Natural Resources agents and/or Department of Interior, Bureau of Lane Management officers to determine if any endangered or threatened species of flora or fauna could be influenced by development of any of the candidate radar sites.

m. Electromagnetic Interference. A survey of electromagnetic equipment in the siting area that could cause or be subject to electrmagnetic interference should be made. Reference 15 provides information on the allocation and use of the frequency band used by ARSR-3 and an interference analysis of several prospective ARSR-3 sites. A plot of microwave facility locations and other transmitters or receivers in the vicinity of the candidate site should be prepared to be used to determine the likelihood of interference to or from the planned radar site. Power densities in excess of the generally accepted radiation hazards criterion can be exceeded out to 375 feet from the ARSR-3 antenna in the direction of the main beam. This level would not be exceeded at ground level with the lower 3 dB point of the main beam at 0 degree elevation due to minimum 37 foot agl position and the sharp fall-off of the gain below the beam. However, consideration must be given in site layout to preclude illumination by the main beam of personnel within 375 feet of the antenna. This could be caused by lowering the beam angle or having occupied areas within 375 feet at a height high enough (37 foot agl) to be in the main beam. Note should be taken of the number of dwelling units located sufficiently close to the ARSR/ATCBI site that television interference could occur.

n. Visual Impacts. After visiting each candidate radar site, any significant or unusual visual impact which would occur from site development should be noted.

72. COST DATA.

a. General. All data necessary to estimate the cost of establishing an ARSR/ATCBI facility at each site location should be collected during the site survey. Some of the items which require special attention because of their potential impact upon the cost of site development include soil analysis and bearing capability; drainage; grading, access road, utility service, and water and sanitation requirements; earth resistivity; and design wind velocity.

b. Data Acquisition. Most of the required site data affecting the preparation of construction cost estimates can be determined by inspection at the site location(s). In cases where there are questions, however, e.g., soil data, subsurface geology, etc.) consultation with local officials, engineers, or contractors is advised.

c. Earth Resistivity.

(1) General. Knowledge of soil resistivity at the radar site of the grounding system required for protection of the site. Because of the dependence of earth resistivity upon subsurface geology, soil moisture content, etc.

The parameter is variable and requires measurement at each potential site location to allow an accurate determination of the proper site grounding system.

(2) Measurement. Earth resistivity measurements should be performed in several places at each site in accordance with procedures described in the latest edition of Order 6950.19, Practices And Procedures For Lightning Protection, Grounding, Bonding, And Shielding Implementation, using a standard earth resistance test set. Representative equipment which may be used for these measurements include James G.Biddle Co., Plymouth Meeting, Pa., Cat. No. 63220, Megger Null Balance Earth Tester; and Associated Research, Inc., Chicago, Illinois, Vibroground Mod. 263, Resistivity Instrument.

(3) Additional Information which should be collected to aid in design and cost estimation for the grounding system includes soil moisture characteristic and depth of water table, deepest-frost penetration, and rock formations at or near the surface.

SECTION 5. SITE PERFORMANCE ANALYSIS

73. GENERAL. In this section, methods and procedures for processing and analyzing information gathered from the preliminary studies and site survey are presented. The analysis procedures described should be applied to each site actually surveyed. This will provide a systematic compilation of radar and beacon performance information to aid in formulation of recommendations for an optimum site. The required analyses are described in the following paragraphs; they cover the following:

a. Site Panoramic Photograph.

b. Screening Analysis.

c. LOS Altitude Coverage Analysis.

d. ARSR Coverage Analysis.

e. Beacon Coverage Analysis.

f. Beacon Vertical Lobing Analysis.

g. ARSR Vertical Lobing Analysis.

h. Beacon False Target Analysis.

i. Clutter Analysis.

j. Tangential Course Analysis.

k. Second-Time-Around Analysis.

74. SITE PANORAMIC PHOTOGRAPH.

a. Utility and Application. The panoramic photographs obtained during the site survey represents an important part of the data collected. The major value of these photographsis asaconvenient reference in support of current or future site investigations and analysis. Some anticipated applications of the photographs include:

(1) a pictorial display of the terrain features about the site,

(2) a reference aid in identifying/locating prominent or troublesome reflecting objects (buildings, hangars, fences, highway traffic, etc.) about the site,

(3) a check and cross-reference for screen angle transit data,

(4) a convenient reference base for trouble-shooting of future ARSR/ATCBI problems caused by modification of the site vicinity through construction (e.g., buildings, roads, grading) and/or natural changes (e.g., vegetation growth).

b. Procedure for Assembly. The panoramic photograph is prepared from the individual overlapping exposures taken at the antenna site, They should be formed into a single strip by matching, cutting and joining the individual prints. The assembled panoramic is then marked to indicate the cardinal directions in azimuth, local horizontal, degrees azimuth and elevation, and salient points or objects appearing in the panoramic. A 40 degree sector around 120 degrees azimuth of the panoramic photograph for Beach North Dakota Site A is reproduced in figure 4-12. The vertical and horizontal angle grid is evident. Three of the navigational fix requirements are marked on the photograph.

75. SCREENING ANALYSIS. The purpose of this analysis is to determine the radar antenna height necessary to achieve line-of-sight visibility to the required navigational fixes from each of the site locations considered. This analysis is preceded by the preparation of a screen angle graph. The screen angle graph is a plot of the angular elevation of both the close-in and distant (or skyline) profile as viewed 360 degrees in azimuth from each site location surveyed. The graph should be plotted in the rectilinear form shown in figure 4-13.

a. Preparation of Screen Angle Graph.

(1) Screening Data/Plot. The radar screen angle graph is derived from optical screen angle data taken during the site survey and entered in the screen angle survey data sheet (figure 4-11). Optical screen angles are converted to radar screen angles recorded on the data sheet, and plotted with the aid of equation 3-9, p. 72, which accounts for normal refraction of radar signals based on the 4/3 earth radius model. The equation is rewritten below:

$$\theta_{rs} = \theta_{os} + \frac{d_s}{1120} \quad (4\text{-}1)$$

FIGURE 4-12 SECTOR OF SITE PANORAMIC PHOTOGRAPH FOR BEACH NORTH DAKOTA SITE 'A'

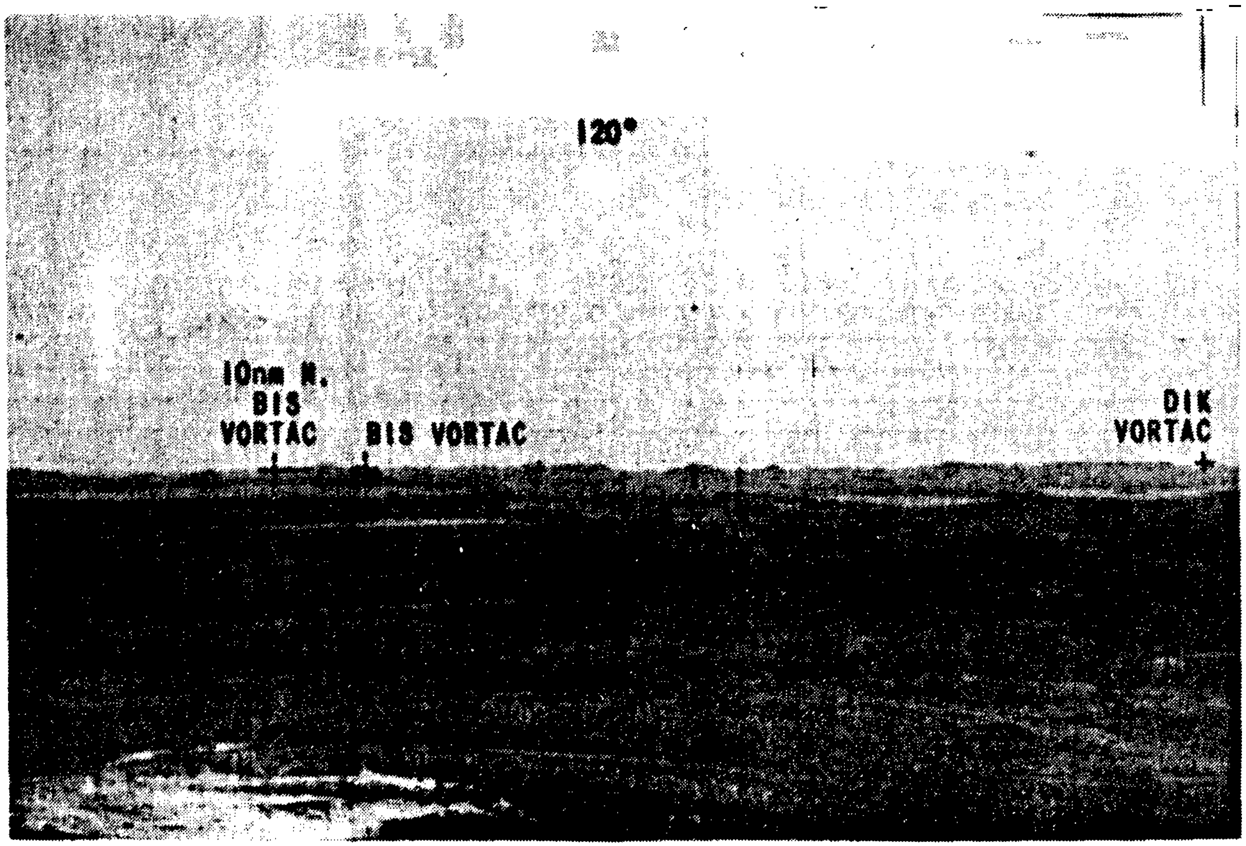
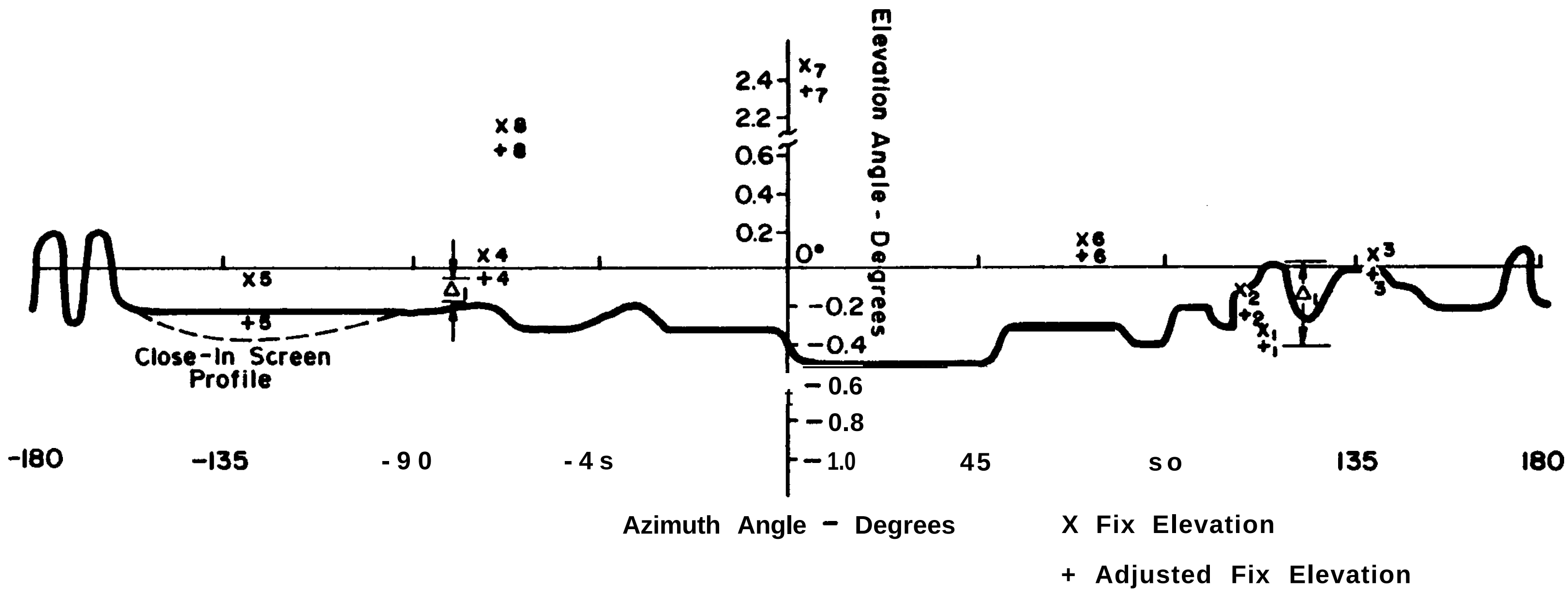


Figure 4 - 13 SCREEN ANGLE GRAPH



where

θ_{rs} = radar screening angle in degrees

θ_{os} = optical screening angle in degrees

d_s = distance to screen object in nautical miles.

(2) Fix Data Treatment. After completing the screening profile plots, the azimuth and elevation angle of each navigational fix and/or critical coverage point should be identified and marked directly on the screen angle chart.

(3) Fix Data Entry. Determination and plotting of all fix locations can be facilitated through data entry in columns C through H of the los coverage worksheet shown in figure 4-14. The fix azimuth and range data of columns C and D are determined from map studies, whereas fix height in column E is obtained directly from the AT coverage requirements. The elevation angle of each fix (column F) can then be determined from a radar coverage chart or from the equation given below:

$$\theta_f = \tan^{-1}\left[\frac{h_f - h_a}{6080\ d_f} - \frac{d_f}{6874\ k}\right] \quad (4\text{-}2)$$

where

θ_f = fix elevation angle (degrees)

h_f = fix altitude (ft. msl)

h_a = antenna height (ft. msl)

d_f = fix range (nmi)

k = equivalent earth radius factor
($k = 4/3$ for "normal" atmosphere)

The eight fixes plotted on figure 4-13 and listed on figure 4-14 are for the Beach North Dakota Site.

(4) Safety Factor. As an additional step it is advised that the elevation angle of each fix be reduced by a safety factor of 0.1 degree (6 minutes) to account for uncertainties in transit measurements, plotting, range estimation, etc. This corresponds to lowering the msl altitude of a fix located at 200 nmi by approximately 2000 feet. As range to the fix decreases this altitude safety factor will become correspondingly smaller. The adjusted elevation angles are recorded in column G of the worksheet and are indicated on the screen angle graph.

(5) Adjusted Fix Heights. The fix altitudes corresponding to the adjusted elevation angles should be determined for each fix location and recorded in column H of the worksheet. The calculation may be made using equation 4-3 below:

Figure 4-14. LOS COVERAGE WORKSHEET

SITE: Beach, ND Site A	RADAR TYPE: ARSR-3	CONDITION: ☐ LP-FAIR ☐ CP-HVY PRECIP
SITE LOCATION: LATITUDE LONGITUDE	SITE ALTITUDE: 2500 FT MSL SURVEY HEIGHT 75 FT AGL ANTENNA HEIGHT: FT MSL	DATE: PREPARED BY:

(A) No.	(B) Name Of Fix	(C) Fix Azimuth (Deg.True)	(D) Fix Range (n.m.)	(E) Fix Height (Ft.MSL)	(F) Fix Elevation Angle (Deg.)	(G) Adj.Fix Elevation ((F) - 0.1°) (Deg.)	(H) Adj.Fix Height (Ft.MSL)	(I) Measured Screen Angle Radar (Deg.)	(J) Radar Screen Altitudes (Ft. MSL)	(K) LOS Coverage Yes	No	Marg.	(L) Tilt Angle For Radar Coverage LP-C	CP-C	CP-R
1	Bismarck (BIS) Vor*	111.8	139.9	10000	-0.37	-0.47	9612	-0.05	14898		X		+0.	-0.5	-0.8
2	10 nm N BIS Vor	108.5	133.5	12000	-0.17	-0.27	10566	-0.10	12974		X		+.85	0.0	-0.'2
3	Dickinson (DIK) Vor	138.8	65.5	6000	+0.08	-0.02	5280	0.03	5627			x	+2.4	+2.0	+1.8
4	Glasgow (GGW) Vor	281.0	118.0	12500	+0.05	-0.05	11180	-0.18	9552	X			+1.3	+0.6	+0.4
5	Miles City (MLS) Vor	229.2	116.5	10000	-0.12	-0.22	8853	-0.18	9348			x	+1.0	+0.5	+0.2
6	Minot (MOT) Vor	70.0	107.0	12000	+0.16	+0.06	10846	0.28	6986	X			+1.5	+1.0	+0.7
7	Williston (ISN) Vor	3.8	35.0	12500	+2.45	+2.35	12120	-0.47	1641	X			t4.	+4.3	+4.5
8	Wolf Point (OLF) in TXN	289.0	78.0	12500	+0.71	+0.61	11657	-0.18	5118	X			+2.5	+2.2	+2.0
	*Vortac														

Maximum Tilt Angle For Coverage Of All Fixes

$$h'_f = h_a + 6080\, d_f \tan \theta'_f + 0.884 \frac{d_f^2}{k} \qquad (4\text{-}3)$$

where h_a, d_f and k are defined as in the previous equation, and

h'_f = adjusted fix height (ft. msl)

θ'_f = adjusted fix elevation angle (degrees)

$\theta'_f = (\theta_f - 0.1)$ degree.

(6) Radar Screen Angles/Altitudes, θ_{rs}, at the azimuth of each fix can be determined directly from the screen angle graph and recorded in column I of the worksheet. These values should be converted to radar screen altitudes, h_s, at each fix location using the following expression, with the results recorded in column J:

$$h_s = h_a + 6080\, d_f \tan \theta_{rs} + 0.884 \frac{d_f^2}{k} \qquad (4\text{-}4)$$

(7) Coverage Estimate. Finally, column K of the worksheet is completed as follows. If the adjusted fix altitude (column H) is greater than the radar screening altitude (column J), full los coverage is provided. On the other hand, if the radar screening altitude is greater than the specified fix altitude (column E), no los coverage is possible. For the intermediate condition, where the radar screening altitude is between the values in columns E and H coverage is considered marginal due to the uncertainty produced by the 0.1 degree safety factor. Worksheet column L entries are discussed in paragraph 77c below.

b. Analysis.

(1) Purpose. An analysis of the screen angle graph should be made to determine answers to the following questions:

(a) Are all navigational fixes and critical coverage points visible from the site at the antenna height selected?

(b) If all fixes are visible, to what minimum height can the antenna be lowered and still provide los visibility?

(c) If some fixes are screened from los visibility, to what height must the antenna be raised in order to achieve visibility?

(2)' Fix Visibility. The answer to the first question can be found by inspection of the screen angle graph or coverage worksheet. Navigational fixes above the screen angle profile are visible; those below are not. One special case may develop, however, where the answer is not so obvious. This occurs when a navigational fix lies somewhere between the close-in and distant screening profiles as illustrated by fix no. 5 in figure 4-13. In such instances it will be necessary to determine if the range to the fix falls within the range between the close-in and distant screen objects,

(3) Antenna Height Reduction. For the case when all navigational fixes are located above the screen profile, it is appropriate to consider how much the antenna can be lowered and still provide full los visibility of all fixes. This will be determined by that navigational fix whose elevation angle is closest to the plotted screen angle profile. For example, let fix no. 4 represent the closest fix to the screening profile in figure 4-13 (i.e., for purposes of this discussion assume fixes 1, 2, 3 and 5 are not present). The angular displacement between the fix and the adjusted screen profile point is shown as Al. If the fix is located at a distance greater than that of the screening object, lowering the antenna height results in a reductionof Al* (For fixes whose distances from the site are less than for the screening object, lowering of the antenna height increases Al; hence, in this investigation we are concerned only with the fix having least separation and is at a distance greater than the screening object.) Assuming this to be the case, the value of Al determines the extent to which the antenna can be lowered without losing los coverage. This is done using the following equation:

$$h_2 = h_1 - \frac{106.12\, d_f\, d_s}{(d_f - d_s)} |\Delta_1| \qquad d_f > d_S \tag{4-5}$$

where:

h_2 = lowered antenna height (ft)

h_1 = antenna height at which survey was taken (ft)

d_f = distance to navigational fix (nmi)

d_s = distance to screening object (nmi)

$|\Delta_1|$ = magnitude of angular separation between fix and screening object (degrees).

(4) Antenna Height Increase. For the case where a navigational fix is screened or lies below the screen angle profile, a similar analysisis made to determine the height to which the antenna must be raised to provide the desired los visibility. Here, however, the angular separation of concern, shown as A2, is that defined by the fix having the largest angular displacement below the adjusted screen profile points. In figure 4-13, fix no. 1 is shown as being the one furthest below the screen profile and thus becomes the defining A2 for raising the antenna height. The value to which the antenna should be raised is given by the following equation:

$$h_3 = h_1 + \frac{106.12\, d_f\, d_s}{(d_f - d_s)} |\Delta_2| \qquad d_f > d_s \tag{4-6}$$

where h_1, d_f, and d_s are defined as in the previous equations, and

h_3 = raised antenna height (ft)

$|\Delta_2|$ = magnitude of angular separation between fix and screening object (degrees),

(5) Final Height Determination. The significant result obtained by the above analysis is the minimum antenna height necessary to provide los visibility to all fixes from a given site location. In most cases, however, this minimum height will not be exactly realized because ARSR tower heights can only be varied in 12½ foot (or sometimes 25 feet) increments between 25 feet and 75 feet. As a result, the actual minimum antenna height to be specified will correspond to the nearest achievable height above the minimum value determined from the screening analysis. It should be rememberedwhen conducting this analysis that antenna height is 12 feet greater than tower height, and that the accuracy of height determinations using equations 4-5 or 4-6 is strongly dependent on the accuracy of df and d_s data.

76. LOS ALTITUDE COVERAGE ANALYSIS. Radar line-of-sight coverage of the controlled airspace can be determined readily with the aid of a los boundary diagram. Initial estimates of the coverage should be determined from the plats obtained from ECAC (Par 51b(3)), prepared from stored digital terrain data. The diagram is a plan view of radar range visibility limits about the antenna site at various flight altitude levels. It is prepared using the radar screening angle data indicated in figure 4-11 and offers a different perspective for assessing radar visility than does the screening graph. The major use of the los boundary diagram is in determining the los visibility of airroutesbetween the navigational fixes in the coverage area. Also, since the diagramis plotted on polar coordinate paper and shows all air routes in the coverage area,itmay be used inidentifying andlocatingtangentialcourse problems for subsequent studies.

a. Preparation of the LOS Boundary Diagram. The radar los boundary diagram should be prepared using Polar Coverage Chart (figure 4-15) or equivalent to a scale of 1:1,000,000 allowing overlay on World Aeronautical Charts. Plots should be prepared covering all flight levels of interest. A representative diagram might include plots for altitudes of 4000, 6000, 8000, 10000, 12000, and 15000 feet. The diagram should also include the msl altitude at which data were collected. Preparation of the diagram may make use of either hand or machine calculation.

b. Machine Calculation/Plotting. A series of FORTRAN computer programs has been developed by FAA engineers for calculation and plotting of los range vs. azimuth for selectable flight altitudes, using screen angle input data of the type described in paragraph 67 above. Depending upon the program used, the computer output may be in the form of data tabulations, small-scale plots, or large-scale plots. The computer programs, described in detail in appendix 3 of this handbook, were developed for use with FAA's CDC time-sharing computer system. They are permanently stored in the computer and may be accessed by any FAA user.

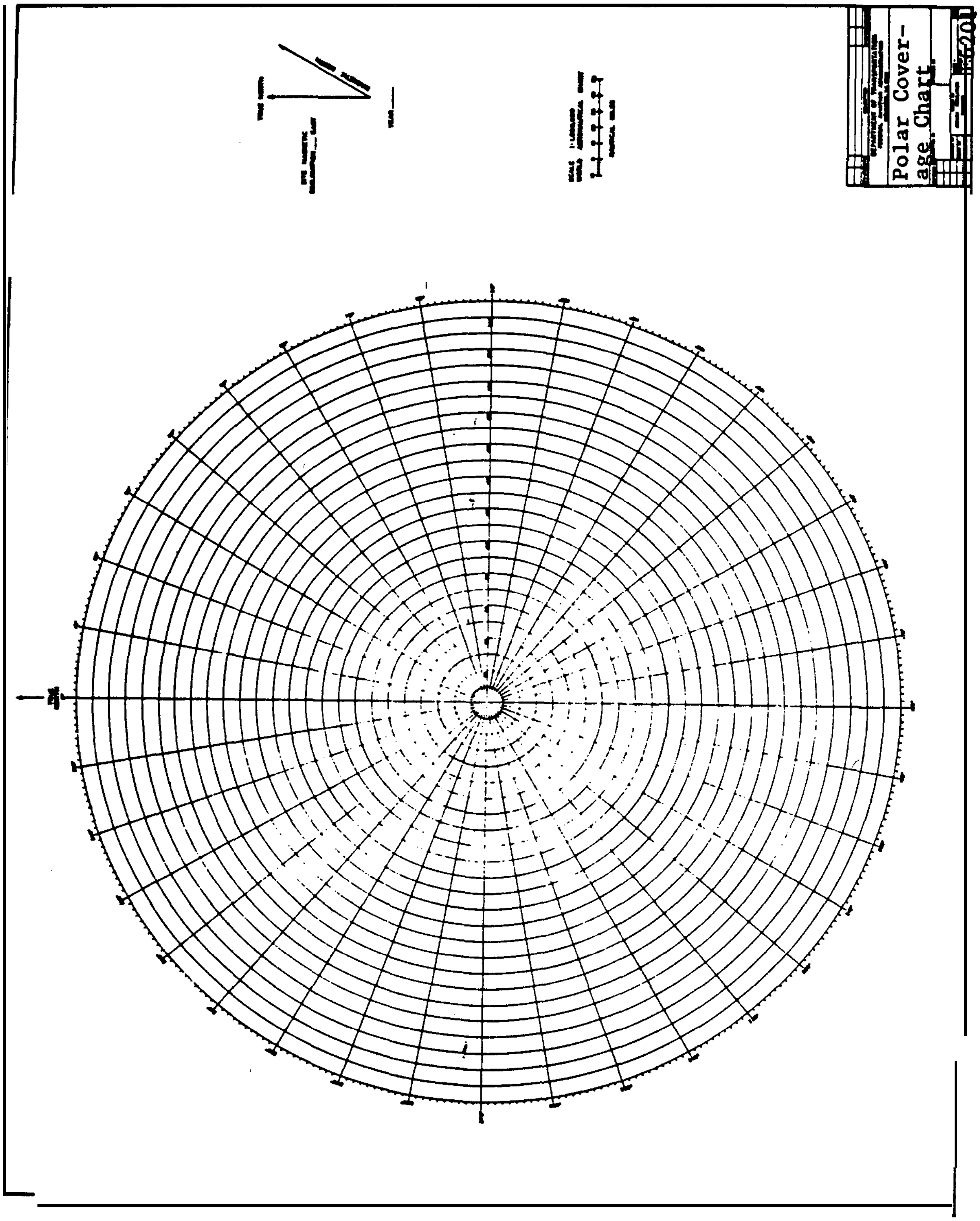


Figure 4-15. POLAR COVERAGE CHART

c. Procedures for Hand Calculation/Plotting.

(1) Data Quantizing. The necessary information to constructthelos boundary diagram is obtained from the transit data taken in the field. The Radar LOS Altitude/Range Cutoff Worksheet (figure 4-16),FAA Form 6310-2(11-73),is a convenient means of tabulating the information concerning screen angles, azimuth sectors and the resultant los cutoff range to the various altitude levels of interest. In transferring data from the screen angle survey data sheet, (figure 4-11) to the los altitude/range cutoff worksheet, it is recommended that, to avoid meaningless detail in the plot, suitable averaging or quantizing techniques be made to enlarge the azimuth sectors to be plotted, One such approach is to define azimuth sectors on the basis that the screening angle profile within the sector does not vary by more than 0.15 degrees (9 minutes). The screening angle over this azimuth sector is then tested as being constant. To eliminate any errors in subsequent analysis of the los boundary diagram, the maximum screen angle over this azimuth sector should be used for determining the corresponding range cutoff distances as a function of altitude.

(2) Worksheet Data Entry. For each azimuth sector quantized, the azimuth angles bounding those sectors should be entered in column 1 of the worksheet and the corresponding radar screen angle entered in column 2. The screen distance entries (column 3) should correspond to the rangeofthescreen object with the largest positive screen angle or largest angle in a positive direction if there are objects with a negative screen angle, The object defining this angle should then be identified by name in column 4. All other objects within this same azimuth sector are disregarded.

(3) Worksheet Completion and Plotting, Knowingthe altitude (relative to the elevation of the antenna) and the screen angle, the cutoff ranges for the various altitude levels of interest are determined from a 4/3 earth-radius screen angle chart given in appendix 2. After all entries are complete, the radar los coverage diagram is plotted as follows:

(a) With the proposed site located at the center, mark off the azimuth sectors defined for the screen angles in the worksheet.

(b) Using the cutoff range for the altitude of interest, as the radii, draw an arc enclosing the azimuth sector.

(c) Repeat step (b) for each azimuth sector listed on the worksheet.

(d) Connect the arc lengths by the radial line segmentsbetween successive azimuth sectors.

(e) Repeat steps (b) through (d) for each altitudeof interest. To facilitate ease in subsequent studies, different range scales may be required for plotting the various altitude contours. In such cases, it is recommended that more than one diagram be prepared.

Figure 4-16 RADAR LOS ALTITUDE RANGE CUTOFF WORKSHEET

SITE IDENTIFICATION : BEACH, ND "A"	SITE COORDINATES :	DATE :
ANTENNA HEIGHT 2575 FT MSL	LONG. 103° 46' 45" W LAT. 47° 40' 42" N	PREPARED BY.

1		2	3	4	5						
AZIMUTH (True North)		RADAR SCREEN ANGLE	SCREEN DISTANCE NM	SCREEN OBJECT	RADAR LOS CUTOFF RANGE IN N.M. ALTITUDE IN FEET						
From	To				3000	4000	6000	8000	10000	12000	15000
0	50	- 0.47	37	Dist. Horiz.	33	53	73	100	123	135	150
50	80	- 0.28	26	" "	30	50	70	98	120	135	150
80	90	- 0.37	30	" "	31	52	72	100	123	135	150
90	100	- 0.18	24	" "	29	50	70	98	120	135	150
100	108	- 0.27	30	" "	30	50	70	98	120	135	150
108	120	+ 0.03	24	" "	25	45	68	95	115	130	145
120	124	- 0.27	26	" "	30	50	70	98	120	135	150
124	140	+ 0.03	24	" "	25	45	68	95	115	130	145
140	150	- 0.08	27	" "	30	50	70	98	120	135	150
150	169	- 0.18	25	" "	28	48	68	98	120	135	150
169	176	+ 0.22	18	Plateau	32	60	70	93	118	133	150
176	180	- 0.2	28	Dist. Horiz.	34	52	75	95	110	130	145
180	186	+ 0.2	20	" "	35	48	75	95	110	130	145
186	191	- 0.3	31	" "	36	50	75	95	110	130	140
191	195	+ 0.3	18	" "	35	58	65	85	118	135	140
195	295	- 0.2	30	" "	36	65	90	110	125	138	150
295	320	- 0.3	33	" "	34	68	95	110	130	140	150
320	330	- 0.2	30	" "	35	68	98	118	130	145	160
330	360	- 0.3	36	" "	36	65	95	110	130	145	160

FAA Form 6310 -2 (11- 73)

(f) Complete the drawings by labeling to show altitudes, true north, map scale, site identification, etc. The radar los coverage diagram in figure 4-17 was machine plotted with the program provided in appendix 3, using the Beach North Dakota Data.

(4) Additional Plot Entries. After constructing the radar los coverage diagram(s), the navigational fixes in and near the controlled airspace should be located and marked directly on the diagram. The azimuthand distance of each fix relative to the site location can be obtained directly from the screen-angle graph and map study computations prepared earlier. All interconnecting air routes are then drawn in straight lines between the various fixes and labeled. The minimum msl altitude at which aircraft can operate (specified by AT, Flight Safety and charts) over the air routes shown, should be marked directly on the diagram alongside each air route line segment.

d. Analysis.

(1) General. Two general results can be obtained from an analysis of the combined radar los coverage and air route diagram. One is to establish the los visibility, or lack thereof, of aircraft operating at theirrespective minimum altitudes over each air route in the area. The second is to identify and locate all potential tangential course problems that can develop as aircraft travel over these air routes.

(2) Visibility. To establish visibility of the air routes, the minimum operating altitude of each air route segment is examined relative to the range/altitude contour plots. Visibility of any point along the air route is established when the range and azimuth of the point fall within a region bounded by a contour whose altitude is lower than that specified for the air route. The air route segments shown in figure 4-17 meet this criterion with the exception of the route segments within 20 nmi of the BIS VORTAC which are beyond the 12,000 foot contour. Lack of los visibility is shown by the cross hatched area indicated.

(3) Tangential course conditions where the mti capability of the ARSR may be seriously impaired can be identified by noting on the combined altitude contour/air route diagram where, if any, air routes are tangent or early tangent to any diameter circle about the site location. These potential problem zones should be marked and/or tabulated for further investigations as discussed in paragraph 82.

77. ARSR COVERAGE ANALYSIS.

a. General. For an ARSR site to provide adequate surveillance of the controlled airspace, two conditions must be met; namely, (1) all required navigational fixes must be visible on a direct line-of-sight from the radar, and (2) given los visibility, the radar must be capable of detecting all aircraft of interest at the range and altitude of each fix. Line-of-sight visibility for each fix (or its absence) has been determined through the previous analysis. In the procedure described here, plots or calculation of ARSR vertical detection capability are used to determine the adequacy of free space

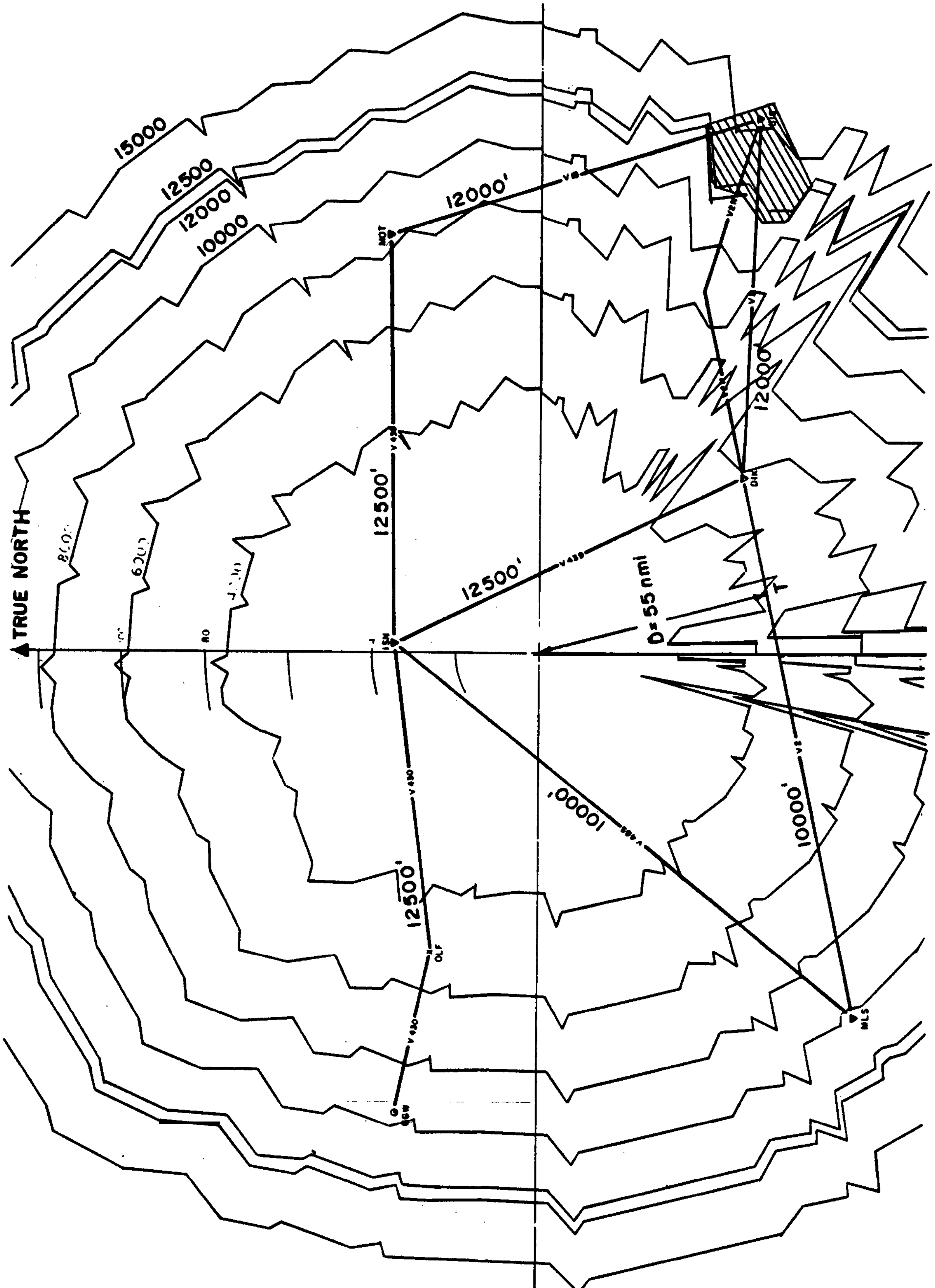


Figure 4-17. RADAR LOS COVERAGE DIAGRAM

radar coverage for the antenna height selected and a nominal antenna tilt. In addition, the analysis provides information on the maximum permissible tilt angle without loss of radar coverage. This represents a refinement of a similar analysis carried out during preliminary work (see paragraph 59c).

b. Radar Coverage Indicator (RCI) Charts. Theanalysis procedure given below makes use of the radar coverageindicator chart of figure 4-18, togetherwithan appropriate rcioverlaychart (figures 4-19 through 4-21). Thelatter give free spacecoverage of a T-33aircraft under several polarization/climatological conditions. The overlay charts shown givecoverage contours for the ARSR-3 under three conditions (i.e., LP-- fairweather, CP-- fairweather, CP--heavyrain). Two coveragecontours areplotted on each chart, one for ARSR-3 with the main (lower beam) antennaonly and one for ARSR-3 operationin thedualmode. The siting engineer shouldselect forusethatrcioverlaycontourwhichcorresponds totheworst-case radar use/climatological conditions expected at the site locale.

c. Procedure

(1) Coverage/Maximum Tilt. Using the coverage requirements entered in the los coverage worksheet (figure 4-14), locate the range and adjusted elevation angle of each fix on the radar coverage indicator chart of Figure 4-18. Also on this chart, mark the locations of such other critical points as may be judged important. When this is completed, apply the appropriate rci overlay contour (from figures 4-19, 20, or 21). The overlay should be adjusted initially for proper alignment and a nominal tilt angle of 0 degree for the lower 3 dB point of the antenna main beam. Using the main beam only contour from the selected chart, determine if coverage of the required fixes can be achieved. If the fix location is within the boundary of the contour, coverage is possible; otherwise, coverage is not achieved. Information is recorded in column L of the los coverage worksheet (figure 4-14) for the maximum tilt angle that will provide lower beam coverage for each of the fixes for the three conditions represented by the three overlays.

(2) Other Considerations. Other important sitingconsiderations deal withtheminimumacceptable tiltangle for radar coverage, and determinationof the appropriaterange forswitching fromdualbeamtomain-beam-onlyoperation. These factorsare determinedprimarily fromclutter considerations, as discussedin paragraph 71.

78. BEACON COVERAGE ANALYSIS. Achievement of adequate free space beacon coverage normally presents little problem in situations where line-of-sight visibility to all desired fixes exists. This good coverage is possible because only a one-way path is involved on interrogation and reply. Interference considerations dictate, however, that beacon interrogators be operated at the lowest possible output power capable of providing the required spatial coverage. This power level is estimated using the following procedure.

a. Procedure. Using the AT coverage requirements, which have already been located on the radar coverage indicator chart (figure 4-18), apply the beacon overlay# chart (figure 4-22) and adjust for a nominal tilt angle of 0 degree.

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Figure 4 -18. RADAR COVERAGE INDICATOR (RCI) CHART

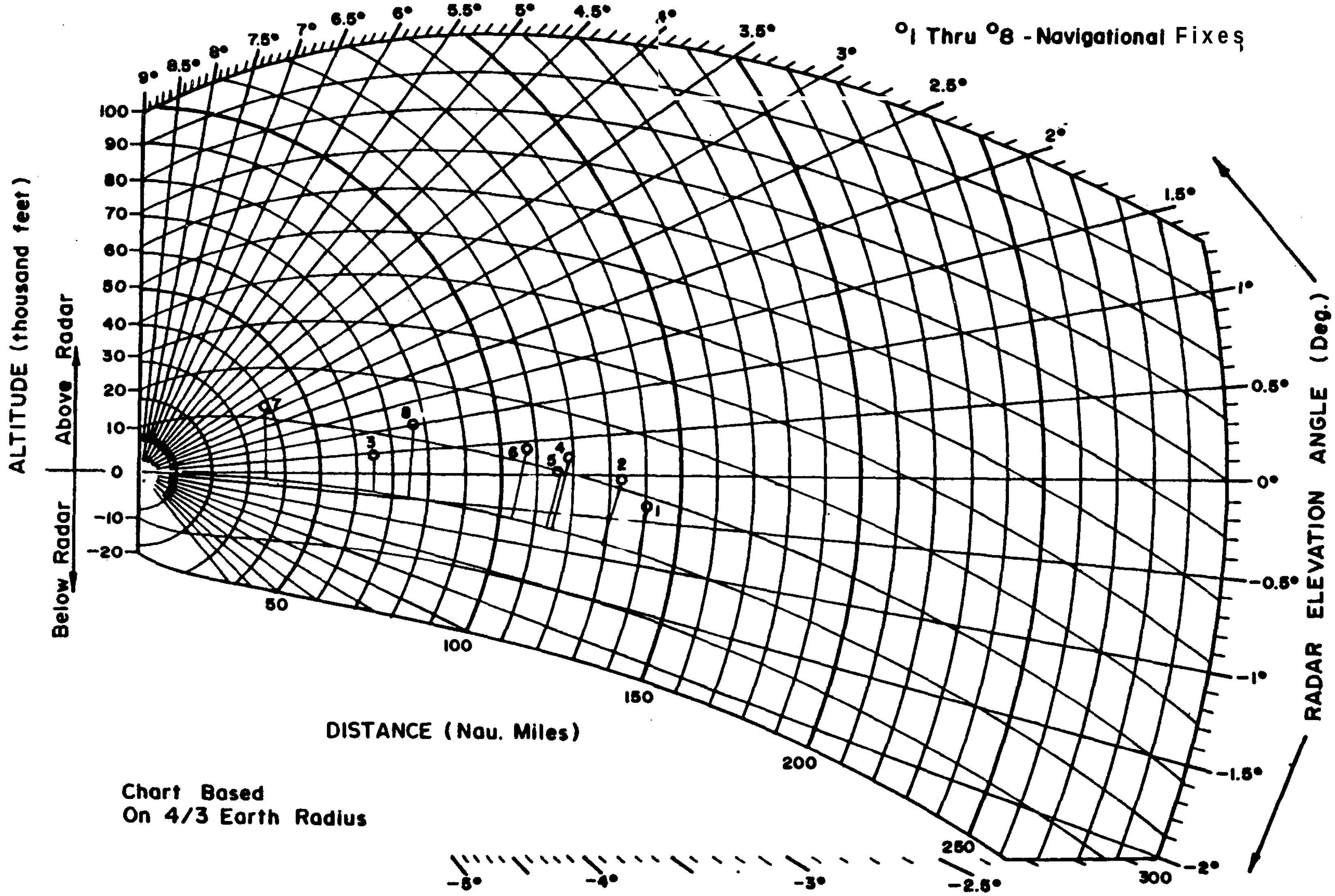


FIGURE 4-19. RCI OVERLAY CHART, ARSR-3, LP-CLEAR

Conditions:

$Pd = 0.8$

$Pfa = 10^{-6}$

$f = 1300$ MHz

$\sigma_t = 0.7\,m^2$

[T-33 Aircraft
Linear Polarization
Clear Weather]

Free Space Radiation

[No Atmospheric Attenuation]

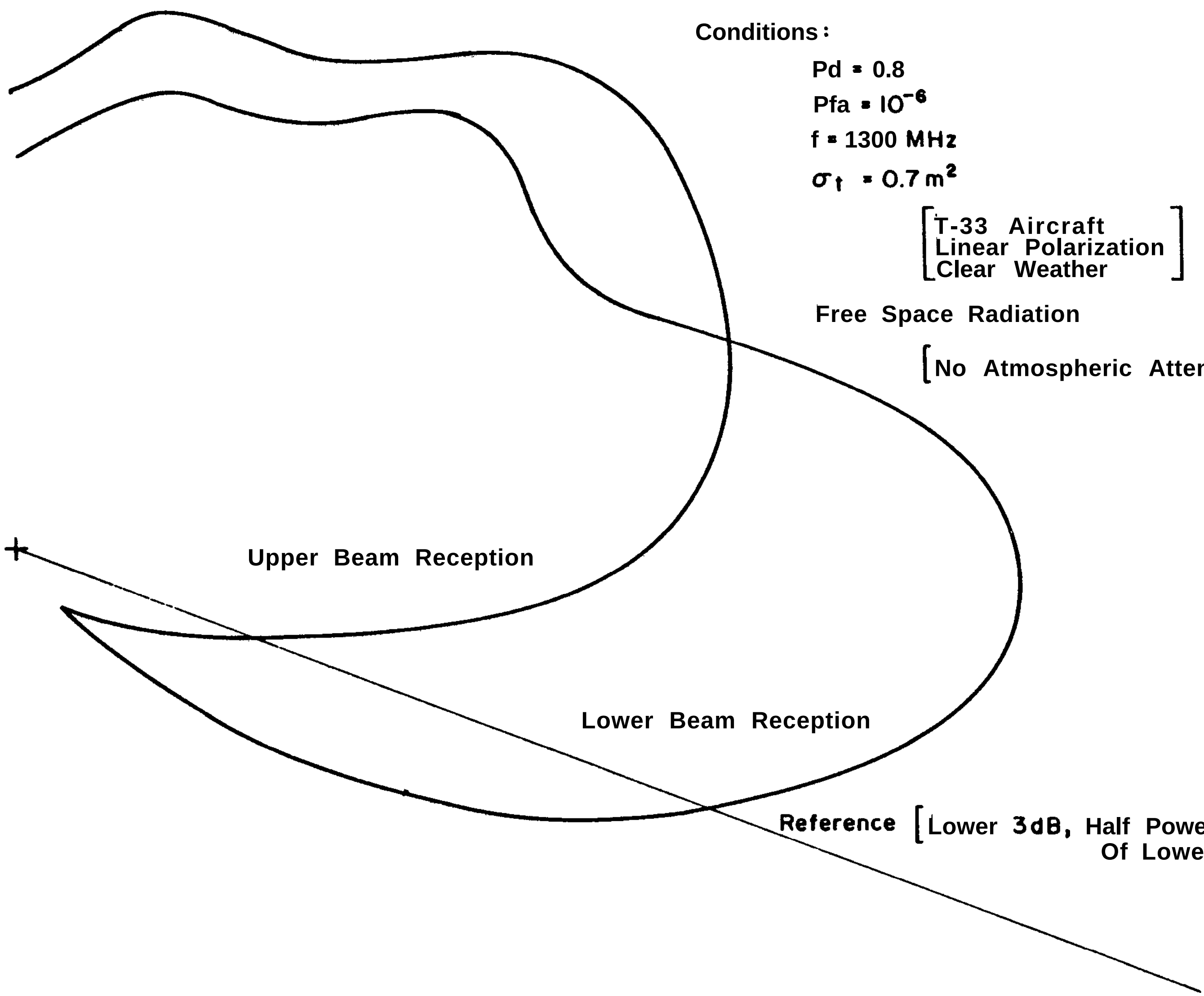


FIGURE 4-20 a CI OVERLAY CHART, ARSR-3, CP-CLEAR

Conditions:

Pd = 0.8

Pfa = 10^{-6}

f = 1300 MHz

σ_t = 0.7 m^2

[T-33 Aircraft
Circular Polarization
Clear Weather]

Free Space Radiation

[No Atmospheric Attenuation]

Reference [Lower 3 dB, Half Power Point Of Lower Beam]

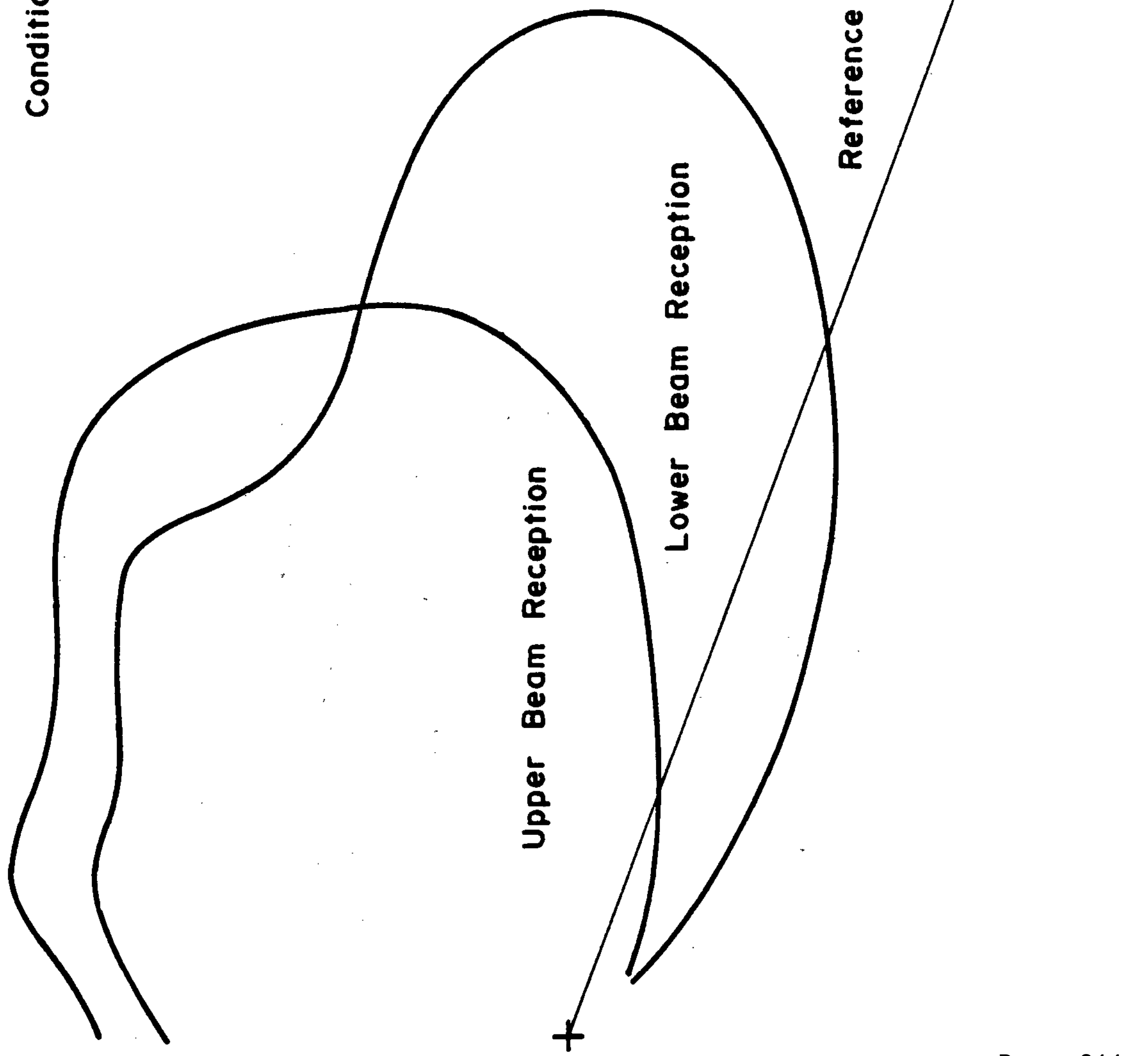
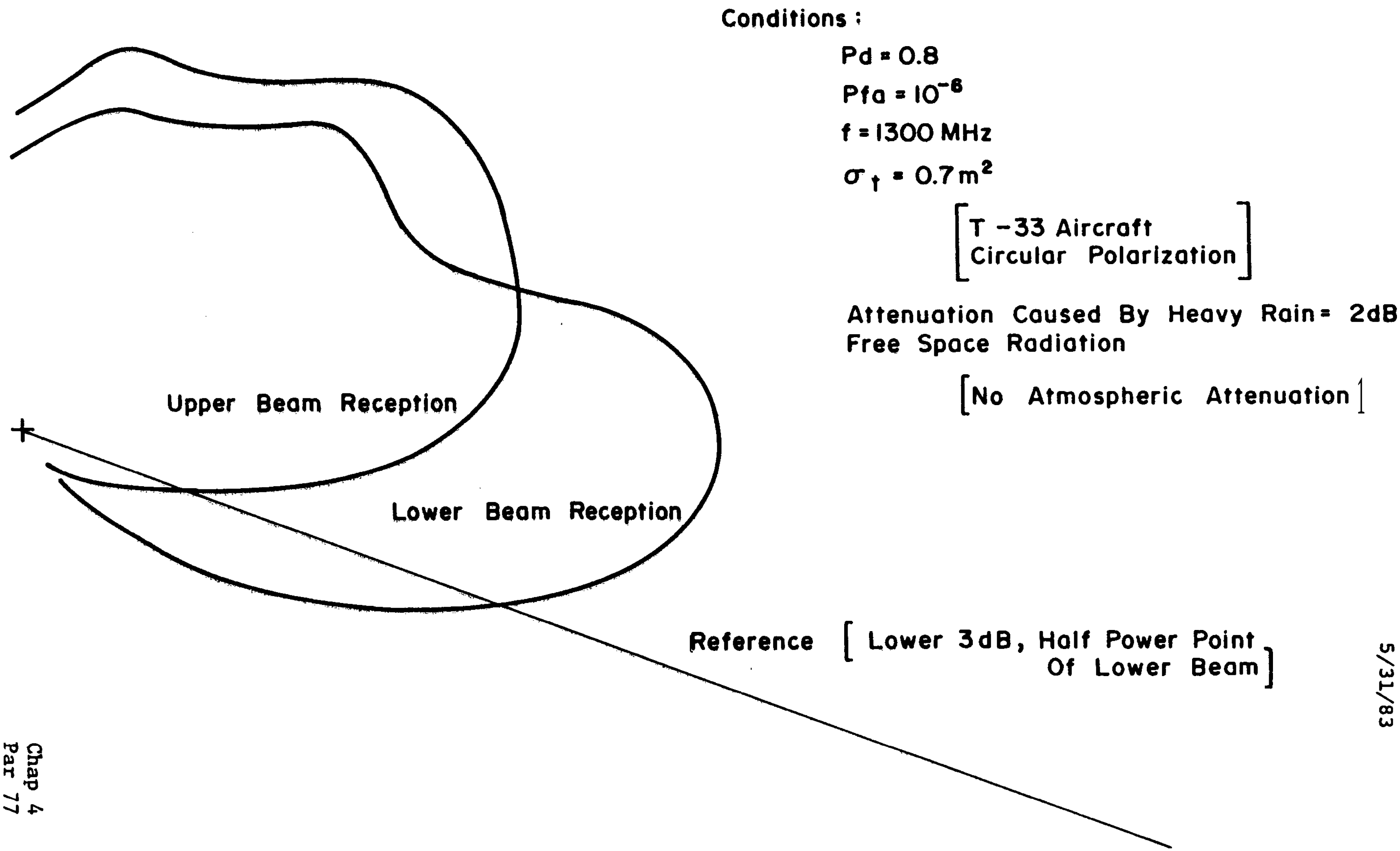


FIGURE 4-21 RCI OVERLAY CHART, ARSR-3, CP-HEAVY RAIN



From the chart parameters, the smallest beacon power required for coverage of all fixes is 50 dBm and the maximum required range is 140 nmi. Lowering the tilt angle to -0.8 degrees, the most negative tilt required in column L of figure 4-14, reduces the required beacon power to 47 dBm for the same maximum range.

b. Analysis. The beacon power determined by the above procedure is the lowest which will provide the requisite coverage, This power level is used in calculating the effects of beacon lobing from equations presented in chapter 3. To account for substandard propagation, an operational transmitter output 3 dB above this level should be specified. It should also be noted here that the Pd values plotted in figure 4-22 represent interrogator output measured at the antenna, To achieve this condition, the transmitter output must be increased by an additional amount equal to the transmission line and plumbing losses for the particular installation.

79. VERTICAL LOBING ANALYSIS. Previouscoverage analyses were based on free space antenna patterns; they are correct only for situations where the local terrain is rough and does not produce vertical lobing. The objectives of a vertical lobing analysis are to identify the azimuth sectors about a site in which lobing can be expected to occur, and to analyze the effect of such lobing upon the ability of ARSR/ATCBI equipment to meet the established coverage requirements. The accuracyof this analysis will depend upon the quality of site survey data covering surface roughness, surface reflectivity, and the size and location of land areas over which these conditions prevail. Since vertical lobing can have a severe detrimental effect on system performance, its consideration is very important to selection of an optimum radar site.

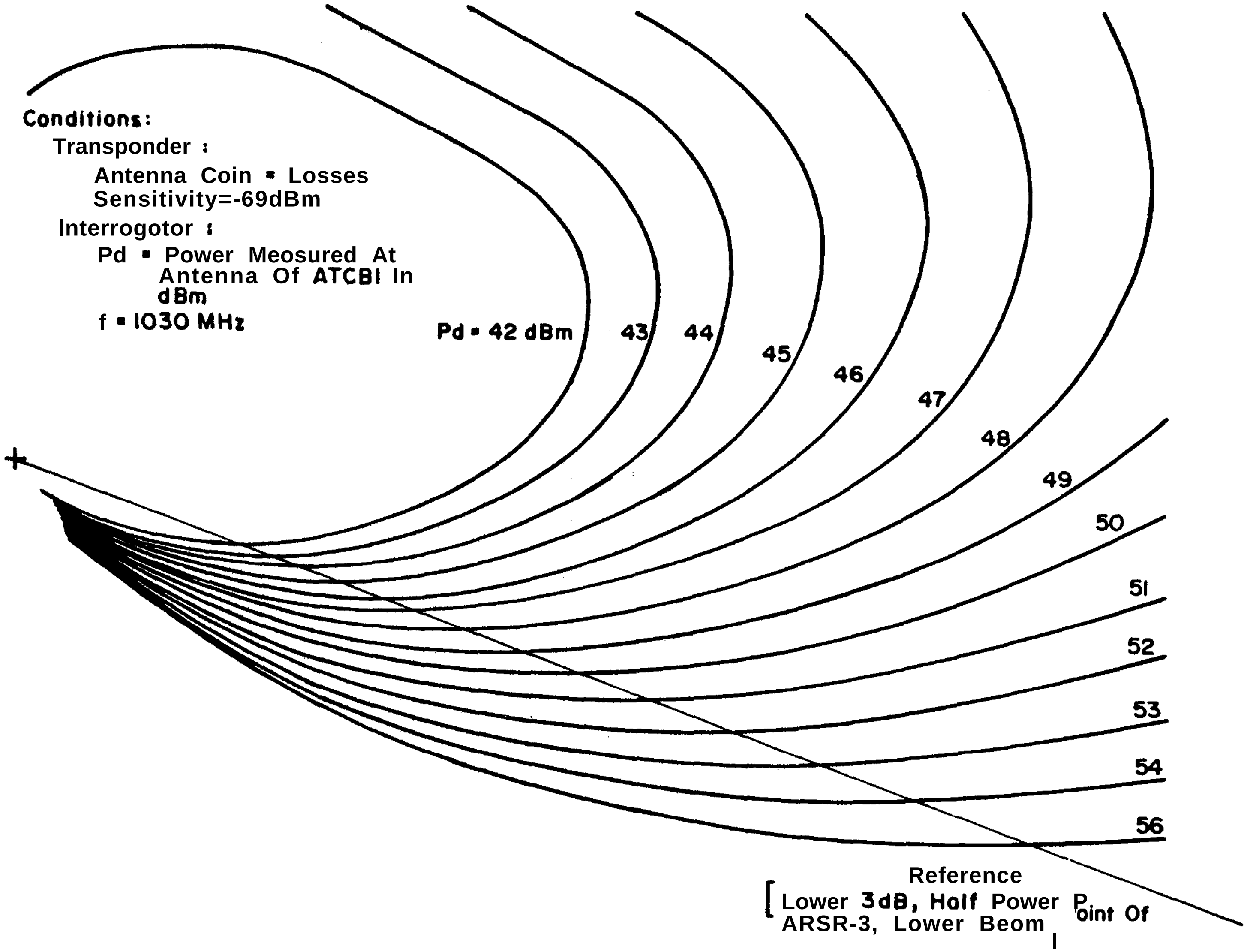
a. Existence of Lobing. The suggested procedure for determining if it is reasonable to expect the occurrence of vertical lobing at a given site is outlined below. The procedure is applicable to both radar and beacon lobing analysis.

(1) Potential Lobing Areas. From site survey observations and panoramic photographs, identify the azimuth sectors containing relatively flat terrain. Determine the msl elevation of each flat region and the range to its near- and far-points. The latter, of course, will not extend beyond the horizon.

(2) Fresnel Zone Location. Determine the effective height of the radar antenna above each flat terrain region by subtracting the terrain msl elevation from that of the antenna. Use this effective height to compute the location of the first Fresnel zone in each area for various null orders. Range to the near-point (d_{1n}), reflection point (d_1) and far-point (d_{1f}) of the Fresnel zones are given by equations 3-34 and 3-35, pages 103 and 105. The distances are plotted in figures 3-34 through 3-39 for lower order nulls. The equations are simplified as follows to yield distances in nautical miles.

$$d_{1n} = k_n h_a^2 f \qquad \text{(near point)} \qquad (4\text{-}7)$$

FIGURE 4-22. RCI OVERLAY CHART, ATCBI-5



$$d_1 = k_r h_a^2 f \qquad \text{(reflection point)} \qquad (4\text{-}8)$$

$$d_{1f} = k_f h_a^2 f \qquad \text{(far point)} \qquad (4\text{-}9)$$

where

h_a = effective antenna height above flat terrain region (ft)

f = operating frequency (MHz)

k_n, k_r, k_f = Fresnel zone parameters (table 4-l)

Representative Freznel zone reflection distances are shown in table 4-2 for the Beach North Dakota site for which data is shown in figure 4-11. In this case, the antenna is 75 feet above relatively smooth terrain with Fresnel reflection zones for the first three nulls estimated to be in the 0.25 to 8 nm range.

(3) Grazing Angle. Determine the grazing angle, ψ_n, to each null reflection point from the expression

$$\psi_n = \tan^{-1} \frac{h_a}{d_1} \qquad (4\text{-}10)$$

Grazing angles for the Beach North Dakota data are included in table 4-2.

(4) Surface Irregularity. Using the values of ψ_n, calculated above, determine the critical height of surface irregularity, Δh_c, from figure 3-33 or equation 3-32, page 103. The equation is rewritten below. Record and compare the calculated values of Ah, with the average measured or estimated surface irregularity for the terrains under study. The latter data may be taken during site survey operations, or derived from topographical maps.

$$\Delta h_c = \frac{61.519}{f \sin \psi_n} \qquad (4\text{-}11)$$

where

Δh_c = critical irregularity height (ft)

f = operating frequency (MHz).

Critical heights for Beach North Dakota grazing angles are **included on table 4-2.**

(5)' Continuation. Conduct the above radar lobing determination for each flat region and repeat for beacon **lobing,** using appropriate antenna height and frequency in step (2).

Table 4-l

FRESNEL ZONE PARAMETERS

Order of Null	k_n	k_r	k_f
1	8.9561×10^{-8}	3.3425×10^{-7}	1.2474×10^{-6}
2	6.3836×10^{-8}	1.6712×10^{-7}	4.3754×10^{-7}
3	5.0295×10^{-8}	1.1142×10^{-7}	2.4681×10^{-7}
4	4.1781×10^{-8}	8.3562×10^{-8}	1.6712×10^{-7}
5	3.5876×10^{-8}	6.6850×10^{-8}	1.2456×10^{-7}
10	2.1450×10^{-8}	3.3425×10^{-8}	5.2084×10^{-8}
15	1.5498×10^{-8}	2.2283×10^{-8}	3.2040×10^{-8}
20	1.2197×10^{-8}	1.6712×10^{-8}	2.2899×10^{-8}

Table 4-2

BEACH NORTH DAKOTA SITE NULL REFLECTION POINT, GRAZING ANGLE, AND CRITICAL HEIGHT

	Near Point	Reflection Point	Far Point	R.P.ψ	Ah,
1st Null	0.5 nmi	1.7 nmi	8.2 nmi	0.4°	6.7'
2nd Null	0.3	1.0	3.3	0.670	4.0'
3rd Null	0.25	0.5	1.6	1.350	2.0'

b. Interpretation of Results.

(1) Area Comparison. Compare the location and extent of potential lobing areas with the Fresnel zones determined through computation in conjunction with the following guidelines.

(a) No Overlap. If none of the flat surveyed areas lie within the first Fresnel zone, no lobing should be expected as long as the heights of the ARSR and ATCBI antennas do not exceed the values used in computations.

(b) Complete Overlap. If the flat area identified covers the first Fresnel zone completely, lobing can be expected to occur if the average irregularity of the surface does not exceed Ah,. Iftheirregularity is greater than Ah,, the surface is too rough to support lobing reflections.

(c) Partial Overlap. If the surveyed area extends only partially over the first Fresnel zone the occurrence of lobing is uncertain. This uncertainty can be resolved somewhat by considering surface smoothness and by comparing the position of the surveyed area relative to the position of the reflection point within the first Fresnel zone. No lobing will be produced by a surface whose average irregularity is greater than Ah,. For smooth surfaces, areas nearest the reflection point contribute most heavily to the total reflection, the contribution decreasing in importance the further the area is from this point.

(2) Mitigating Factors. It should be noted, when conducting this analysis, that, the presence of vertical reflecting surfaces (e.g., buildings or fences) near the Fresnel zone may screen or break up a lobing patternwhich may otherwise occur. This fact may be used to avoid lobing effects through careful selection of site location, or through installation of fences to eliminate lobing (see reference 8).

c. Effects of Lobing on Coverage. If vertical lobing is expected and cannot be prevented by screening or adjustment of antenna height, an analysis should be made to determine the impact such lobing will have on the coverage capabilities of the ARSR and Beacon, This assessment may be as follows:

(1) Requirements. Locate and identify those navigational fixes which lie in the azimuth sector(s) where vertical lobing is expected to occur.

(2) Elevation Angles. Using the antenna height specified by screening considerations (paragraph 75) determine the elevation angle of each of the above navigational fixes relative to the site location. If the elevation angle to a fix exceeds the critical grazing angle (specified above for the given terrain roughness) by more than one-fourth the angle of the first null, it can be ignored insofar as lobing effects are concerned. The effects of lobing on the coverage for the navigational fixes for the Beach North Dakota Site listed in figure 4-14 are summarized in table 4-3. The elevation angle to each of the fixes is shown in figure 4-18 and listed in table 4-3. Assuming that the grazing angles listed in table 4-2 are applicable to all coverage sectors, four of the eight fixes would have a potential lobing problem.

Table 4-3

POTENTIAL COVERAGE PROBLEMS
FOR BEACH NORTH DAKOTA NAVIGATIONAL FIXES DUE TO LOBING

Fix No.	Elevation Angle Degree	Lobing Coverage	
		Adequate	Problem
1	-0.3		X
2	0.0		X
3	0.5	X	
4	0.3		X
5	0.05		X
6	0.4	X	
7	2.9	X	
8	1.0	X	

(3) Earth Gain Factor. For those identified navigational fixes whose elevation angles are less than the critical grazing angle, compute the earth gain factor, η, at this elevation angle by letting θ in equation 3-22, page 80, equal the elevation angle to the fix (in radians). The equation is

$$\eta = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}} \cos\left(\frac{4\pi h_a \theta}{\lambda}\right)\right] \quad (4\text{-}12)$$

where G_1 = numerical antenna power gain in direction of target

G_2 = " " " " " reflection point

h_a = antenna height (ft)

λ = wavelength (ft)

(4) Coverage Determination. Determine if coverage is obtained at each fix using the relationships derived in paragraph 39 of chapter 3 (see equation 3-30, page 88. If the actual range, R, to a fix is less than the value R_r, then coverage is obtained. If not, no coverage is obtained. Similar considerations may be given to lobing effects or coverage of traffic at other points in the air-controlled space.

$$R_r = \eta R_f$$ (for ATCBI @ 1030 MHz) (4-13)
(for ARSR-3 main antenna only @ 1250-1350 MHz)

or

$$R_r = \sqrt{\eta_e \eta_t R_f}$$ (for ARSR-3 dual beam antenna @ 1250-1350 MHz) (4-14)

where

η_e = value of η for echo path

η_t = value of η for transmit path.

(5) Tilt Angle and Height Effects. When severe lobing effects are predicted, attempts should be made to specify a new tilt angle which will enable satisfactory coverage to be achieved. Changing the antenna tilt will change the antenna gain factor in the direction of the target and reflection point. Tilt will not affect the reflection point or null angle and will not change the basic lobing pattern. If no acceptable tilt angle will remove the coverage deficiency, a new antenna height may be selected and the analysis repeated. Screening considerations should not be ignored in selecting new antenna heights.

d. Alternatives for Severe Lobing. If serious lobing difficulties are present for all usable height/tilt angle combinations, consideration must then be given to (1) alternate site locations, (2) mitigation of the effect by installation of fences as described in reference 8, or (3) altering air route structure or control procedures to minimize operational problems caused by lobing. The latter action would require consultation and concurrence by Air Traffic Division personnel.

80. FALSE TARGET ANALYSIS. Evaluation of potential ATCBI sites must include an analysis of the expected severity of beacon false target effects associated with each particular site location. This is very important since false targets represent one of the most severe (and persistent) problems with beacon system operation.. The analysis described below is largely graphical and follows techniques described in paragraph 39e of chapter 3.

a. Procedure. On a horizontal coverage chart centered about the radar site, locate all significant air routes and plot the location of all potentially harmful reflectors identified at the site survey. Then, for each reflector:

(1) Plot azimuth radials one degree beyond the extremities of the reflecting surface. This defines the angular region where beacon false targets may appear due to this reflector.

(2) Plot the path of signals reflected from the extended reflector surface due to the above radials, Reflector orientation, required for these plots, may be determined from site survey data or maps.

(3) Compute maximum range, Rl, between target and reflector for false targets, using the reflector dimensions and ATCBI powerdetermined above. This is done with the nomographs of figures 3-43aand 3-43b. Note the range on the diagram.

(4) Note airways crossing the reflected signal sector at ranges less than R_1 from the surface. Translate the affected range segment to the false target radial sector, taking into account the radar to reflector range, R_2.

b. Analysis. Once the regions of appearance and of origin of false targets are identified, the severity of the problem is readily determined. Situations where traffic in one active airway can create false targets in another airway are clearly unacceptable. An example case is presented in figure 4-23. In the example, a hazardous condition could develop whenregular commercial traffic on airplane A is falsely interrogated by a reflected path, producing apparent targets in the region X which itself contains regular commercial traffic. In such a situation consideration should be given to (1) removal or masking of the reflecting structure (see reference 9 for masking details), (2) selection of a different ARSR/ATCBI site, or (3) revision of the air route. The latter possibility should only be considered as a last resort and would, of course, require coordination and approval'from Air Traffic and Flight Standards divisions;

81. CLUTTER ANALYSIS.

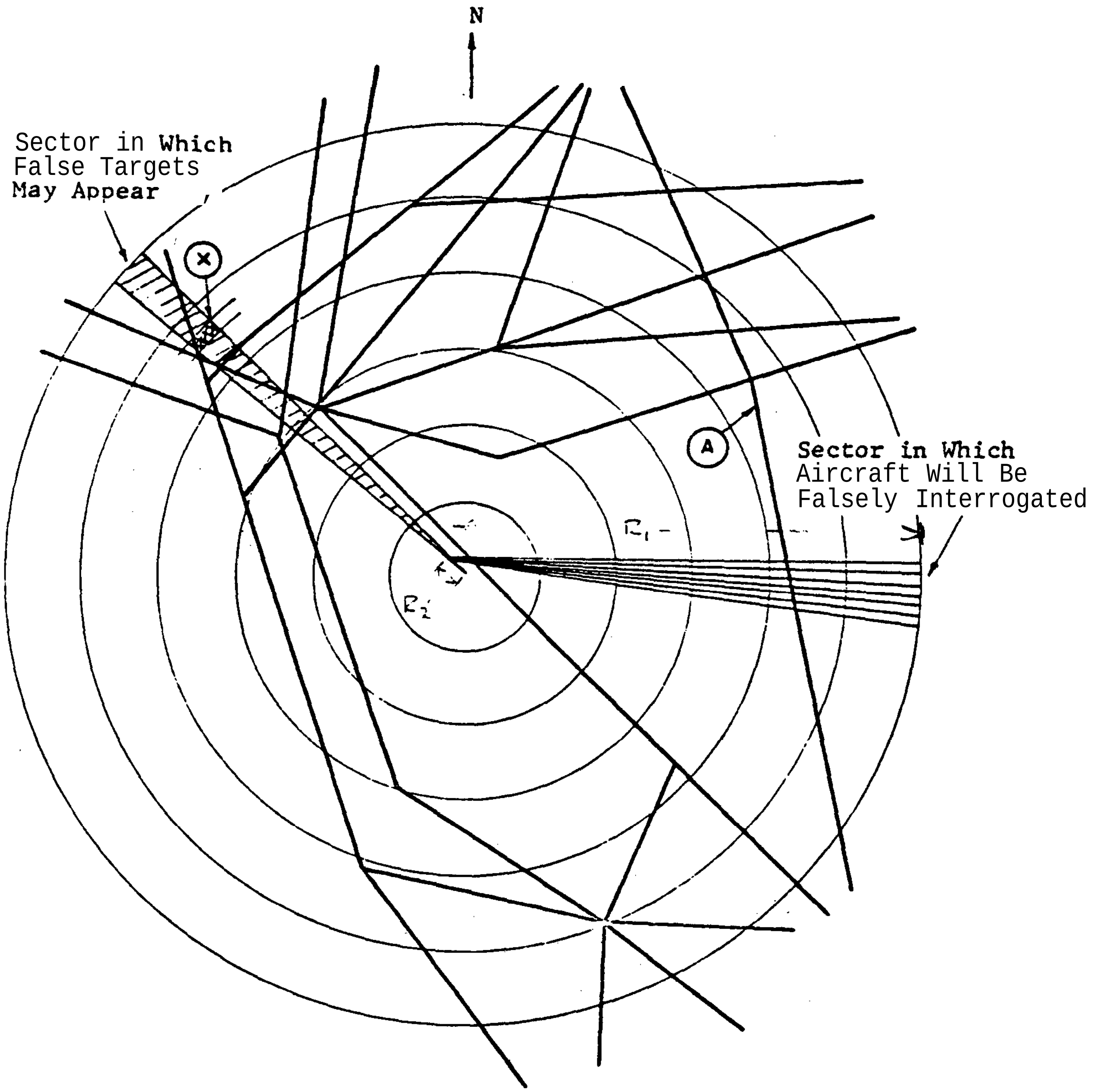
a. General. Despite improvements in the surveillance radar equipment, ARSR coverage of targets can still be severely degraded by the effects of ground clutter. Therefore, until such time as new radar detection and processing techniques (such as the Moving Target Detector) eliminate this problem, it is necessary that a worst-case clutter analysis be carried out as part of the site selection process. The analysis, using principles outlined in paragraph 39 of chapter 3, provides estimates of:

(1) Range/azimuth parameters for mtiand antenna beam switching of the ARSR-3 radar.

(2) System clutter coverage capability and tilt angle dependence.

b. Clutter Boundaries. From map studies and site survey operations, determine the boundaries of the region of clutter visibility, from the radar site. The maximum range of the clutter zone along a given azimuth radial is simply the range to the radar horizon, or to a screening object, whichever is smaller. In rugged terrain the clutter visibility region may be discontinuous due to the presence of multiple screening objects. In general, the maximum range of clutter will vary for different azimuth angles in accordance with the terrain and screening features. The overall clutter visibility boundary may be plotted on a polar diagram similar to thosealready drawnforlosvisibility.

FIGURE 4-23 EXAMPLE OF FALSE TARGET ANALYSIS



c. Antenna Switching Range.

(1) General. As mentioned in chapter 2, the selection of a single or dual beam antenna configuration for the ARSR-3 radar is largely dictated by clutter considerations. The high beam antenna is used in the clutter region to the extent of its coverage capability, For target ranges beyond the coverage capability of the radar in its dual beam mode, however, the single (main) beam mode must be employed even if clutter is present. The singlebeam mode is also used for all ranges where no clutter is visible.

(2) Maximum Switching Range, The maximum allowable range for switching from dual to single beam operation in each of eight azimuth sectors, depends on the antenna tilt angle and target/polarization/climatological conditions as indicated in table 4-4. The range information in this table was derived by application of the ARSR-3 RCI overlay charts. For various assumed tilt angles, the maximum switching range is defined by the intersection of the coverage overlay for dual beam operation with the earth's surface.

(3) Switching Range Adjustment. For the maximum acceptable tilt angle, as defined in the previous analysis (and indicated on the worksheet of figure 4-13), the maximum ARSR-3 antenna switching range will usually be set as indicated in table 4-4 for the condition being examined. Exceptions would occur in those azimuth sectors where the clutter boundary diagram indicated clutter visibility to be limited to a shorter range. In such cases, antenna beam switching would be adjusted for the shorter ranges indicated in the diagram.

d. Clutter Coverage Analysis.

(1) General. Clutter computations basically involve determination of the signal-to-clutter ratio (s/c) at various range points withinthe clutter zone, for different values of antenna tilt angle. This ratio can then be used to determine if target detection is possible.

(2) Radar Clutter Data. If mobile radar equipment is available for collection of clutter data, this should be used since it will provide an accurate measurement of the particular clutter background associated with the site. As an alternative, ARSR equipment already installed in a nearby location may be used to collect clutter data. Data gathered by this means, though not as accurate as mobile radar data, is probably preferable to purely theoretical clutter predictions.

(3) Analysis Procedure. From the measured data, site survey operations, or map studies, identify the ground areas of maximum clutter within view of the radar. Consideration should be concentrated on those areas azimuthally within 1.5 degrees of overhead airways or fixes.

(a) Using Estimated Clutter Information. When no measured data is available, estimate clutter effects as follows:

Table 4-4

MAXIMUM ANTENNA SWITCHING RANGE FOR ARSR-3

Antenna Tilt Angle 1/	Maximum Allowable Range for Dual Beam Operation (nautical miles)		
	Fair Weather LP Operation	Fair Weather CP Operation	Heavy Rain CP Operation
0°	64	43	38
0.5°	45	35	30
1.00	36	30	25
1.5°	32	22	21
2.0°	26	20	17
2.5°	24	17	15
3.0°	20	14	11
3.5°	19	10	9
4.0°	16	8	8

1/ Lower 3 dB half power point of lower beam.

1 Calculate clutter grazing angle, ψ, for several range points within the clutter zone from

$$\psi = \tan\left(\frac{h_a - h_r}{6080R}\right) \qquad (4\text{-}15)$$

where

h_a = msl antenna height at site (ft)

h_r = msl elevation of terrain at range R (ft)

R = range to detection point (nmi).

2 Determine clutter area, A_c, from equation 3-40, page 118, which reduces to the form

$$A_c = 10667 \text{ R} \sec \psi \qquad (4\text{-}16)$$

3 Determine normalized clutter cross section, σ_o, from table 3-3or 3-4, and compute the actual clutter cross section, σ_c, from equation 3-41, page 118.

$$\sigma = A_c \sigma_o \qquad (4\text{-}17)$$

4 Antenna Gains. Determine the transmit and receive antenna gains G_t and G_r in the direction of a target at this range and at the maximum elevation of concern. Also determine the corresponding gains G_{te} and G_{rc} in the direction of the clutter patch. Antenna tilt angle, α, must be accounted for in these gain determinations. Initial calculations should use the lowest value of α as determined from los studies (figure 4-13).

5 Compute s/c from equation 3-39, page 117 using smallest value of target cross section, σ_t, expected. For a T-33 aircraft, $\sigma_t = 0.7$ sq. meter (cp). Remember that $G_t \neq G_r$ and $G_{tc} \neq G_{rc}$ for the ARSR-3 in its dual beam mode

$$s/c = \frac{\sigma_t G_t G_r}{\sigma_c G_{tc} G_{rc}} \qquad (4\text{-}18)$$

6 **Discretes.** In areas containing discrete clutter sources (buildings, water towers, mountains, etc.), estimate the clutter crosssection, σ_c, in much the same manner as for a target of similar dimensions. Use this value to determine s/c as above.

(b) Using Measured Data. When actual clutter power data is available from field measurement it should be used directlyin clutteranalysis. To be useful, clutter power measurements must be made using the same frequency, pulse width, polarization, antenna beamwidth and height as the ARSR. In this case:

1 Signal Power - Normal. For each range point considered within the clutter zone, compute received signal power S, from equation 4-19, using the smallest σ_t expected.

$$S = \frac{P_t G_t G_r \lambda^2 \sigma_t}{(4\pi)^3 R^4} \tag{4-19}$$

2 Signal Power - Lobing Situation. If lobing is expected above the clutter area, the appropriate expression for signal power, S, becomes

$$S = \frac{P_t G_t G_r \lambda^2 \sigma_t}{(4\pi)^3 R^4} \eta_c^2 \quad \eta_t^2 \quad . \tag{4-20}$$

e. Interpretation of Results.

(1) Basic Steps, Clutter boundaries, antenna switching range, and mti switching range(s) are determined directly in the respective analyses above. Clutter coverage may be determined from the computed values of s/c. It can be assumed that target detection at the range being examined will occur satisfactorily in the mti mode if the following condition is met; otherwise, no detection may be assumed.

$$s/c > -23 \text{ dB} \tag{4-21}$$

(2) Continuation. Clutter analysis is repeated for all clutter areas considered potentially troublesome and a general judgement formed as to the severity of the overall clutter problem. If clutter obscures a significant portion of the controlled airspace, consideration should be given to (a) altering antenna height to reduce the visible clutter area, (b) modifying the return from large scatterers by removal or masking, (c) selection of another radar site affording better natural screening, or (d) modification of the coverage requirements (requires coordination with Air Traffic division). If clutter is not seen to present a serious operational problem, consideration may also be given to lowering the antenna tilt angle below its maximum value, thereby achieving better long range coverage of low altitude targets. This action, of course, will increase ground illumination and worsen any existing clutter problems.

82. TANGENTIAL COURSE ANALYSIS. Each siting analysis should include examination of potential tangential course problems which may be associated with the particular site. Such an analysis will indicate the presence or absence of tangential courses which for the radar's mti receiver, can cause loss of targets in the controlled airspace. Techniques to be followed are described in detail in paragraph 39f of chapter 3. Basic procedures are outlined below.

a. Procedure. On a coverage chart (FAA Drawing E-6201), figure 4-24, centered about the radar site, locate all significant air routes and note target ground speeds for each as determined during preliminary siting data acquisition. The los boundary diagram already contains this data and may be used for tangential course analysis. For each target path within the boundaries of mti usage which approach tangency with a circle about the radar:

(1) Construct a perpendicular from the radar site to the extension of the airway path.

(2) Determine the maximum dropout region length, L_{dm}, from figure 3-46, using the previously determined target ground speed for the airway in question, and assuming the minimum detectable radial velocity, v_{rm}, is 15 kt.

(3) Determine the actual dropout distance, L_d, by noting the length of overlap (if any) of the airway with the region L_{dm}. This is illustrated in figure 4-24.

(4) Evaluate the duration, T_d, of coverage loss for any L_d determined above from figure 3-48. Compare this with the maximum tolerable dropout time, TD, as determined from equation 4-22.

$$T_D = \frac{120}{W_r} \tag{4-22}$$

where

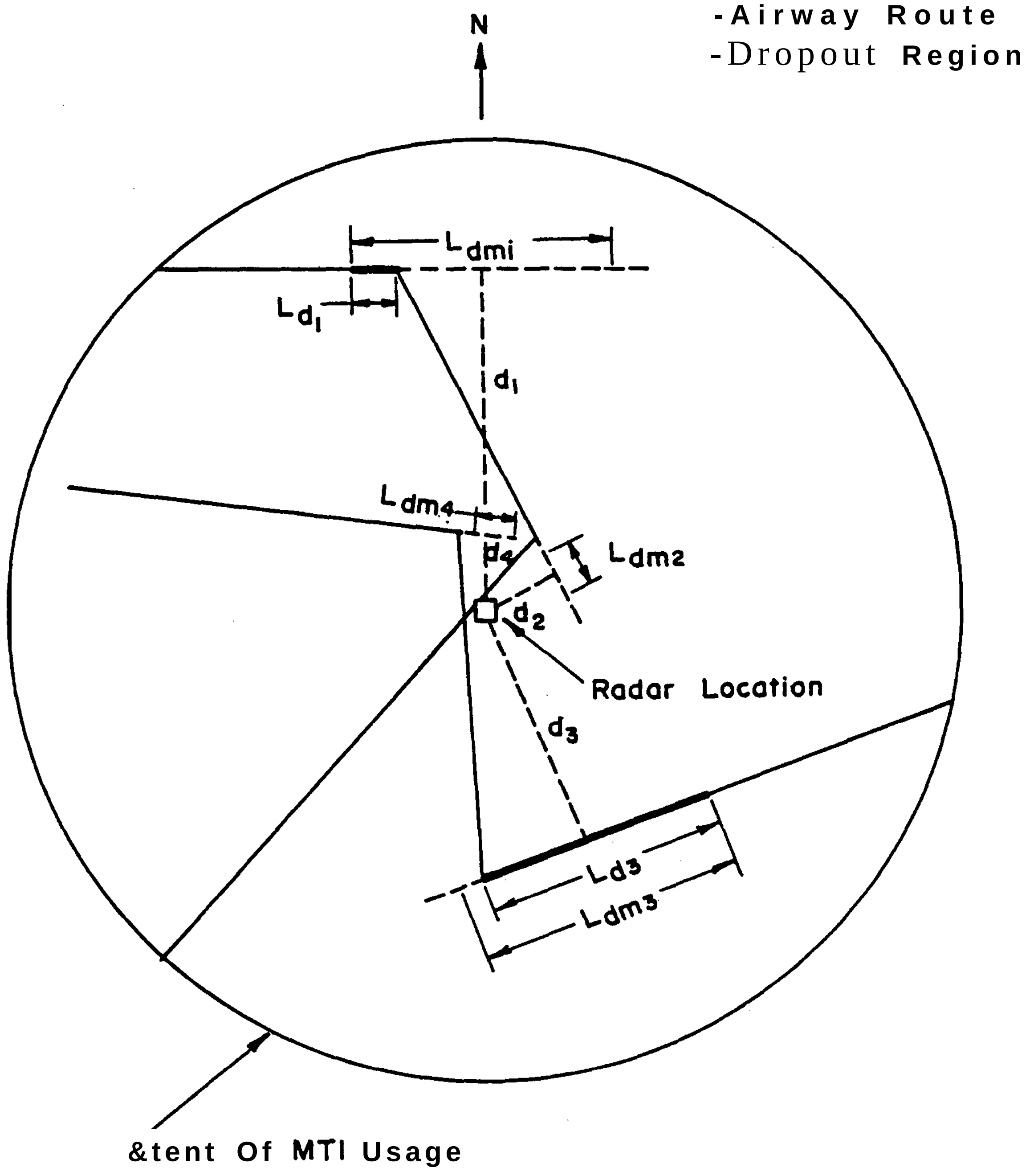
W_r = radar scan rate (rpm)

$$T_D = 24 \text{ sec (ARSR-3).} \tag{4-23}$$

Referring to the polar coverage plot of figure 4-17, it can be seen that the V-2 airway is tangent to a radial from the radar site at point 'T', at a distance D = 55 nmi from the site. Referring to figure 3-46 and assuming a 400-knot aircraft ground speed, an L_{dm} = 4.5 nmi with a dropout time of 40 seconds would be expected. This exceeds the 24-second maximum tolerable dropout time and, therefore, could cause tangential course problems.

b. Analysis. In cases where for each tangential course $T_d < T_D$, there are no intolerable signal losses and the site can be considered free of significant tangential course problems. Where one or more courses existinwhich $T_d \geq$ TD, however, coveragelosses willoccur. Theseproblems should be resolved by either (1) selecting another site, (2) modification of air route patterns, or (3) acceptance of the situation. The latter approach will require coordination and agreement by both Air Traffic and Flight Standards division representatives.

FIGURE 4-24 ILLUSTRATION OF TANGENTIAL COURSE ANALYSIS



83. SECOND-TIME-AROUND ANALYSIS. Second-time-around (sta) echoes are produced by targets or clutter at distances greaterthanthefirst rangeambiguity. If of sufficient amplitude, target returns from the sta. region are detected and displayed at an apparent range equal to their distance beyond the point of ambiguity. Sufficiently strong clutter from this region will also be displayed; it is not cancelled in the mti receiver when the radarprf is jittered. In order to cancel the second-time-around clutter, the variable interpulse transmission must be changed to a fixed interpulse period. RAG (Range and Azimuth Gate Generator) gates are used to provide a fixed interpulse period in selected azimuth sectors for this purpose. A brief investigation of potential sta problems should be carried out as part of radar site selection. This may be done as indicated below.

a. Procedure. From maps and aeronautical charts, locate air routes and large clutter sources (primarily mountains) at ranges from 200 to 600 nmi. Determine their height and their los visibility from the radar site. This may be done with the aid of screen angle calculation techniques developed for previous analyses. The visibility determination should also consider the effects of local atmospheric conditions which may cause the effective earth radius factor, k, to take on values higher than the normal value of $k=4/3$. Once visibility is established, the following procedure is followed for eacn visible airway or clutter echo source.

(1) Determine Detectability. Estimate radar cross section for the distant target/clutter object, and determine detectability, This may be done using radar coverage diagrams plotted in figures 3-1 and 3-2. Where necessary, these curves may be extrapolated for larger targets by noting that range coverage increases as σ^4, other parameters remaining fixed. If the estimated target/clutter is detectable at the true range, sta echo can be expected.

(2) Apparent Echo Range. In cases where distant targets/clutter are detectable, determine the apparent echo range, R_a, and azimuth. The apparent azimuth corresponds to the true azimuth of the echo source; apparent range is found from the relationship given below and figure 2-7 which gives values for the ambiguous range.

$$R_a = R - R_A$$

where

R = true range of echo source

R_A = nearest ambiguous range less than R.

b. -Analysis. Once all second-time-around echoes are determined, their apparent ppi position should be compared with the location of normal returns from traffic in the controlled airspace. If confusion of echoes represents a threat to safe operations, consideration should be given to (1) altering the radar prf to a value which places sta echoes at lesstroublesome ppi positions (this would require coordination with Frequency Management personnel), (2) using the rag to provide a fixed interpulse period in the azimuth sector affected to permit mti reduction of the eta, (3) changing antenna height/tilt to reduce sta visibility or detectability, or (4) selecting an alternate radar site.

SECTION 6. SITE ENVIRONMENTAL ANALYSIS

84. GENERAL. An environmental assessment must be conducted as part of the site selection process to assure that the new ARSR/ATCBI site will not produce an unacceptable environmental effect, and further to assure that all activities related to site development are performed in compliance with both the NEPA laws and FAA environmental protection policies.

85. RESPONSIBILITY. The environmental assessment should be carried out by the duly designated Airway Facilities division staff member using data collected by the site survey team. Collection of any additional data required for the environmental assessment is the responsibility of the personnel preparing the assessment.

86. PROCEDURES.

a. General. Environmental assessment documentation should be prepared in accordance with the policies and procedures set forth in the latest edition of Order 1050.1. Upon completion of the assessment a determination is made whether establishment of the planned ARSR/ATCBI site is or is not a major Federal action significantly affecting the quality of the human environment. This determination will be followed by preparation of an Environmental Impact Statement (EIS) or Finding Of No Significant Impact (FONSI), as appropriate.

b. Considerations. In preparing the environmental assessment, a number of environmental factors must be considered, as indicated in Order 1050.1. They include:

(1) Noise Impacts.

(2) Air Quality Impacts.

(3) Water Quality Impacts.

(4) Social Impacts.

(5) Land Use Impacts.

(a) Special Use Areas.

(b) Historical and Archaelogical Sites.

(c) Flood Hazards.

(d) Wetlands.

(e) Coastal Zone Management.

(f) Energy Supply and Natural Resources Development.

(g) Wildlife and Waterfowl.

(h) Endangered Species.

(i) Solid Waste Disposal.

(6) Electromagnetic and Light Emissions.

(7) Visual Impacts.

c. Analysis of the environmental effect of establishing an ARSR/ATCBI site at the candidate location(s) should consider the probable impacts, both beneficial and adverse, of such an action ofr each of the factors indicated above. Emphasis should be given to:

(1) Actions which will be taken to enhance beneficial impacts.

(2) Identification of those adverse effects which are unavoidable.

(3) Actions which will be taken to minimize unavoidable adverse effects.

(4) Alternatives to the planned action.

SECTION 7. COST ANALYSIS

87. GENERAL. A complete cost estimate shall be prepared for each site surveyed. This will include all pertinent cost factors necessary to insure that the completed site, buildings, associated structures and site access will be adequate for the purpose intended. Unusual cost factors due to unique local conditions should be accurately defined and justified. Additional supplementary analyses may be required to establish realistic cost estimates.

88. COST ITEMS. The cost items which must be considered for an ARSR/ATCBI site are indicated below. This may be done with the aid of FAA Form 2500-40, Cost Estimate Form, as illustrated in figure 4-25.

a. Engineering.

(1) Civil.

(2) Electrical.

(3) Drafting.

b. Construction.

(1) Supervision.

FIGURE 4-25 COST ESTIMATE FORM FOR ARSR / ATCBI SITE ANALYSIS

COST ESTIMATE – FY 19 | DATE PREPARED

		ITEM EXPLANATION	DETAIL AMOUNT A	SUMMARY AMOUNT B	TOTALS C
SECTION A – REGIONAL COST					
1		ENGINEERING			
	A	CIVIL (man days @ $)	$		
	B	ELECTRONIC (man days @ $)			
	C	DRAFTING (man days @ $)			
	D	TOTAL ENGINEERING		$	
2		CONSTRUCTION			
	A	SUPERVISION (man days @ $)			
	B	SITE PREPARATION			
	C	ACCESS ROADS AND PARKING AREAS			
	D	BUILDING/TRAILERS			
	E	ENGINE GENERATOR			
	F	UTILITIES			
	G	CABLE INSTALLATION/ANTENNA STRUCTURES			
	H	INITIAL SUPPLIES AND WORKING EQUIPMENT *(Schedule B items)*			
	I	OFFICE FURNITURE			
	J	REGIONAL PURCHASES			
	K	REGIONAL FREIGHT			
	L				
	M				
	N	TOTAL CONSTRUCTION – ☐ NONE REQUIRED			
3		ELECTRONIC INSTALLATION			
	A	INITIAL SUPPLIES AND WORKING EQUIPMENT *(Schedule B items)*			
	B	REGIONAL PURCHASES			
	C	REGIONAL FREIGHT			
	D	INSTALLATION			
	E				
	F				
	G				
	H	TOTAL ELECTRONIC INSTALLATION – ☐ NONE REQUIRED			
4		FLIGHT INSPECTION *(Hours @ $ per hour)*			
5		*(Sum of Lines 1D + 2N + 3H + 4)* SUBTOTAL – REGIONAL COST			$
SECTION B – WASHINGTON OFFICE COST					
6		CONSTRUCTION MATERIEL			
	A	ATTACHED FAA FORM 3871	$		
	B	PROVISIONING			
	C	FACTORY INSPECTION			
	D	TOTAL CONSTRUCTION MATERIEL – ☐ NONE REQUIRED		$	
7		ELECTRONIC EQUIPMENT			
	A	ATTACHED FAA FORM 3871			
	B	PROVISIONING			
	C	FACTORY INSPECTION			
	D	TOTAL ELECTRONIC EQUIPMENT – ☐ NONE REQUIRED			
8		FREIGHT *(Washington Office)*			
	A	FOR CONSTRUCTION MATERIEL			
	B	FOR ELECTRONIC EQUIPMENT			
	C	TOTAL FREIGHT – ☐ NONE REQUIRED			
9		*(Sum of lines 6D + 7D + 8C)* SUBTOTAL WASHINGTON OFFICE COST			$
10		*(Sum of Lines 5 + 9)* UNIT TOTAL			$

PROJECT TITLE:	PRIORITY	ITEM NO.	REGION	PAGE
LOCATION:				

FAA Form 2500-40 (7-67) SUPERSEDES FAA FORM 2635.1 C FAA AC 73-7115

(2) Site Preparation.

(3) Access Roads and Parking Areas.

(4) Building (Electrical/Mechanical/Plumbing).

(5) Engine Generator and Fuel Tank.

(6) Utilities (water, sanitary, electrical service).

(7) Special 3¢ Electrical Service.

(8) Antenna Tower and Cable Installation.

(9) Initial Supplies and Working Equipment.

(10) Office Furniture.

(11) Purchases.

(12) Freight.

(13) Property Procurement/Lease.

c. Electronic Installation.

(1) Purchases.

(2) Freight.

(3) Installation Costs.

(a) ARSR.

(b) ATCBI.

(c) Ancillary Equipment.

(d) Site Test and Flight Check.

d. Flight Inspection.

e. Support Items (e.g., garage, emergency crew quarters, over-snow vehicle and garage, site security provisions, etc.).

f. Maintenance Costs (Annual).

(1) Staff.

(2) Housing/Operations.

(3) Travel.

g. Annual Leased Communications Service.

(1) Cable Cost (amortized over ten years).

(2) Tariff for Leased Circuits (including one regular exchange line).

89. COST ESTIMATE PREPARATION. An estimate considering all of the above cost factors should be prepared for each candidate site. Additional supporting cost estimates should also be prepared for each support item requiring construction (e.g., garages, emergency quarters, etc.). Some of the cost items may require supplementary analyses as indicated below. If relative maintenance costs are substantially different between candidate sites, the life cycle, maintenance costs should be considered in site selection.

90. SUPPLEMENTARY ANALYSES.

a. Grounding System. In order to properly estimate site electrical construction costs, a preliminary design for the site grounding system is required. This ground design is dependent upon earth resistivity and soil data collected at the site survey. Design analysis and cost estimates should follow guidelines and procedures described in the latest edition of Orders 6950.19, Practices And Procedures For Lightning Protection, Grounding, Bonding, And Shielding Implementation and 6950.20, Fundamental Considerations of Lightning Protection, Grounding, Bonding, And Shielding.

b. Other Analyses. In addition to conducting the siting analyses described above, the engineer should undertake such other studies as are required for the resolution of specific problems related to the particular siting operation in question, Among these supplementary studies, he should locate any required RML equipment associated with the particular site. RML siting information is necessary for accurate estimation of the cost of establishing an ARSR/ATCBI site.

91. COST SUMMARY. Upon completion of all'principal and supplementary cost estimates, a simple one-page summary of the information should be prepared to aid in site comparison. A representative example of such a summary is shown in figure 4-26, reproduced from reference 16.

SECTION 8. SITING REPORT

92. PURPOSE AND SCOPE. The purpose of the siting report is to describe and summarize the results of the investigations, surveys, and analysis associated with the siting effort. It is intended to provide a record of, as well as an engineering data source for the site, and may be regarded as the source file for information relative to the construction, installation, flight check, and commissioning of the site. The siting report should present the necessary information in a logical form readily understandable by the user, and all pertinent data which has a bearing on the recommendations as to site suitability or preference shall be included;

Figure 4-26. SUMMARY OF COSTS FOR THREE PROSPECTIVE SITES FOR THE BEACH NORTH DAKOTA ENROUTE RADAR

ITEM COSTS	SITES A	SITES B	SITES C
PLANTS			
Engineering	$ 69,500	$ 69,500	$ 50,800
Construction Supervision	34,500	34,500	34,500
Site Preparation	9,200	9,100	9,100
Access Road	3,600	59,000	95,000
Building Construction & E/G Installation	169,000	182,700	192,200
Water and Sanitation	38,700	43,100	44,200
Tower Work	75,700	37,900	37,900
Schedule B & Regional Purchases	6,300	6,300	6,300
Property Procurement	6,100	6,100	6,100
30 Power Line	3,800	53,200	32,300
Subtotal	$416,400	$501,400	$508,400
ELECTRONIC			
Engineering	$ 59,100	$ Same	$ 45,700
Regional Purchase	1,000	Same	Same
Installation	19,900	Same	Same
Flight Checks	34,000	Same	22,700
Subtotal	$114,000	$114,000	$ 89,300
SUPPORT ITEMS			
Emergency Crew Quarters	$ 0	$108,700	$108,700
Garage at LRR	17,300	17,300	17,300
Over-snow Vehicle	0	16,100	16,100
Lower Vehicle Garage	0	26,300	26,300
Subtotal	$ 17,300	$168,400	$168,400
ESTABLISHMENT TOTAL	$547,700	$783,800	$766,000
MAINTENANCE OPERATIONS (Staffing, Housing, and Travel)	$148,300	$184,700	$184,700
ANNUAL LEASED COMMUNICATION SERVICE	$ 84,400	$ 81,900	$ 81,900

93. REPORT CONTENT AND ORGANIZATION. A sample outline of the content and organization of the siting report is given in appendix 4. The specific content is flexible and should be adapted as applicable to the particular siting activities and findings. The basic organization format, where a statement of the problem and a summary review of results and conclusions precede the detailed accounts, analysis and investigations, etc., should be adhered to in order to provide for a quick and comprehensive review of the siting effort without resorting to details.

94. DISTRIBUTION. A minimum of nine copies of the report should be prepared and the distribution of the report should include the following with a total of 11 copies being distributed.

a. Local Site Airway Facilities Sector Chief, 1 copy.

b. Local Site Air Traffic Facility Chief, 1 copy.

c. Regional Air Traffic Division, 1 copy.

d. Regional Airway Facilities Division, 1 copy.

e. Regional Flight Standards Division, 1 copy.

f. Headquarters Air Traffic Service, 1 copy.

g. Headquarters Airway Facilities Service, 3 copies.

h. Associate Administrator for Aviatipn Standards, 1 copy.

i. Headquarters System Research & Development Service, 1 copy.

SECTION 9. FINAL SITE SELECTION

95. REVIEW AND COORDINATION. In the event that final site selection is still in doubt, use of mobile radar equipment should be considered as a means of alleviating any final uncertainty. The final selection of the ARSR/ATCRBS site will require the concurrence and approval of a number of regional and local FAA offices. These offices, identified by the distribution list given in the previous section, will be called upon to review the siting report and present their objections, suggestions and/or approval of the findings and recommendations described in the siting report. Conferences and meetings between representatives of these offices and members of the siting team should be held as necessary to present and discuss these views.

96. CONCURRENCE. Once agreement between all cognizant offices has been reached regarding the location and requirements of the ARSR/ATCRBS site, an appropriate approval/concurrence memorandum should be signed by a representative of each cognizant office. This memorandum should identify the site selected with reference to the siting report, noting all exceptions or changes made with respect to the findings and recommendations made in the report. It should then be inserted as a permanent addendum to the siting report.

APPENDIX 1

REFERENCES

1. M. I. Skolnik, Radar Handbook, McGraw Hill, 1970.

2. F. E. Nathanson, Radar Design Principles, McGraw Hill, 1969.

3. J. D. Kraus, Antennas, McGraw Hill, 1950.

4. H. Jasik, Antenna Engineering Handbook, McGraw Hill, 1961.

5. L. V. Blake, A Guide to Basic Pulse Radar Maximum Range Calculation, Part I - Equations, Definitions, and Aids to Calculation, Report 6930, Naval Research Laboratory, AD 701-321, December 23, 1969.

6. R. Jacobson, User's Guide to the FAA Radar Coverage Time Share Programs (CVRG and CVRG10), January 1979 (included in Appendix 3 of this siting handbook).

7. C. R. Burrows and S. S. Attwood, Radio Wave Propagation, Academic Press, 1949.

8. G. F. Spingler, Experimentation and Analysis of Siting Criteria, Report NA-69-36, FAA/NAFEC, September 1969.

9. F. K. Preikschat, "Screening Fences for Ground Reflection Reduction," Microwave Journal, P. 46, August 1964.

10. M. I. Skolnik, Introduction to Radar Systems, McGraw Hill, 1962.

11. "The ARSR-3 Story," Westinghouse Electric Corporation, Baltimore, MD.

12. Handbook of Geophysics, Revised Edition, the Macmillan Company, New York, 1960.

13. N. Murarka, et. al., Secondary En Route Beacon Splits, Report IITRI-E6253-1, IIT Research Institute, July 1973.

14. N. Murarka and D. Lanera, Investigation of False Target Problem at the Las Vegas En Route Radar Beacon Site, Report IITRI-E6253-2, IIT Research Institute, August 1973.

15. R.D. Grigg, Long Range Radar Compatibility Analysis in the 1300-1350 MHz Frequency Band, Report FAA-RD-76-200, IITRI/ECAC, January 1976.

16. Siting Report, Beach North Dakota Long Range Radar, Airway Facilities Engineering Branch, ARM 430, November 1973.

APPENDIX 2

DATA FORMS

WORKSHEET FOR PRELIMINARY RADAR COVERAGE ESTIMATION

Assumed Antenna Height ________ Radar **Type ARSR-,**

MSL Elevation Of Antenna Center ______ **Aicroft Type** ______

Fix Identification	MSL Altitude Of Fix (Feet)	Difference Between Fix 8 Antenno Altitude (Feet)	Maximum Coverage Ronge To Fix (From Coveroge Diogrom, nmi)

PRELIMINARY SITE INSPECTION CHECKLIST

SITE INSPECTED :	PAGE I OF 2
DATE :	PERSONNEL :

SITE ACCESSIBILITY : (note roads or Improvements req'd, with est. of cost)

DATALINE / RML REQUIREMENTS : (availability of commercial telephone data service and suppliers ; - as applicable)

ELECTRICAL POWER PROVISIONS : (avail. of comml. pwr. and loc. of nearest access pt.)

SANITATION : (note any sewer, water connections req'd. ; est. cost)

TERRAIN TYPE : (note gen. char. of terrain near site)

DRAINAGE : (note any special grading/leveling req'ts.; ert cost)

ENVIRONMENT : (note nearby natural or other sources of harmful radiation, shock , vibration , corrorlve atmospheres, recreational or historic site, environmentally sensitive areas, etc)

(continued)

SITE INSPECTED :	PAGE 2 OF 2
SURFACE TRAFFIC : (·est. length , dir. , dist. of visible roadways 8 R.R. lines)	
SCREENING CHARACTERISTICS : (est. range, ht. of close - In and distant screening objects for all azimuths)	
AREA DEVELOPMENTS : (est. nature , extent of future developement In the site area)	
CLUTTER / LOBING ASSESSMENT : (est. severity of clutter in unscreened areas , note regions of poss. lobIng)	
REFLECTORS : (note size , range of potentially harmful reflectors)	

SCREEN ANGLE SURVEY DATA SHEET

Site Identification ____________ Close -In / Low Angle Screen ____________

Site Location { Longi tudc ____________ Skyline / Distant Screen ____________

Latitude ____________

Survey Elevation (AGL) ____________ Recorder ____________

Site Elevation (MSL) ____________ Dote ____________

AZIMUTH (Mag. North)		AZIMUTH (True North)		SCREEN ANGLE	SCREEN DISTANCE (Nautical Miles)		SCREEN ANGLE	DESCRIPTION OF SCREEN OBJECT
From	To	From	To	(uptical)	Estimated	Measured	(Radar)	

FAA-Form 6310-5 (12-73)

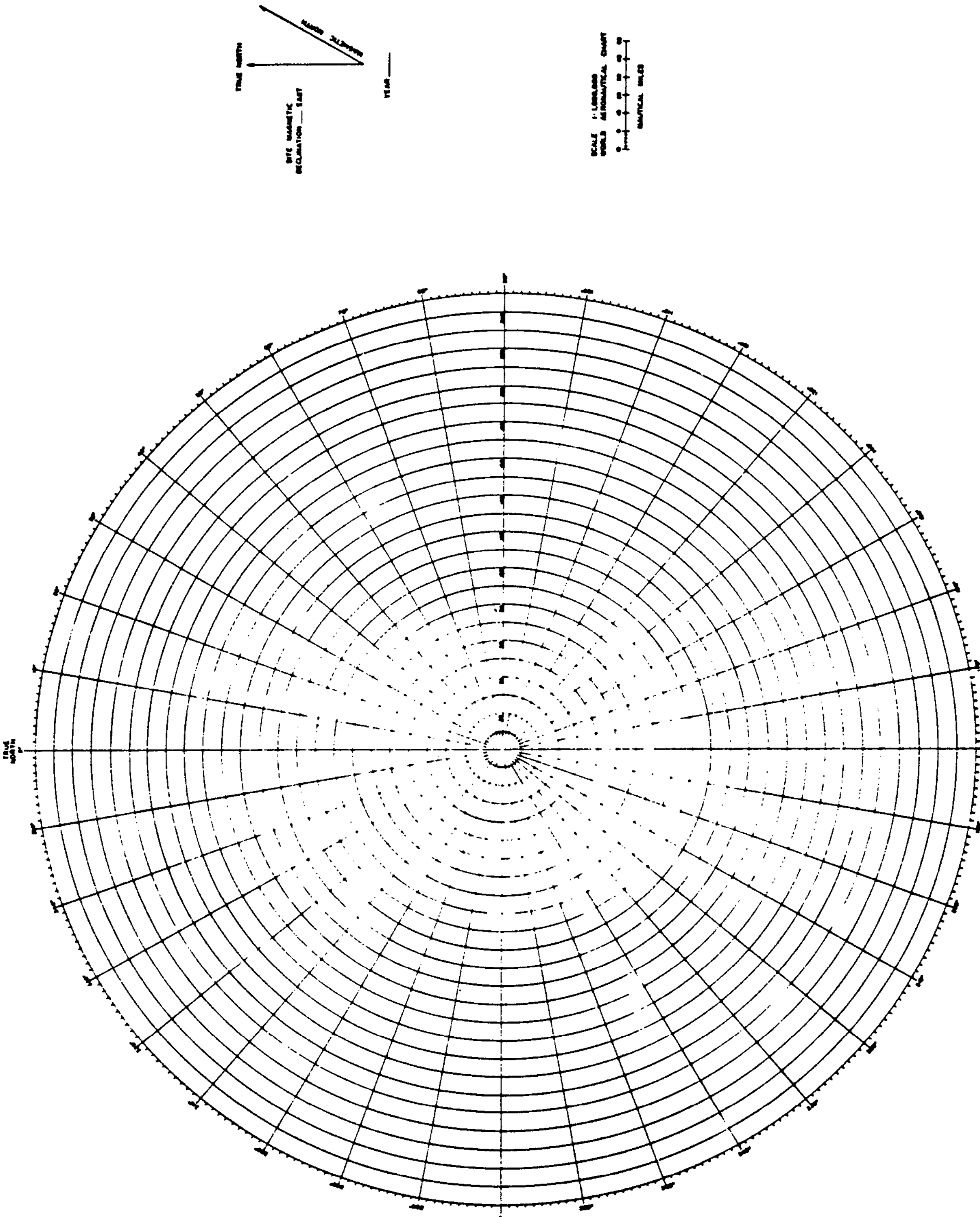
LOS COVERAGE WORKSHEET

SITE :	RADAR TYPE:	CONDITION : ☐ LP-FAIR ☐ CP-HVY PRECIP
SITE LOCATION : LATITUDE LONGITUDE	SITE ALTITUDE : FT MSL SURVEY HEIGHT : FT AGL ANTENNA HEIGHT: FT MSL	DATE : PREPARED BY:

A No.	B Nom. Of Fix	C Fix Azimuth (Deg.True)	D Fix Range (n.m.)	E Fix Height (Ft.MSL)	F Fix Elevation Angle (Deg.)	G Adj.Fix Elevation (F-0. 1°) (Deg.)	H Adj.Fix Height (Ft.MSL)	I Measured Radar Screen Angle (Deg.)	J Radar Screen Altitudes (Ft. MSL)	K LOS Coverage Yes	No	Maw	L Tilt Anglo For Radar Coverage LP-C	CP-C	CP-R

Maximum Tilt Anglo For Coverage Of Ail Fixes ________

POLAR COVERAGE CHART



FAA Drawing No. E6201

RADAR LOS ALTITUDE RANGE CUTOFF WORKSHEET

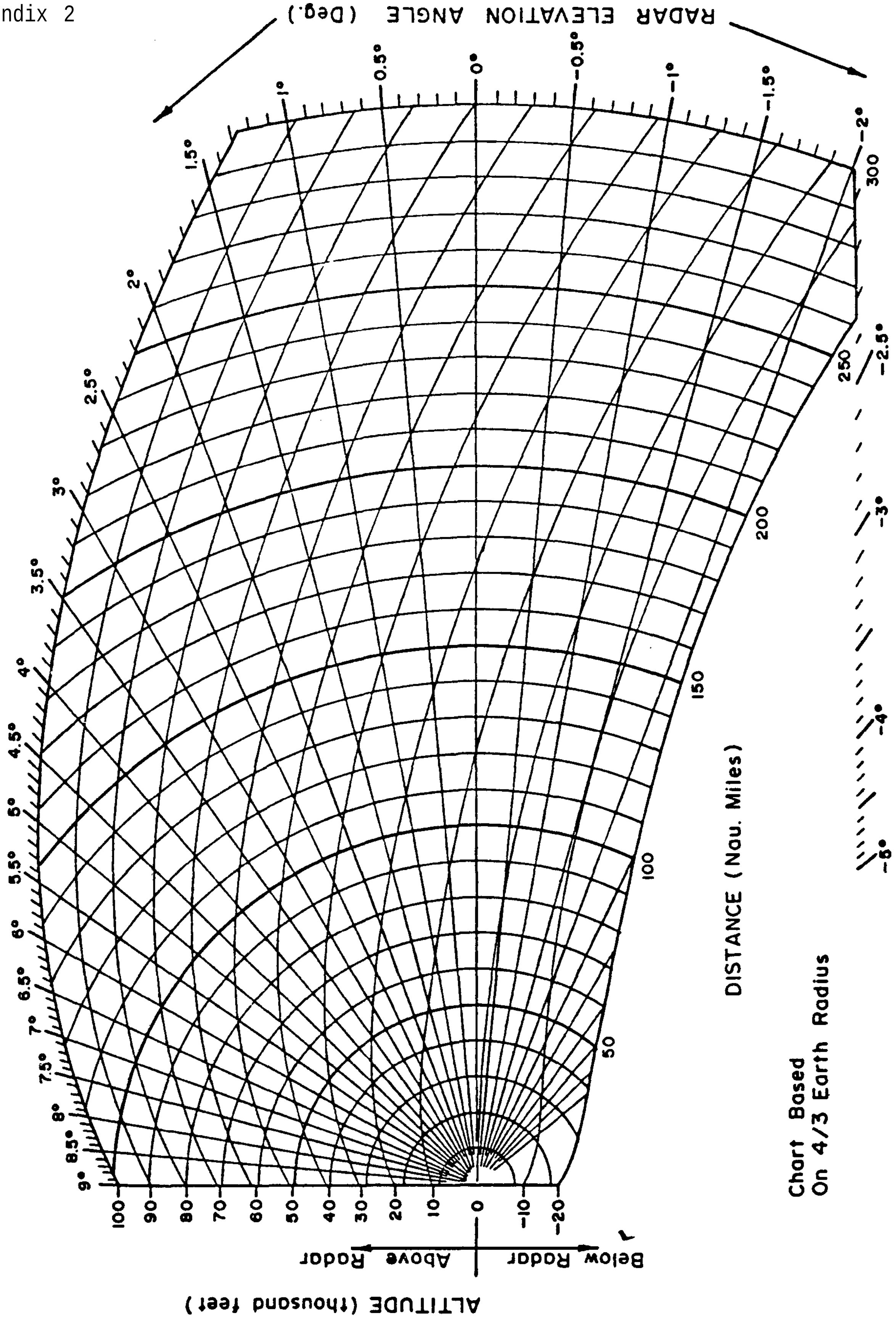
SITE IDENTIFICATION : ______ SITE COORDINATES : ______ DATE : ______

ANTENNA HEIGHT ______ FT MSL LONG. ______ LAT. ______ PREPARED BY. ______

1		2	3	4	5						
AZIMUTH (True North)		RADAR SCREEN ANGLE	SCREEN DISTANCE NM	SCREEN OBJECT	RADAR LOS CUTOFF RANGE IN N.M. ALTITUDE IN FEET						
From	To				100	eoo	1000	2000	3000	4000	5000

FAA Form 6310-2 (11-73)

RADAR COVERAGE INDICATOR (RCI) CHART



RIS: BU 2500-

F & E COST ESTIMATE SUMMARY (FY-)

PROGRAM IDENTIFICATION: BUDGET ITEM (1-2)	PROJECT CODE: FACILITY (3-6)	(7)	WORK CODE (8-10)	SUFFIX (11)	ORIGINATOR (12-13)	PROGRAM SUBMISSION: FY (14-15)	S (16)	LINE NO. (17)	ACTION (18)	PROJECT: SUBMIT ORGANIZATION (19-20)	REGION (21-22)	LOCATION: ID (23-25)	(26-27)	SUFFIX (28)	RUNWAY: NUMBER (29-30)	LETTER (31-32)

REGIONAL COSTS

CARD 1

ITEM A	CARD COL. NO. B	DETAIL AMOUNT C	SUMMARY AMOUNT D	TOTALS E
1. PLANT ENGINEERING — A. PLANT ENGINEERING (man-days + other costs)	(33-36)			
B. DRAFTING (man-days + other costs)	(37-40)			
☐ NONE REQUIRED — C. TOTAL				
2. ELECTRONIC ENGIN. — A. ELECTRONIC ENGINEERING (man-days + other costs)	(41-44)			
B. DRAFTING (man-days + other costs)	(45-48)			
☐ NONE REQUIRED — C. TOTAL				
3. CONSTRUCTION — A. LABOR (man-days)	(49-52)			
B. OTHER CONSTRUCTION COSTS (Except land acquisition)	(53-56)			
C. LAND ACQUISITION	(57-60)			
☐ NONE REQUIRED — D. TOTAL				
4. ELECTRONIC INSTAL. — A. LABOR (man-days)	(61-64)			
B. OTHER INSTALLATION COSTS	(65-68)			
☐ NONE REQUIRED — C. TOTAL				
5. FLIGHT INSPECTION (hours at $ per hour)	(69-72)			
6. REGIONAL UNIT COST				

Last position - tenths of thousands

FOR WASHINGTON OFFICE USE ONLY	7. REGIONAL COSTS REVISED ☐ (If "Yes", enter "C" in box) (73)	8. MASS CHANGE INDICATOR ☐ (If "Yes", enter "M" in box) (74)

CARD 4

9. SUMMARY OF MANPOWER REQUIREMENTS BY CATEGORY *(Man-Days)*

LINE NO. (17) 7 / ACTION (18) ___	PLANT ENG(1)	ELEC ENG (2)	CONSTR (3)	ELEC INSTL. (4)	FLT INSP (5)	COST CTR	MASS CHG.
	(33-36)	(37-40)	(41-44)	(45-48)	(49-51)	(52-56)	(74)

LINE NO. (17) 8

ACTION (18) ___

WASHINGTON OFFICE COSTS

ITEM	CARD COL. NO.	DETAIL AMOUNT	SUMMARY AMOUNT	TOTALS
10. CONSTRUCTION MATERIAL — A. EQUIPMENT LIST ATTACHED	(33-37)			
B. PROVISIONING (Parts common) %	(38-41)			
C. PROVISIONING (Other than parts common) %	(42-45)			
D. FACTORY INSPECTION %	(46-49)			
E. FREIGHT %	(50-53)			
☐ NONE REQUIRED — F. TOTAL				
11. ELECTRONIC EQUIPMENT — A. EQUIPMENT LIST ATTACHED	(54-58)			
B. PROVISIONING (Parts common) %	(59-62)			
C. PROVISIONING (Other than parts common) %	(63-66)			
D. FACTORY INSPECTION %	(67-70)			
E. FREIGHT %	(71-74)			
☐ NONE REQUIRED — F. TOTAL				
12. F & E TRAINING %	(75-79)			
13. WASHINGTON OFFICE UNIT COST				
14. TOTAL UNIT (Region + Washington Office) COST — TEMPORARY COSTS ☐ (If "Yes", enter "T" in box) (80)				

REMARKS	DATE

PROJECT TITLE	BUDGET ITEM	PAGE NO.
LOCATION		

FAA Form 2500-40 PG 1 (6-77) SUPERSEDES PREVIOUS EDITION GPO 918-62

RIS: AF 2500-4

F & E PLANT COST ESTIMATE WORKSHEET (FY-)

	ITEM DESCRIPTION	PD	NPD	UNIT COST	TOTAL COST
A. CIVIL, MECHANICAL AND ELECTRICAL ENGINEERING	1. MD INITIAL SURVEY AND SITE INVESTIGATION				
	2. MD PRELIMINARY SKETCHES, DRAWINGS, ETC.				
	3. MD FINAL SURVEY, LAYOUT, COORDINATION ETC.				
	4. MD SITE SELECTION REPORTS				
	5. MD ENVIRONMENTAL ASSESSMENT				
	6. MD CIVIL ENGINEERING DESIGN, SPECIFICATIONS, ETC.				
	7. MD MECHANICAL ENGINEERING DESIGN, SPECIFICATIONS, ETC.				
	8. MD ELECTRICAL ENGINEERING DESIGN, SPECIFICATIONS, ETC.				
	9. MD TEMPORARY FACILITY				
	10. MD TECHNICAL SUPERVISION, FOLLOW-ON SUPPORT				
	11. MD CLEAR EXCEPTIONS, AS BUILT DRAWINGS, ETC.				
	12. MD OTHER ENGINEERING *(Explain)*				
	13. TOTAL PD MAN-DAYS *(Lines 1 - 12)* @ $ Per MD				
	14. TOTAL NPD MAN-DAYS *(Lines 1 - 12)* @ $ Per MD				
	15. TOTAL PD & NPD MAN-DAYS *(Lines 13 & 14)* = MAN-DAYS				
	16. OTHER ENGINEERING COSTS				
	A. SITE SURVEY WORK *(Tree clearing, grading etc. for site tests)*				
	B. ENGINEERING SUPPLIES AND EQUIPMENT				
	C. ENGINEERING CONTRACT FOR SITE SURVEY				
	D. A/E CONTRACT FOR DESIGN				
	E. OTHER ENGINEERING COSTS *(Explain)*				
	17. PLANT ENGINEERING COSTS *(Lines 13, 14 & 16)*				
B. DRAFTING	1. MD PLANT ENGINEERING SKETCHES, FINAL DRAWINGS, ETC.				
	2. MD AS-BUILT DRAWINGS				
	3. TOTAL MAN-DAYS *(Lines 1 & 2)* = MD @ $ Per MD				
	4. OTHER DRAFTING COSTS *(Explain)*				
	5. TOTAL PLANT DRAFTING *(Lines 3 & 4)*				
C. CONSTRUCTION	1. MD RESIDENT ENGINEER FOR CONSTRUCTION CONTRACT				
	2. MD GOVERNMENT FORCE CONSTRUCTION SUPERVISION				
	3. MD GOVERNMENT FORCE CONSTRUCTION *(Explain)*				
	4. MD REGIONAL SHOP WORK				

JOB ORDER NUMBER	PROJECT CODE	TYPE OF ESTIMATE *(Radar, communications, automation, etc.)*
ESTIMATOR	PROJECT TITLE	
REVIEWER	LOCATION	

FAA Form 2500-40 PG 2 (6-77) SUPERSEDES PREVIOUS EDITION

ITEM DESCRIPTION	PD	NPO	UNIT COST	TOTAL COST
5. MD FLIGHT CHECK, JOINT ACCEPTANCE INSPECTION, CAPITALIZATION, ETC.				
6. MD PREPARED AS-BUILT DRAWINGS				
7. MD SITE CLEAN-UP				
8. MD OTHER CONSTRUCTION *(Explain)*				
9. **TOTAL PD MAN-DAYS** *(Lines 1 - 8)* @ $ Per MD				
10. **TOTAL NPD MAN-DAYS** *(Lines 1 - 8)* @ $ Per MD				
11. **TOTAL PD & NPD MAN-DAYS** *(Lines 9 & 10)* = MAN-DAYS				
12. OTHER CONSTRUCTION COSTS				
A. INITIAL SUPPLIES AND WORKING EQUIPMENT *(Schedule B)*				
B. REGIONAL FREIGHT				
C. REGIONAL PURCHASES *(Explain)*				
D. UTILITIES: POWER, CONTROL WATER/SEWAGE SYSTEMS, ETC. *(Explain)*				
E. RF CABLE INSTALLATION: TYPE, LENGTH, ETC. *(Explain)*				
F. ACCESS ROADS & PARKING AREAS: TYPE, LENGTH, NUMBER OF PARKING SLOTS, ETC. *(Explain)*				
G. ANTENNA TOWERS & STRUCTURES: NUMBER, HEIGHT, TYPE, ETC. *(Explain)*				
H. SITE PREPARATION: CLEARING, EXCAVATION, LANDSCAPING, FENCING, ETC. *(Explain)*				
I. BUILDING: NEW, EXPANSION, REFURBISH, TYPE, SIZE, HEIGHT, ETC. *(Explain)*				
J. ENGINE GENERATOR				
K. OTHER COSTS: CONTRACTOR BONDS, INSURANCE, DISMANTLING OF OLD SITES, ETC. *(Explain)*				
13. **SUB-TOTAL** *(Lines 12a - k)*				
14. CONTINGENCIES (% of line 13)				
15. **TOTAL OTHER CONSTRUCTION** *(Lines 13 & 14)*				
16. LAND ACQUISITION COSTS				
17. **TOTAL CONSTRUCTION** *(Sum of lines 11, 15 & 16)*				

REMARKS

GPO 918-828

RIS: AF 2500-4

F & E ELECTRONICS COST ESTIMATE WORKSHEET (FY-)					DATE
	ITEM DESCRIPTION	PD	NPD	UNIT COST	TOTAL COST
A. ENGINEERING	1. MD FIELD SURVEY AND INVESTIGATION				
	2. MD SITE SELECTION COORDINATION, REPORTS ETC.				
	3. MD SITE TESTS				
	4. MD TEMPORARY FACILITY				
	5. MD TECHNICAL DESIGN, DRAWINGS, SPECIFICATIONS, ETC.				
	6. MD TECHNICAL SUPERVISION FOLLOW-ON SUPPORT				
	7. MD CLEAR EXCEPTIONS, AS-BUILT DRAWINGS, ETC.				
	8. MD OTHER ENGINEERING *(Explain)*				
	9. **TOTAL PD MAN-DAYS** *(Lines 1 - 8)* @ $ per MD				
	10. **TOTAL NPD MAN-DAYS** *(Lines 1 - 8)* @ $ per MD				
	11. **TOTAL PD & NPD MAN-DAYS** *(Lines 9 & 10)* = MAN-DAYS				
	12. OTHER ENGINEERING COSTS A. ENGINEERING SUPPLIES AND EQUIPMENT				
	B. SPECIAL EQUIPMENT FOR SITE TESTS				
	C. ENGINEERING CONTRACTS FOR SITE SURVEY				
	D. ENGINEERING CONTRACTS FOR DESIGN				
	E. OTHER ENGINEERING COSTS *(Explain)*				
	13. **TOTAL ELECTRONIC ENGINEERING COSTS** *(Lines 9, 10, & 12)*				
B. DRAFTING	1. MD SKETCHES, FINAL DRAWINGS ETC.				
	2. MD AS-BUILT DRAWINGS				
	3. **TOTAL MAN-DAYS** *(Lines 1 & 2)* = MD @ $ per MD				
	4. OTHER DRAFTING COSTS *(Explain)*				
	5. **TOTAL ELECTRONIC DRAFTING** *(Lines 3 & 4)*				
C. INSTALLATION	1. MD RESIDENT ENGINEER FOR INSTALLATION CONTRACT				
	2. MD SUPERVISION OF FIELD CREW				
	3. MD INSTALL RACKS, DUCT, WIRING, ETC. AT REMOTE FACILITY *(VOR, RCAG, ARSR, ILS, etc.)*				
	4. MD TUNE UP AND ALIGNMENT AT REMOTE FACILITY				
	5. MD INSTALL RACKS, DUCT, WIRING, ETC. AT CONTROL FACILITY *(ARTCC, FSS, ATCT, etc.)*				
	6. MD TUNE UP AND ALIGNMENT AT CONTROL FACILITY				
	7. MD FLIGHT CHECK FACILITY				
	8. MD JOINT ACCEPTANCE INSPECTION, CAPITALIZATION, ETC.				
	9. MD PREPARED AS-BUILT DRAWINGS				
	10. MD SITE CLEAN-UP				
	11. MD DISMANTLE OLD EQUIPMENT				
	12. MD INSTALL AND TUNE UP TEMPORARY FACILITY				

JOB ORDER NUMBER	PROJECT CODE	TYPE OF ESTIMATE *(Radar, communications, automation, etc.)*
ESTIMATOR	PROJECT TITLE	
REVIEWER	LOCATION	

FAA Form 2500-40 PG 3 (6-77) SUPERSEDES PREVIOUS EDITION

C. INSTALLATION (Cont)

ITEM DESCRIPTION	PD	NPD	UNIT COST	TOTAL COST
13. MD DISMANTLE TEMPORARY FACILITY				
14. MD REGIONAL SHOP WORK				
15. MD OTHER INSTALLATION *(Explain)*				
16. TOTAL PD MAN-DAYS *(Lines 1 - 14)* @ $ per MD				
17. TOTAL NPD MAN-DAYS *(Lines 1 - 14)* @ $ per MD				
18. TOTAL PD & NPD MAN-DAYS *(Lines 16 & 17)* = MAN-DAYS				
19. OTHER INSTALLATION COSTS				
A. INITIAL SUPPLIES AND WORKING EQUIPMENT *(Schedule B items)*				
B. REGIONAL FREIGHT				
C. REGIONAL TURNKEY INSTALLATION CONTRACT				
D. RENTAL COSTS FOR SPECIAL TOOLS AND EQUIPMENT				
E. REGIONAL PURCHASES *(Explain)*				
F. OTHER *(Specify and explain)*				
20. SUBTOTAL INSTALLATION (Except labor) *(Lines 19a - f)*				
21. CONTINGENCIES (% of line 20)				
22. TOTAL OTHER INSTALLATION COSTS (Except labor) *(Lines 20 & 21)*				
23. TOTAL ELECTRONICS INSTALLATION *(Lines 18 & 22)*				
24. FLIGHT INSPECTION (hours at $ per hour)				

REMARKS

GPO 918-824

APPENDIX 3

COMPUTER PROGRAM FOR RADAR LINE-OF-SIGHT PLOTS

Line-of-Site Calculations

A polar plot of line-of-site coverage has proven to be a valuable aid for predicting **peformance** of a new radar or UHF communications facility during site selection and analysis procedures. Such a plot can be generated by making elevation angle measurements to the horizon (or other screening object) with a surveying transit at many points in azimuth to obtain a profile of the screening horizon around a prospective site. This data can then be reduced to polar plots (figure 1) by graphical techniques of plotting screening angle and desired aircraft altitude (figure 2) on 4/3 earth curvature charts to determine maximum line-of-site range. This is rather tedious work; considering the fact that a detailed horizon profile could have 200 or more data points and 10 to 15 polar points may be desired, considerable time and labor are required to properly analyze a site. Further- &ore, if polar line-of-sight coverage charts are desired for different antenna heights, one must either compute a new screening angle for each data point or make new field measurements with transit heights equal to each proposed antenna height. Either method requires many manhours.

A FORTRAN computer program has been developed by Rocky 'Mountain Region engineering personnel to reduce this horizon profile data with a minimum of effort. This program uses an X-Y plotter to draw a polar plot on tracing paper.

The program requires screening angle data to be entered and stored on a permanent file in the system. These files are stored on the Boeing time- sharing system.

To use this program, screening angle data from field data measurements must first be entered into the computer system. This data would be recorded on FAA Form 6310-S. This data must then be entered into a permanent file in the computer in a specified format. The file would be created as follows:

After logging into the system with a Teletype or other conversational terminal, enter NEW, filename CR (where filename is any alphanumeric name desired having one to six characters, and CR represents carriage return. The system responds:

READY

The data must be entered as follows:

All lines begin with a 3-digit line number followed by a space. The first line contains the site elevation (MSL) and the survey transit height in feet.

Example:

001 02475.0 25.4
Decimal point locationsmust be observed and used. Successive lines contain screening data as follows:

002 011 00 +01 08.20 020 00 +05 12.50 030 10 +00 25.00 041 15 -02 15.00
003 050 35 -08 18.50 059 00 -15 25.00 070 05 -12 30.00 082 15 -10 28.00

006 262 00 +04 15.00 285 30 +00 15.00 310 00 -01 12.80 335 20 -01 13.50
007 350 00 +00 10.00 360 00 +01 08.50

The general form is:

NNN AAA BB CCC DD.DD AAA BB CCC DD.DD ---

N - Line number digits
A - Azimuth degrees
B - Azimuth minutes
C - Elevation angle in minutes include + or - sign.
(3 digits can be used and will be assumed positive by the computer)
D - Distance to screening object in nautical miles.

The 360.00 point must be entered as this tells the computer to stop the computation process.

Azimuth angles, ranges, and identification of various fixes or landmarks may be entered into the data file to provide marks on the polar plots for reference points. **(VORTAC's,**cities, airports, intersections)

These are entered as follows:

029 005.7 008.5 HANCO
030 074.5 021.0 SANDD
031 104.5 003.8 VOR
032 087.0 021.6 TERLI
033 124.5 021.6 HAZON
034 139.0 006.8 COLIJ

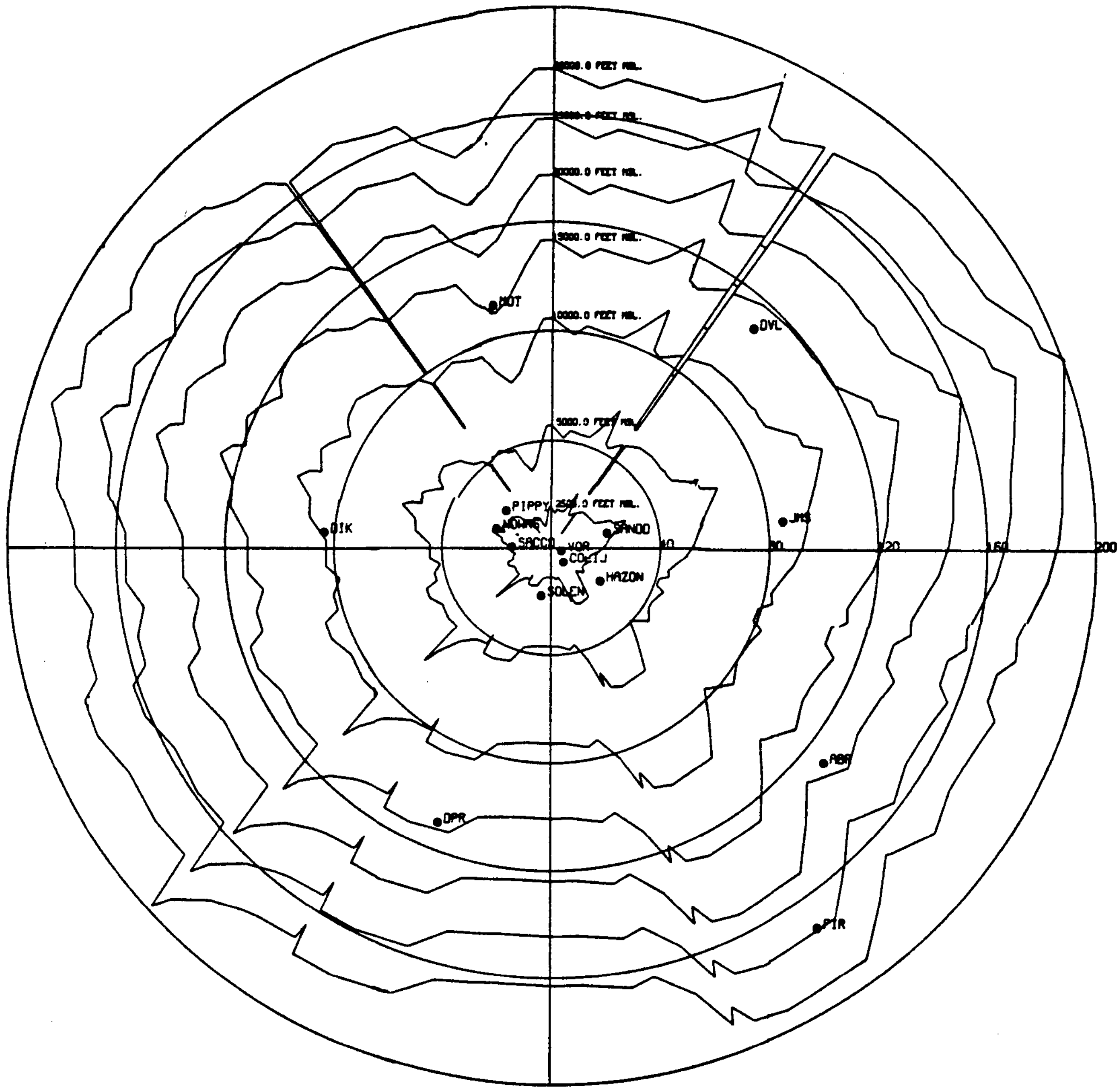
10 Characters Maximum

Any number of these fixes or landmark points may be entered. Fix names are limted to 10 characters. The general form is:

NNN XXX.X YYY.Y AAAAAAAAAA

N - Line number digits
Y - Azimuth angles to fixes in degrees **(045.3)**
Y - Ranges to fixes in nautical miles **(015.2)**
A - 1 to 10 character alphanumeric fix name

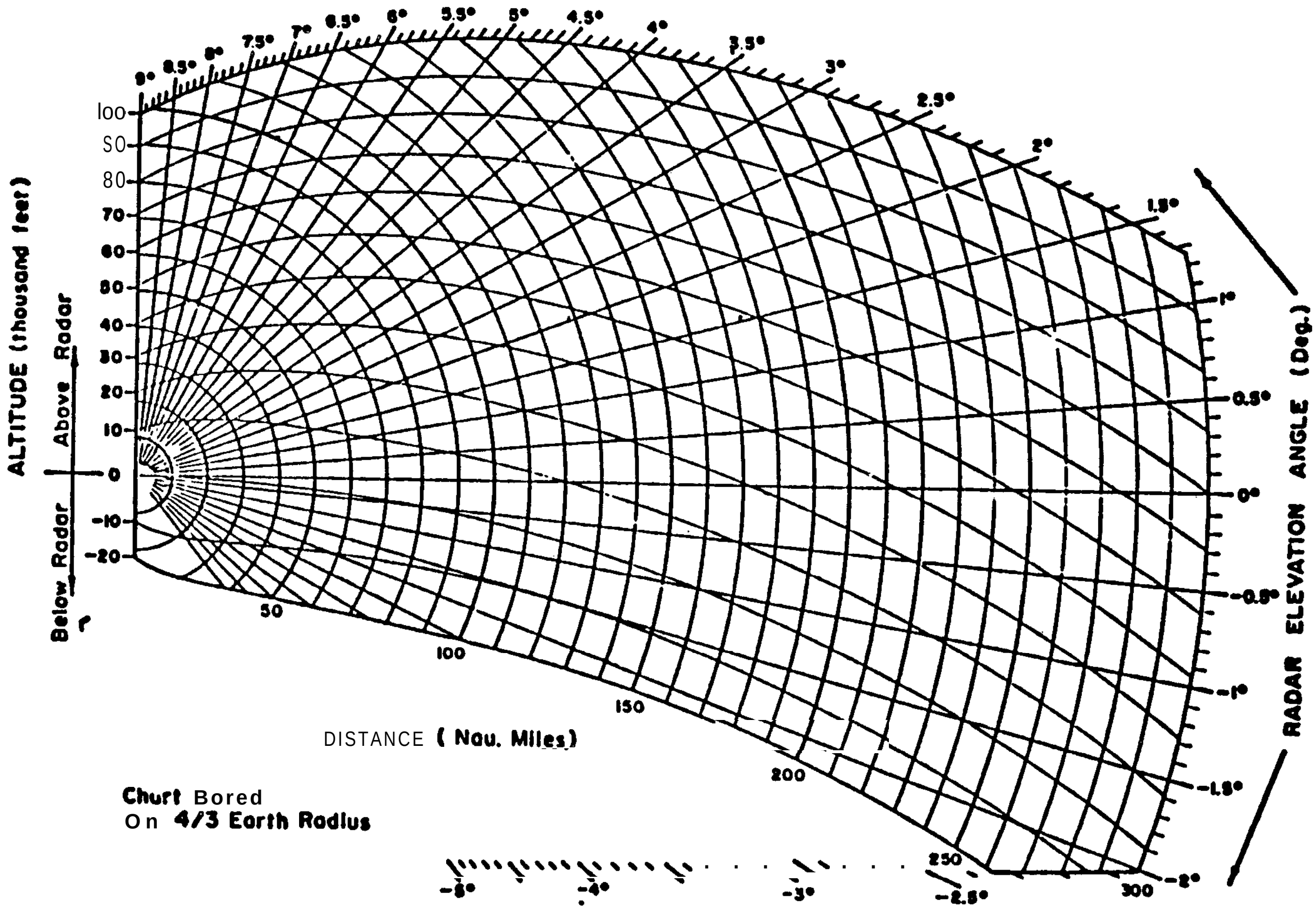
FIGURE 1. RADAR LOS BOUNDARY DIAGRAM



NOTES: 1. Range is in nautical miles.
2. K factor is 4/3.

TRUE
NORTH

FIGURE 2 RADAR COVERAGE INDICATOR (RCI) CHART



After all data is entered, type:

SAVE (CR)

The system will respond READY and the data is now saved as a permanent file.

The following pages show listings of two sample data files: one for near horizon profile and one for far horizon profile.

The program uses a Boeing-owned plotter to plot polar coverage charts on tracing paper. Using a 200 NM maximum range, this drawing size will overlay directly on sectional aeronautical charts, scale: 1:1,000,000. Any other maximum range may be used and the polar plot will be automatically scaled for proper size. Because these plots are drawn at a Boeing center, mailing must be used to deliver finished plots.

The plotter is man as follows:

```
N>GET,LOSPLTE/UN=YFA093      See Note 1
N>LOSPLTE(ERODN1=XXXXX)
 MAXIMUM RANGE OF INTEREST  (NM)=I>200
 SITE DESIRED=I>BISF1
 ANTENNA HEIGHT (FEET ABOVE GROUND)=I>62
 AFTER QUESTION MARK, ENTER ALTITUDE CONTOUR DESIRED
 ENTER 0 (ZERO) TO STOP PROGRAM
I>2500
I>5000
1~10000
I>15000
I>20000
I>25000
I>30000
I>0
```

If the plot requires both a near and a far horizon profile then it is run as follows:

```
N>GET,LOSPLTE/UN=YFA093
N>-LOSPLTE
 MAXIMUM RANGE OF INTEREST  (NM)=I>200
 SITE DESIRED=>TWO
 NEAR HORIZON PROFILE NAME=I>BISN1
 FAR HORIZON PROFILE NAME=I>BISF1
 ANTENNA HEIGHT (FEET ABOVE GROUND)=I>62
 AFTER QUESTION MARK, ENTER ALTITUDE CONTOUR DESIRED
 ENTER 0 (ZERO) TO STOP PROGRAM
I>2500
I>5000
I>10000
I>15000
I>20000
I>25000
I>30000
I>0
```

SAMPLE DATA FILE

Near Horizon Profile

```
N>OLD,BISN1
N>LNH
001 01671.1 028.0 BIS NEAR1
GO2 000 00 20 01.84 005 46 21 02.07 008 50 21 01.46 013 34 22 01.38
OU3 018 26 22 01.37 021 30 20 01.35 025 58 20 01.43 026 53 22 01.45
004 029 01 22 01.44 034 02 21 01.30 034 03 21 01.30 035 12 21 01.22
UU5 035 13 21 01.22 U4U 45 2U Uu.82 046 51 20 01.15 050 15 18 01.56
UU6 053 3U 16 01.95 055 22 15 02.18 057 00 10 02.07 059 50 02 01.89
UU7 U64 58 -13 01.56 Ub7 28 -2U 01.40 069 28 -20 01.37 076 28 -20 01.37
008 081 15 -2U 01.35 085 12 -20 01.36 089 11 -20 01.39 093 46 -20 01.39
009 096 00 -20 01.43 101 15 -17 01.60 103 58 -15 01.69 106 10 -14 01.76
U1U 1U9 4U -12 U1.87 111 4U -01 01.87 115 00 -01 01.87 118 20 -01 01.87
U11 121 4U -U1 01.87 127 00 00 01.75 132 14 02 01.63 132 51 02 01.64
U12 137 3U U2 01.75 142 45 U3 01.86 149 58 03 02.11 153 00 -03 02.35
U13 156 5U -10 02.65 158 4U -10 02.61 159 12 -1U 02.60 162 U3 -1U U2.55
U14 166 3U -U8 U2.28 169 31 -05 U2.04 175 SO -01 01.56 179 29 04 01.28
015 186 30 -05 03.14 187 00 -06 03.30 190 08 03 03.29 194 48 03 03.62
016 199 23 03 03.63 207 00 03 03.48 212 10 03 03.41 212 44 03 03.40
017 213 01 03 03.39 218 06 07 02.29 22U 1U 1U 01.63 223 43 10 U0.98
U18 226 54 19 00.88 227 45 24 00.85 229 41 U1 UU.98 234 59 01 01.09
U19 24U 45 U1 03.05 241 45 01 03.08 247 12 U1 03.25 251 30 01 03.26
U2U 253 4U U2 03.26 257 38 01 03.26 261 38 -01 03.26 265 18 -03 03.26
021 212 02 -03 03.32 277 28 -03 03.90 282 29 -U3 U5.01 286 35 -U3 US.01
U22 288 3U -U3 U5.U1 289 15 -03 05.U5 293 58 06 05.76 296 02 10 06.07
U23 298 38 1U U5.U8 299 53 10 04.57 302 00 10 06.45 304 03 10 03.53
U24 307 47 10 02.98 314 38 10 02.07 315 20 1U 01.96 318 02 10 01.97
025 321 58 10 01.98 324 10 10 02.00 324 11 10 02.00 324 37 10 02.00
U26 324 38 1U 02.00 331 45 1U 02.03 337 25 1U U3.U6 339 52 1U 02.07
U27 342 15 1U 02.01 346 1U 1U 01.91 349 45 1U U1.82 354 28 1U 01.70
U28 357 41 2U U1.68 360 0U 2U 01.84
U29 274.1 083.9 DIK
U3U 0'14.5 U21.0 SANDD
U31 104.5 003.8 VOR
U32 34b.2 UY1.7 MDT
U33 124.5 021.6 HAZON
U34 139.U UU6.8 COL1J
U35 I Y 1 . 5 U18.U SOLEN
U36 272.U U14.3 SACCO
U37 29U.U 021.3 NOWNS
U38 31U.U U21.4 PIPPY
U39 U42.3 1U9.5 DVL
U4U U83.U u15.4 JMS
U41 11M.7 121.4 ARR
U42 2U2.1 1U9.9 DPR
U43 145.2 172.2 PIR
N>
```

SAMPLE DATA FILE

Far Horizon Profile

```
  OLD,BISF1
N>ENH

001 01671.1 028.0 BIS FAR1
002 UUU UU 22 U6.U9 UU5 46   28 Ub.UY UU8 5U   24 06.U9 U13 34   25 06.09
UU3 U18 26 25 06.09 021 30   20 06.09 025 58   20 01.43 026 53   26 04.22
UU4 U29 U1 28 03.92 034 02   25 02.61 034 03   70 02.61 035 12   70 02.61
UU5 U35 13 25 02.61 040 45   19 04.07 046 51   18 04.35 050 15   18 04.35
UU6 US3 3U 18 04.62 055 22   17 04.78 057 UU   17 05.22 059 50   16 06.09
UU7 U64 58 U8 06.09 067 28   07 08.01 069 28   05 03.48 076 28   08 06.96
008 081 15 11 07.65 085 12   12 07.83 089 11   15 05.22 093 46   18 05.22
009 U96 00 20 05.76 101 15   25 05.22 103 58   26 03.26 106 10   31 03.26
010 109 40 31 03.27 111 40   26 03.48 115 00   28 03.48 118 20   29 03.48
011 121 40 28 04.35 127 00   25 03.48 132 14   30 05.04 132 51   31 05.22
012 137 30 21 05.22 142 45   10 05.22 149 58   10 04.91 153 00   10 04.35
013 156 50 11 04.99 158 40   17 06.09 159 12   12 05.22 162 03   27 03.48
014 166 30 37 03.48 169 31   31 09.57 175 50   34 09.57 179 29   34 09.57
015 186 3U 34 U9.57 187 00   34 09.59 190 08   33 09.69 194 48   31 09.85
016 199 23 22 10.01 207 00   20 10.26 212 10   20 10.44 212 44   31 09.98
017 213 01 25 09.76 218 06   25 05.66 220 10   24 04.61 223 43   22 02.86
018 226 54 22 01.27 227 45   24 '00.85 229 41  22 08.05 234 59   21 08.30
019 240 45 22 08.49 241 45   22 08.53 247 12   18 08.75 251 30   18 08.92
020 253 40 24 08.38 257 38   24 07.38 261 38   28 06.96 265 18   23 06.96
021 272 02 23 07.44 277 28   16 07.83 282 29   15 07.83 286 35   09 07.83
022 288 3U 12 07.83 289 15   16 07.83 293 58   13 07.83 296 02   15 07.83
023 298 38 18 08.92 299 53   20 08.85 302 00   17 08.05 304 03   17 05.21
024 307 47 17 04.35 314 38   22 03.48 315 20   24 03.45 318 02   28 03.33
025 321 58 30 03.15 324 10   35 03.05 324 11   65 03.05 324 37   65 03.05
U26 324 38 35 03.05 331 45   31 03.48 337 25   35 03.05 339 52   35 03.04
027 342 15 45 02.88 346 10   54 02.61 349 45   49 02.61 354 28   35 02.61
028 357 41 24 03.87 360 00   22 06.09
029 005.7 008.5 HANCO
030 074.5 021.0 SANDD
031 104.5 003.8 VOR
032 087.0 021.6 TERLI
033 124.5 021.6 HAZON
034 139.0 006.8 COLIJ
035 191.5 018.0 SOLEN
036 272.0 014.3 SACCO
037 290.0 021.3 NOWNS
038 31U.0 U21.4 PIPPY
```

The profile names used in the two examples above are the file names created using screening data. The program will switch from near to far horizon profile data, as required, to obtain line-of-sight contours for the specified altitudes.

When using both a near and far horizon profile data, i.e., identical azimuths must be used for each screening point. If azimuth 112°15' is used for a near horizon screening point, this same azimuth must be used for the far horizon screening point.

If these azimuths do not match, the LOSPLTE will not run and the error will be indicated as in the following example:

-LOSPLTE

```
MAXIMUM RANGE OF INTEREST (NM) =I>60
SITE DESIRED=I>TWO
NEAR HORIZON PROFILE NAME= I>GTFN3
FAR  HORIZON PROFILE NAME=I>GTFF3
ANTENNA HEIGHT (FEET ABOVE GROUND) =I>25
AFTER QUESTION MARK, ENTER ALTITUDE CONTOUR DESIRED
ENTER 0 (ZERO) TO STOP PROGRAM
I>4120
ERROR IN DATAAZIMUTHS DO NOT AGREE AZ=171.37    AZF=171.03
TYPE 'STOP' TO TERMINATE RUN I>STOP
*TERMINATED*
```

An antenna height does not have to be the same as the height the data was taken. The program computes new screening angles. The following is an example of a typical run of this program.

NOTE: 1. xxxxx = alphanumeric designation for local Boeing plotter. ERODN1 is designator for Denver Boeing plotter.

TYPICAL RUN OF LOSPLTE

```
N>-LOSPLTE
 MAXIMUM RANGE OF INTEREST (NM)=I>200
 SITE DESIRED=I>TWO
 NEAR HORIZON PROFILE NAME- I>BISN1
 FAR HORIZON PROFILE NAME=I>BISF1
 ANTENNA HEIGHT (FEET ABOVE GROUND)=I>62
 AFTER QUESTION MARK, ENTER ALTITUDE CONTOUR DESIRED
 ENTER 0 (ZERO) TO STOP PROGRAM
I>2500
I>5000
I>10000
I>15000
I>20000
I>25000
I>30000
I>0
```

```
THE SUB-
PLOT NO.   1 WITH THE TITLE

HAS BEEN COMPLETED.

PLOT ID. READS
PLOT 1     14.25.39   WBD 26 AUG,1981    JOB=IN3A354 .   ISSCO   DISSPLA VER 7.5

DATA FOR PLOT

POLAR PLOT
NO. OF  CURVES DRAWN 29
HORIZONTAL  SCALE  17.5INS.
VERTICAL  SCALE ,  17.5INS.
RADIUS STEP SIZE   .1000E+01 UNITS/INCH
THETA FACTOR   .1745E-01UNITS/RADIAN

     .......................................
     . LOCATION OF CURRENT PHYSICAL ORIGIN .
     . X=    2.00       Y=    1.75    INCHES .
     .     FROM LOWER LEFT CORNER OF PAGE    .
     .......................................
```

```
THE SUB-
PLOT NO.   2 WITH THE TITLE

HAS BEEN COMPLETED.

PLOT ID. READS
PLOT 2      14.26.00   WED 26 AUG,1981    JOB=IN3A354 .  ISSCO   DISSPLA VER 7.5

DATA FOR PLOT'

NO. OF CURVES DRAWN 2
-----------------------------
HORIZ. AXIS LENGTH   6.5 INS.
VERT. AXIS LENGTH    7.0 INS.
-----------------------------
HORIZ. ORIGIN 0.         VERT.  ORIGIN 0.
-----------------------------
HORIZ. AXIS LINEAR
STKP SIZE  .1000E+01 UNITS/INCH
-----------------------------
VERT.  AXIS LINEAR
STEP SIZE  .1000E+01 UNITS/INCH
-----------------------------

    .....................................
    . LOCATION OF CURRENT PHYSICAL ORIGIN .
    . X=  25.00      Y=   u.ou     INCHES .
    .     FROM LOWER LEFT CORNER OF PAGE   .
    .....................................


PLOT NO.   1 WITH THE TITLE

HAS BEEN COMPLETED.

PLOT ID. READS
PLOT 1      14.26.43   WED 24 AUG,1981    JOB=IN3A354 .  ISSCO   DISSPLA VER 7.5

END DISSPLA -- 11633 VECTORS GENERATED IN     1 PLOT FRAMES.
81/08/26. 14.26.59. FILE TAPE99 IS NOW JO8 IN3AKXV.
81/08/26. 14.26.59. LENGTH IN PRUS IS                  44.
EXIT.
```

APPENDIX 4. OUTLINE OF SITING REPORT

1. PRELIMINARY PAGES

    i. Title Page

    ii. Foreword (describing authorization for siting, type equipment to be installed, principal ARTCC served, period of study, and names/titles of contributing personnel).

    iii. Distribution Page

    iv. Table of Contents

    v. List of Illustrations

2. TECHNICAL CONTENT

    I. SUMMARY REVIEW OF RESULTS AND RECOMMENDATIONS

        A. Identification of Candidate Sites

        B. Performance Comparison

            1. Coverage Capability

            2. Other Factors (e.g., false targets, lobing, clutter, tangential courses, etc.)

        C. Environmental Factors

        D. Summary Cost Comparison

        E. Site Selection Recommendations

            1. Identification of Recommended Site

            2. Coverage Deficiencies/Limitations

            3. Recommended Installation/Operational Parameters (e.g., antenna height, tilt, STC, RAG, etc.)

            4. Flight Check Recommendations

    II. SITING REQUIREMENTS

        A. ATC Requirements

            1. Area Positive Control

            2. Jet Routes

3. Airways

4. Navaids

5. Other

B. Equipment/Operational Requirements (e.g., frequency, prf, etc.)

III. PRELIMINARY INVESTIGATIONS

A. Siting Area Identification

B. Data From Preliminary Site Visit

C. Reasons for Rejecting Various Site Possibilities

D. Reasons for Selecting Sites for Detailed Survey

IV. PHYSICAL DESCRIPTION OF SITES SURVEYED

A. Location (including topographical map(s))

B. MSL Elevation

C. Site Terrain/Geological Features (incl. soil condition, slope gradients, etc.)

D. Surrounding Terrain Features (mountain, coastal, etc.)

E. Complete FAA Form 402

F. Panoramic Photographs

G. Real Estate Data

1. Acreage of land selected

2. Anticipated Area Growth (10 yrs.)

3. Easements and ROW requirements for roads, utilities, prevention of future construction, etc.

4. Name of Owner or Agent

5. Occupancy

6. Availability

7. Purchase or Lease Cost, Term

H. Meteorological/Climatological Data

V. SITE PERFORMANCE ANALYSIS

A. Screening Profile Graph

1. LOS Coverage to Fixes

2. Recommended Antenna Height

B. LOS Boundary Diagram (incl. air route coverage)

C. Vertical ARSR Coverage

1. Range Coverage to Fixes

2. Recommended Tilt Angle

D. Beacon Coverage (incl. recommended power)

E. Lobing Analysis

F. Beacon False Target Analysis

G. Clutter Analysis

1. Radar In-Clutter Coverage

2. Permanent Echoes

3. Surface Traffic

H. Tangential Course Analysis

I. Second-Time-Around Analysis

J. Summary of Recommended Parameters

VI. ACCESS/TRANSPORTATION

A. Vehicular Routes to Site(s)

1. Improvement Requirements

2. Maintenance Requirements (incl. snow removal)

B. Area Transportation

1. Vehicle Routes/Access

2. Rail Service

3. Air Service (private and commercial)

4. Freight Service

VII. UTILITY REQUIREMENTS/DATA

A. Commercial Electric Power

1. Supplier(s)

2. Plant extension requirements (show 3ϕ powerline route)

3. Estimated Time/Cost to Provide Service

B. Emergency Electric Power Requirements (incl. fuel tank capacity)

C. Communications Service (regular telephone and leased data lines)

1. Supplier(s)

2. Plant Extension Requirements (show intended cable route)

3. Estimated Time/Cost to Provide Service

4. Maintenance Availability

D. Water & Sanitary

1. Alternatives Considered (w/cost, effectiveness data backup)

2. Recommended Approach

VIII. SITE IMPROVEMENTS REQUIRED

A. Grading

B. Clearing

C. Landscaping

D. Security

IX. OTHER DATA/ANALYSES

A. RML Requirements

1. RML PATH

2. Repeater Requirements

3. Estimated RML Tower Height/Location

4. Recommended Frequencies

B. Grounding System

1. Earth Resistivity Profile

2. Preliminary Ground Design

3. Estimated Cost

X. ENVIRONMENTAL DATA/ANALYSIS

A. Noise

B. Air Quality

C. Water Quality

D. Social and Socio-Economic Impacts

E. Special Use Areas

F. Historical and Archaeological Sites

G. Flood Hazards

H. Wetlands

I. Coastal Zone Management

J. Energy Supply/Consumption Impacts

K. Construction Impacts

L. Endangered Species

M. Electromagnetic Interference/Radiation Safety

N. Visual Impacts

XI. COST ANALYSIS

A. Construction

B. Housing, Personnel, Operations

XII. EQUIPMENT AND SCHEDULE

APPENDIX 5. GLOSSARY

agl	above ground level
aoc	automatic overload control
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ASR	Airport Surveillance Radar
AT	Air Traffic
ATC	Air Traffic Control
ATCBI	Air Traffic Control Beacon Interrogator
ATCRBS	Air Traffic Control Radar Beacon System
ATD	Air Traffic Division
CFAR	Constant False Alarm Rate
cos	cosine
cp	circular polarization
csc	cosecant
css	cross-section sensitivity
DABS	Discrete Address Beacon System
dBir	decibels above isotropic level
dBm	decibels --when a power of 1 milliwatt is the reference level
DOD	Department of Defense
DOT	Department of Transportation
dte	digital target extractor
ECAC	Electromagnetic Compatibility Analysis Center
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
fm	frequency modulation
FONSI	Finding of No Significant Impact
GFM	Government-furnished material
HZ	Hertz (cycles/second)
if	intermediate frequency
IFR	instrument flight rules

ILS	Instrument Landing System
isls	improved side-lobe suppression
kW	kilowatt
los	line-of-sight
lp	linear polarization
mea	minimum en route altitude
MERF	Mobile En Route Radar Facility
mhos	reciprocal of ohms
MHz	megahertz
moca	minimum obstruction clearance altitude
mots	modulation oriented transmitter synthesis
msl	mean sea level
mtd	moving-target detector
mti	moving-target indicator
nmi	nautical mile(s)
PAR	precision-approach radar
pfa	probability of false alarm
pd	probability of detection
ppi	plan position indicator
pps	pulses per second
prf	pulse-repetition frequency
rag	range/azimuth gate
rci	radar coverage indicator
rf	radio frequency
rfi	radio-frequency interference
RML	remote microwave link
rpm	revolutions per minute
s/c	signal-to-clutter
sid	standard instrument departure
sin	sine
sls	side-lobe suppression
s/n	signal-to-noise ratio

sta	second-time-around
stc	sensitivity time control
t/r	transmitter/receiver
TRACAB	terminal radar approach control in tower cab
TRACON	terminal radar approach control
TSC	Transportation Systems Center
tv	television
USGS	U. S. Geological Survey
VOR	very-high-frequency omnidirectional radio range
VORTAC	very-high-frequency omnidirectional radio range tactical air navigation

APPENDIX 6

USER'S GUIDE TO THE FAA RADAR COVERAGE TIME SHARE PROGRAMS

INTRODUCTION

CVRG2 and CVRGlO are computer programs in the FAA's CDC time-share system which compute signal-noise ratios of radar echoes for user-selected one- or two-beam enroute or terminal surveillance radar. These programs use the radar range equation to compute the signal-noise ratios for multiple user-selected values of aircraft altitude and range, and for user-selected values of radar target cross section, site elevation, peak power, receiver sensitivity parameters, antenna tilt, and principal-plane elvation patterns for one or two antenna beams. The patterns consist of up to 54 gain values spaced one degree apart. The programs also compute upper and lower beam receiver noise temperatures, and range and elevation of the radar horizon line of sight for the given value of site elevation. CVRG2 makes the computations for a single input value of antenna tilt. CVRGlO makes the computations for ten values of antenna tilt. The user selects the nominal intermediate tilt value and the increment between each successive tilt.

The program is based on the assumption that the lower beam is used for transmission, and that one or both beams may be used for eception. It also assumes that the surrounding terrain is at mean sea level, and uses propagation refraction corresponding to 4/3 earth radius.

HOW TO OPERATE THE PROGRAM

1. Sign on at the time share terminal (see CDC Users' Manual).
   KB, user number, charge number. Then password when requested.

2. Generate and name an input data file, as described in the section below entitled Input File. Store this file in the time share system's permanent files. this step is unnecessary for ARSR-3, ARSR-2 and FPS-60, as input data files for these radars entitled ARSR-3, ARSR-3, and 'FPS-60 have already been permanently stored.

3. Call up Program CVRG2 (CVRG10 if computations for more than one value of antenna tilt are desired) as primary local file as follows:

   OLD, CVRG2 (or CVRG10)

4. Get the input data file from the time share permanent files and run the program by doing the following:

   GET, TAPES = (input data file name, either ARSR-3, ARSR-2, or FPS-60)
   READY $
   FTNTS (to enable FORTRAN computer)
   READY $
   RUN

   ($ denotes computer's automatic response)

5. The local terminal then prints the input parameters, except for the antenna pattern, with appropriate format, at the local terminal (see figure 2b), and also stores the entire set of input data and output data on a local file named TAPE7.

6. To dispose the TAPE7 data to a high speed-printer, perform the following operations at the local terminal.

```
BATCH
$RFL,0.
/RFL,20000
RFL,20000.    $
/REWIND,TAPE7
$REWIND,TAPE7
/DISPOSE,TAPE7=PRE
$DISPOSE,TAPE7 = PRE
/NULL (this takes the terminal out of the batch mode)
READY  $
```

Note: a number of runs may be disposed in this manner, and printed later using the procedure below.

7. To print the results stored in the output files at the system's high-speed printer, proceed as follows.

Turn on high-speed printer (POWER ON & START).
Activate its associated CRT data terminal.
Type in: IMPO, (user no.), (password), KB.
Operate SEND key.

The printer then prints inputs and outputs for all stored runs previously "disposed".

INPUT FILE (TWO-BEAM RADAR CASE).

The input data file is unformatted, and is comprised of a series of 129 numbers separated by commas (130 for CVRG10). A sample file is shown in figure 1. Decimal or integral input numbers may be used, except for the two cases noted below. The sequence shown is mandatory, and all items must be inserted. An explanation of the various inputs follow.

The first 108 numbers are the user's inputs for the radar antenna elevation gain patterns (in dB) for the upper (A) and lower (B) principal azimuth plane beams, starting at 9 degrees below the beam peak and spaced at one-degree intervals up to 44 degrees above the beam peak. These inputs alternate between A and B beams, starting with the A beam.

The last 22 inputs are the various radar system parameters in the following sequence:

Δh_2, Q_A, Q_B, h_1, f, F_A, F_B, B, C, I_A, I_B,

N_A, N_B, ΔR, σ, L_A, L_X, L_B, T_A, T_o, P, ΔE

where

Δh_2: The first aircraft sltitude (ft) for which signal-noise calculations sre to be made, snd the altitude step between each succeeding set of calculations. An integer value must be used. Suggested value: 2500.

Q_A, Q_B: Elevation of the nose of the upper and lower beau8 relative to the horizon (use negative values for nose position above horizon).*

hl: Site (antenna axis) elevation (feet above sea level).

f: Radar transmitter frequency (MHz).

F_A, F_B: Upper and lower beau noise figure (dB).

B: 3-dB receiver bsndwidth (kHz).

c: Bandwidth correction factor (set to 1).

I_A, I_B: Elevation angle (deg) of first data point of upper and lower antenna patterns. In the sample run, -9 degree8 below the nose is used for both beams.

N_A, N_B: Reference sngles for upper and lower beams, usually set to zero.

AR: Incremental value of target ground range parameter (nm). Integer value must be used, Suggested value8 10 for enroute radars, 3 for terminal radars.

σ: Tsrget radar cro88 section (square meters).

L_A, L_B: Upper snd lower beam receiver loss (dB).

L_X: Transmitter loss (dB).

T_A: Antenna noise temperature (100 deg K for nose of beam 2 deg above horizon).

---

*For CVRG10, these are the values for the fifth of the ten calculatlone.

T_O: Actual receiver temperature (290 deg K).

P: Peak transmitter power (kW).

vE: Increment of antenna tilt between sucessive calculations (degrees). This required for CVRG10.

INPUT FILE (ONE-BEAM CASE).

When using the program for a single-beam radar, only the lower (B) beam inputs are used. A large number (e.g., 300) is entered for F_A, and any number, usually zero for convenience, must be inserted for each upper beam gain input and for the quantities Q_A, I_A, N_A, and L_A, to allow the program to run properly.

OUTPUT PRINTOUT

During the run, some of the input data are printed at the local terminal in the format of Figure 6b to let the operator know if the program is running correctly. All input data, including the antenna patterns, and several calculated quantities, are printed on the high-speed printer, along with the tabulated signal-noise output data. The printout of the input data and out-put data are shown in figures 2a, 2b, 2c, and 3 for a CVRG2 sample run using a data input file names SN1. Aircraft range is printed out in nautical miles, aircraft altitude in feet, and signal/noise in dB.

EQUATIONS USED

The radar range equation used for the signal noise (S) calculations is:

$$S = \frac{C^2}{(4\pi)^3} \times \frac{Pa}{f^2 L_X T_S B} \times \frac{G_T \; G_R}{R^4}$$

See table 1 for an explanation of the variables. The first of the above three factors is invariable, the second includes all the single-valued data inputs, and the third includes the variable parameters.

The system noise temperature, T_S, is obtained from input variables for the cases of the upper and lower beams by:

$$T_s = T_a + 290\,(L_r - 1) + L_r T_o\,(F-1)$$

where different values are used for L_r and F in the cases of the upper (A) and lower (B) beams.

G_T and G_R are derived as follows. In the case of the lower beam, $G_T G_R = G_B^{\,2}$, and in the caae'of the upper beam, $G_T G_R = G_A G_B$, where G and G_B are the interpolated values of the upper and lower bearn gains o4tained from the input antenna gain data (see Input File section).

The values of R are computed from:

$$R = \sqrt{R_g^{\,2} + \frac{(h_2-h_1)^2}{6080^2}}$$

where Rg and H_2 are multivalued inputs, and h_1 is single valued.

The horizon range (R_h) is computed from:

$$R_h = 1.23 \sqrt{h_1}$$

The elevation angle of the horizon (θ_h) is:

$$\theta_h = 0.0108 \sqrt{2h_1} \ .$$

Table 1 Explanation of Variables

Variable	Program Name		Units
S	SIGNOS	Signal/noise ratio for 50% target detection probability	
c		Propagation velocity	m/sec
P	TXPOW	Peak transmitter power	kW
	SIGMAW	Target cross section	sq m
f	FREQ	Radar transmitter frequency	MHz
L_x	ZSYLOS	System loss factor	
L_r	ARXLOS BRXLOS	Receiver loss factor upper/lower Beam	
h_1	HIVALU	Site elevation	ft
h_2	KH2VAL	Aircraft elevation	ft
F	ANF BNF	Radar noise factors, upper/lower Beam	
B	BW	Receiver 3-dB bandwidth	kHz
R_h	RLS	Horizon range	nmi
R_g	ZRVALU	Target ground range	nmi
R	ZRVALS	Target slant range	nmi
G_T		Line of sight gain, transmit antenna	
G_R		Line of sight gain, receive antenna	
G_A	AGAIN	Line of sight gain, upper beam	
G_B	BGAIN	Line of sight gain, lower beam	
T_s	ATSVAL,BTSVAL	System noise temperature	deg K
T_A	TVALU	Antenna noise temperature	deg K
T_o	TOVALU	Physical temperature of receiver	deg K
θ_h	THETA	Angle of line of sight to horizon	deg

Figure 1. Sample Data Input Set

ANTENNA PATTERN DATA

```
0.5,2,4,5.5,6,7,5,4,12,12.2,
20,22,25.6,27.4,29.1,30.7,32,33.3,32.8,33.8,
32,32.4,30.4,30,29.7,29.6,29.5,29.8,28.8,28.7
27.5,27.7,27.1,27.5,26.6,26.5,25.3,25.6,24.6,25.4,
24,24.6,23 2,24,23.1,24.2,23.1,23.7,22.6,23.5,
22,23,22,22,21,22,21,22,22,22,
22,22,22,22,22,22,22,22,22,22,
22,22,22,21,22,21,22,21,22,21,
22,21,22,21,21,20,20,19.4,19.4,19.4,
19,17,18,16,17,15,16,14,14,13,
13,10,12,11,12,10,11,11,
```

MISCELLANEOUS INPUTS

```
2500,-6,-2,1260,1300,3.5,4,500,1,-9,-9,
0,0,10,2,1,3.1,100,290,5000,0.5
```

FIGURE 2A

ANTENNA GAIN TABLE

	UPPER BEAM			LOWER BEAM		
SEQ	DEGREES	GAIN DB	GAIN FACTOR	DEGREES	GAIN DB	GAIN FACTOR
1	-9.00	.50	1.122	-9.00	2.00	1.585
2	-8.00	4.00	2.512	-8.00	5.50	3.548
3	-7.00	6.00	3.981	-7.00	7.00	5.012
4	-6.00	5.00	3.162	-6.00	4.00	2.512
5	-5.00	12.00	15.849	-5.00	12.20	16.596
6	-3.00 4 00	20.00	100 000	-3.00 4	22.00	158.489
7		25.60	363.078		27.40	549.541
8	-2.00	29.10	812.831	-2.00	30.70	1174.898
9	-1.00	32.00	1584.893	-1.00	33.30	2137.962
10	0 00	32.80	1905.461	0.00	33.8 0	2398.833
11	l:oo	32.00	1584.893	1.00	32.40	1737.801
12	2.00	30.40	1096.478	2.00	30.00	1000.000
13	3.00	29.70	933.254	3.00	29.60	912.011
15	5.00	29.50	891.251	4.00	29.8 0	954.993
16	5.00	2728562.341		6758.5	27.70	588.844 28741.310
17	7.00	27.10	512.861	7.00	27.50	562.341
18	8.00	26.60	457.088	8.00	26.50	446.684
19	9.00	25.3 0	338.844	9.00	25.60	363.078
20	10.00	24.60	288.403	10.00	25.40	346.737
21	11.00	24.00	251.189	11.00	24.60	288.403
22	12.00	23.20	[illegible]	12.00	24.00	251.189
23	13.00	23.10	204.174	13.00	24.20	263.027
24	14.00	23.10	204.174	15.00	23.50	234.423
25	15.00	22.60		181.970		223.872
26	16.00	22.00	158.4	16.00	23.00	199.526
27	17.00	22.00	158.489	17.00	22.00	158.489
28	18.00	21.00	125.893	18.00	22.00	158.489
29	19.00	21.00	125.893	19.00.00		158.489
30	20.00	22.00	158.489	20.00	22.00	158.489
31	21.00	22.00	158.489	22.021.00		158.489
32	22.00	22.00	158.489	22.0	22.00	158.489
33	23.00	22.00	158.489	23.00	22.00	158.489
34	24.00	22.00	158.489	24.00	22.0	158.489
35	25.00	22.00		25.00	22.00	158.489
36	26.00	22.00	158.489	26.00	22.00	158.489
37	27.00	22.00	158.489	27.00	21.00	125.893
38	28.00	22.00	158.489	28.00	21.00	125.893
39	29.00	22.00	158.489	21.0029.00		125.893
40	30.00	22.00	158.489	30.00	21.00	125.893
41	31.00	22.00	158.489	31.00	21.00	125.893
42	32.00	21.00	125.893	32.00	21.00	125.893
43	33.00	21.00	125.893	33.00	20.00	100.000
44	34.00	20.00	100.000	34.00	19.40	87.096
45	35.00	19.40	87.096	35.00	19.40	87.096
46	36.00	19.00	79.433	36.0	17.00	50.119
47	37.00	18.00	63.096	37.00	16.00	39.811
48	38.00	17.00	50.119	38.00	15.00	31.623
49	39.00	16.00	39.811	39.00	14.00	25.119
50	40.00	14.00	25.119	40.00	13.00	19.953
51	41.00	13.00	19.953	41.00	10.00	10.000
52	42.00	12.00	15.849	42.00	11.00	12.589
53	43.00	12.00	15.849	43.00	10.00	10.000
54	44.00	11.00	12.589	44.00	11.00	12.589

FIGURE 2B.

```
OTHER INPUT DATA

TX POWER = 5000.00 KW      UPPER TILT REF =   -6.00 DEGREES    TARGET  SIZE   =    2.00 SQ METER
NF UPPER =     3.50 DB     LOWER TILT REF =   -2.00DEGREES    REC LOSS UPPER  =    1.00 DB
NF LOWER =     4.00 DB     UPPER LIMIT    =   -9.00DEGREES    REC LOSS LOWER  =    1.00 DB
FREQ      = 1300.00 MHZ    LOWER LIMIT    =   -9.00 DEGREES    SYSTEM  LOSS   =    3.00 DB
BANDWIDTH =  500.00 KHZ    UPPER NOSE     =    0.00 DEGREES    SITE ELEV      = 1260.00 FEET
BW FACTOR =     1.00       LOWER NOSE     =    0.00 DEGREES
```

FIGURE 2C.

```
CALCULATED VALUES
RADAR LINE OF SIGHT           =   43.66 NM
ANGLE TO RADAR HORIZON        =    -.54
REC LOSS FACTOR UPPER         =    1.26
REC LOSS FACTOR LOWER         =    1.26
NOISE FACTOR UPPER            =    2.24
NOISE FACTOR LOWER            =    2.51
SYS NOISE TEMP UPPER          =  627.33
SYS NOISE TEMP LOWER          =  127.06
SYSTEM LOSS FACTOR            =    2.00
RADAR FIXED PARAMETER UPPER = 2638.19
RADAR FIXED PARAMETER LOWER = 2276.32
```

FIGURE 3.

S/N VS RANGE/ALTITUDE/ANTENNA

TILT ANGLE = 0.00 NOSE OF LOWER BEAM= 2.00 NOSE OF UPPER BEAM = 6.00

ALT =	2500		5000		7500		10000		12500		15000		17500		20000		22500		25000	
RANGE	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER
10	41.6	60.3	53.2	56.5	56.5	53.0	52.0	48.7	49.3	45.6	45.9	[illegible]	43.2	41.3	[illegible]	39.7	38.3	36.6	37.4	36.3
20	23.0	45.7	34.7	48.0	39.8	46.9	41.2	41.6	43.9	40.7	44.1	[illegible]	41.6	37.9	[illegible]	36.5	38.2	34.7	36.4	32.6
30	14.1	37.2	28.4	41.0	27.9	41.9	32.1	40.6	33.9	37.9	34.6	[illegible]	36.5	33.7	[illegible]	33.9	36.0	33.0	35.1	31.0
40	6.7	31.2	13.1	34.0	10.9	36.3	23.1	36.9	26.5	36.1	20.1	[illegible]	29.2	31.0	[illegible]	29.3	31.2	20.0	32.0	28.7
50	1.9	26.6	7.3	29.4	10.0	31.7	16.2	32.6	19.2	33.0	22.1	[illegible]	23.7	31.2	[illegible]	29.5	25.4	27.4	25.0	25.4
60	-1.5	23.0	12.2	25.2	15.9	27.3	8.4	29.0	13.5	29.4	15.9	[illegible]	18.3	29.6	[illegible]	20.5	21.0	27.4	21.9	25.0
70	-4.3	19.0	-2.6	21.6	1.5	23.6	4.1	25.3	7.2	26.4	10.9	[illegible]	13.0	27.1	[illegible]	27.1	16.9	26.3	17.9	25.0
80	-6.7	17.0	-6.3	18.6	-2.6	20.4	[illegible]	22.0			5.6	[illegible]	8.6	24.5	[illegible]	24.0	11.9	25.0	14.0	24.0
90	-8.9	14.8	-8.8	16.8	-6.6	17.4	-3.3	19.0	-1.1	20.3	.6	[illegible]	3.8	22.1	[illegible]	27.4	8.2	22.7	9.5	22.9
100	-10.9	12.2	-10.5	13.6	-10.1	14.8	-6.9	15.3	-4.4	17.6	-2.5	[illegible]	-1.0	19.8	[illegible]	20.3	4.5	20.6	6.1	20.0
110	*****	*****	-12.3	11.4	-11.9	12.6	-10.6	13.7	-7.6	15.1	-5.6	[illegible]	-3.9	17.3	[illegible]	18.2	.2	18.6	2.6	18.9
120			-14.0	9.4	-13.6	10.5	-13.3	11.5	-11.0	12.7	-8.6	[illegible]	-6.8	14.9	[illegible]	15.0	-4.1	16.7	-1.5	17.1
130	*****	*****	-15.6	7.8	-15.2	8.6	-14.9	9.5	-14.6	10.4	-11.6	[illegible]	-9.6	12.7	[illegible]	13.6	-6.7	14.5	-5.6	15.2
140			*****	*****	-16.7	6.7	-16.3	7.7	-16.1	8.6	-15.0	[illegible]	-12.5	10.6	[illegible]	11.5	-9.2	[illegible]	-8.0	13.0
150	*****	*****	*****	*****	*****	*****	-17.7	5.9	-17.4	6.0	-17.2	[illegible]	-15.6	8.5	[illegible]	9.5	-11.8	[illegible]	-10.4	11.8
160	*****	*****	*****	*****	*****	*****	-19.0	4.2	-18.7	5.1	-18.5	[illegible]	-18.3	6.6	[illegible]	7.5	-14.4	[illegible]	-12.9	9.5
170	*****	*****	*****	*****	*****	*****	*****	*****	-20.0	3.4	-19.7	[illegible]	-19.5	5.0	[illegible]	5.6	-17.3	6.5	-15.4	7.4
180	*****	*****	*****	*****	*****	*****	*****	*****	-21.2	1.8	-20.9	[illegible]	-20.7	3.4	[illegible]	4.1	-20.3	4.7	-18.2	6.6
190	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	-22.1	[illegible]	-21.8	1.0	[illegible]	2.5	-21.4	3.2	-21.8	3.4
200	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	[illegible]	-22.9	.3	[illegible]	1.0	-22.5	1.7	-22.3	0.3
210	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	[illegible]	-.4	-23.5	.2	-23.3	.0
220	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	-24.5	-1.2	-24.3	-.6
230	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	-25.3	-2.0
240	*****			*****			*****			*****		*****			*****	*****	*****	*****	*****	*****
250	*****	*****	*****	*****	*****	*****	**								*****	*****	*****	*****	*****	*****

ALT =	27500		30000		32500		35000		37500		40000		42500		45000		47500		50000	
RANGE	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER
10	36.5	36.1	35.7	35.0	36.2	35.5	34.9	33.3	34.6	32.9	34.3	32.6	33.0	32.1	32.2	29.1	31.0	27.6	27.2	22.0
20	34.6	31.9	33.2	30.1	31.9	29.1	30.6	28.9	29.4	28.0	28.1	27.1	26.0	25.4	26.2	24.5	25.7	24.4	25.0	24.0
30	33.0	29.7	32.3	29.4	31.5	28.2	30.4	26.7	29.1	25.3	28.0	25.0	26.9	24.0	26.0	22.0	25.1	22.0	24.3	22.0
40	32.5	29.0	31.7	28.0	30.5	26.6	29.1	25.5	27.8	24.6	27.3	24.4	26.7	23.5	25.9	22.3	25.0	21.3	24.1	20.3
50	27.1	25.1	27.9	24.0	28.3	24.9	28.7	25.1	27.9	24.1	26.9	23.0	25.0	22.1	24.5	21.1	23.9	20.7	23.4	20.0
60	22.2	23.9	22.6	22.3	23.7	22.0	24.5	21.6	24.9	21.7	25.3	21.0	25.4	21.0	24.7	21.0	24.0	20.1	23.1	19.0
70	18.7	24.2	19.3	22.0	19.6	21.1	19.0	19.6	20.0	19.4	21.5	19.1	22.0	18.9	22.4	19.1	22.7	19.2	22.7	19.1
80	15.2	23.8	15.9	22.6	16.6	21.5	17.1	20.5	17.2	18.0	17.3	17.4	18.2	17.1	18.9	16.9	19.5	16.6	19.0	16.7
90	11.3	22.5	12.6	21.8	13.4	21.1	14.0	20.3	14.6	19.3	15.0	18.1	15.2	16.0	15.1	15.3	16.0	15.1	16.6	14.9
100	7.3	21.0	8.7	21.0	10.2	20.4	11.2	19.7	11.0	19.0	12.3	18.3	12.9	17.3	13.2	16.3	13.3	15.1	13.3	15.0
110	4.1	19.1	5.3	19.5	6.3	19.8	7.9	19.0	9.0	18.4	9.7	17.0	10.3	17.2	10.7	16.8	11.2	15.6	11.6	14.7
120	.7	17.3	2.3	17.5	3.4	17.7	4.4	17.9	5.7	17.8	6.9	17.3	7.0	16.7	8.4	16.2	8.8	15.6	9.3	14.9
130	-3.3	15.7	-1.0	15.9	.5	16.1	1.7	16.2	2.6	16.4	3.4	16.6	4.9	16.2	5.9	15.7	6.6	15.2	7.1	14.7
140	-7.0	13.9	-5.1	14.4	-2.0	14.6	-1.2	14.7	-.8	14.9	.9	15.1	1.7	15.2	2.0	15.1	4.0	14.7	4.0	14.5
150	-9.5	11.9	-8.3	12.6	-7.0	13.1	-4.5	13.3	-2.9	13.5	-1.7	13.6	-.7	13.0	.1	13.9	.0	14.1	2.0	13.0
160	-11.6	10.0	-10.6	10.7	-9.6	11.3	-8.7	11.9	-6.3	12.1	-4.5	12.3	-3.3	12.4	-2.3	12.6	-1.6	12.7	-.7	12.0
170	-14.0	8.7	-17.0	8.9	-11.7	9.5	-10.0	10.2	-10.0	10.7	-8.1	11.0	-6.2	11.2	-4.9	11.3	-3.0	11.0	-3.0	11.6
180	[illegible]	6.4	-15.1	7.1	-13.9	7.8	-12.9	8.4	-12.0	9.0	-11.3	9.6	-10.0	10.0	-7.9	10.1	-6.6	10.3	-5.4	10.4
190	[illegible]	4.6	-17.6	5.4	-16.2	6.1	-15.1	6.7	-14.1	7.3	[illegible]	7.9	-12.5	8.4	-11.7	8.9	-9.7	9.1	-8.1	9.2
200	[illegible]	2.9	-20.3	3.6	-18.6	4.4	-17.3	5.1	-16.2	5.7	[illegible]	6.3	-14.4	[illegible]	-13.6	7.3	-12.9	7.0	-11.6	[illegible]
210	[illegible]	1.4	-23.0	2.0	-21.3	2.7	-19.7	3.4	-18.4	4.1	[illegible]	4.7	-16.4	[illegible]	-15.6	5.0	-14.6	6.3	-14.1	6.0
220	[illegible]	.8	-24.0	.6	-23.0	1.1	-22.5	1.2	-20.9	2.5	[illegible]	3.1	-19.5	[illegible]	-17.5	4.2	-16.7	4.0	-15.9	5.3
230	[illegible]	-1.4	-24.9	-.8	-24.8	-.3	-24.6	.2	-23.6	.8	[illegible]	[illegible]	-20.7	[illegible]	-19.6	2.7	-19.7	3.3	-17.0	3.0
240	[illegible]	-2.7	-25.7	-2.2	-25.7	-1.6	-25.5	-1.1	-25.4	-.6	[illegible]	-.1	-23.2	[illegible]	-21.9	1.2	-20.7	1.0	-19.4	2.3
250	*****	*****	-26.0	-3.5	-26.6	-2.9	-26.4	-2.4	-26.3	-1.9	[illegible]	-1.4	-26.0	[illegible]	-24.4	-.4	-23.0	.2	-21.9	.0

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