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Radar Beacon Transponder (RBX) Installation and Siting Criteria

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16. Abstract

The Radar Beacon Transponder (RBX) is a ground-based facility used in conjunction with other elements of the Active Beacon Collision Avoidance System (BCAS) to control the threat detection sensitivity level of BCAS aircraft and to convey displayed Resolution Advisories from the BCAS aircraft to the local ATC terminal facility.

This paper describes the mechanisms of specular multipath reflection and signal shadowing, and discusses their impact on the RBX link power budget. Criteria for choice of RBX antenna height and location are presented.

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CONTENTS

ILLUSTRATIONS

RBX SITING CRITERIA

1. Introduction

A Radar Beacon Transponder (RBX) is a ground-based facility used in conjunction with other elements of the Active Beacon Collision Avoidance System (BCAS) to control the threat detection sensitivity level of BCAS aircraft and to convey displayed resolution advisories from the BCAS aircraft to the local ATC terminal facility (Ref. 1). Desensitization of the BCAS threat detection parameters is necessary in regions of high traffic density to reduce the number of unwanted alarms.

Control of the BCAS sensitivity level and the transfer to ATC of displayed resolution advisories will be accomplished by one or more RBX ground stations located within a terminal control area. In most areas the required coverage can be achieved with a single RBX centrally located near the terminal airport. In extended areas, such as the Los Angeles Basin, additional outlying RBX's may be required to achieve the desired coverage.

The character of the terrain and the dimensions and location of man-made obstructions surrounding the RBX antenna can significantly alter the RBX link signal levels and degrade the RBX performance at low elevation angles. Consequently, these environmental influences should be considered, whenever possible, in the RBX site selection process. This paper describes the mechanism of specular multipath reflections and the shadowing by man-made obstructions and discusses their impact on the RBX link power budget. Criteria for choosing antenna height and location to reduce the degrading influence of the environment are presented. In addition to the siting criteria discussed, most of the information contained in the FAA siting handbook for ATCRBS (Ref. 2) can be applied equally well to the RBX. Figures 3-6 in this document were derived from Reference 2.

In some cases RBX site selection will be determined by factors other than the characteristics of the surrounding environment. An example is the possible requirement that an airport-sited RBX be collocated with an existing ATCRBS terminal sensor. For this configuration the RBX antenna would be mounted either on the ATCRBS tower structure or in close proximity to it and the only means available for reduction of environmentally-induced signal fades would then be the choice of RBX antenna height. This option could also be seriously limited because of airport height restrictions and because of obstructing the view of nearby ATCRBS antennas.

2. RBX Coverage Requirement

The RBX is required to provide reliable performance for BCAS aircraft to a range of 50 nmi. Reliable performance implies that there be sufficient signal-to-noise ratio (S/N) on both the uplink and downlink at 50 nmi range to provide the reply probability specified in the RBX Engineering Requirement (Ref. 3). In an ideal environment (i.e. one which does not cause antenna lobing fades, signal blockage or interference) and with the RBX equipment

characteristics specified in the engineering requirement, both the uplink and downlink signal levels are expected to exceed the minimum required signal level by a margin of 6 dB (Ref. 1). The ability to re-interrogate in the event of a miss will increase the effective margin by another 1.5 dB. Thus the total margin available to compensate for the fades due to multipath, shadowing and the orientation of the aircraft antenna is about 7.5 dB. Since the fade of a diversity-equipped aircraft antenna is not expected to exceed 1.5 dB more than 5% of the time, the remaining margin available to offset the effect of RBX antenna lobing nulls and shadowing is approximately 6 dB. In order to keep these fades within the limits necessary for acceptable RBX performance, the RBX antenna location and height must be carefully selected.

3. Effect of Antenna Lobing on RBX Signal Level.

The free-space elevation gain pattern of an antenna is altered as a result of the interaction between the direct signal and interfering multipath signals reflected by the surrounding terrain. Figure 1 illustrates the geometrical relationship between the direct and reflected signal paths for two different antenna heights. The effect of the combination of the direct and reflected signals results in a succession of lobes (in-phase interference) and nulls (out-of-phase interference) in the elevation pattern of the antenna as a function of elevation angle. Figure 2 illustrates an effective elevation pattern of an RBX antenna situated 55 feet above a perfectly flat surface of infinite extent. The environmental factors that influence the position and depth of the first one or two major nulls are of principal interest in an RBX siting exercise since the presence of these nulls will affect the maximum range capability of the RBX.

The depth of the nulls are determined by the magnitude of the reflected signal relative to the direct signal. In addition, the null depths are influenced by the underside cutoff rate of the elevation pattern, the reflection coefficient of the surface surrounding the reflection point, the degree to which the surface behaves as a coherent specular reflector, and the amount of reflected signal blockage. Figure 2 shows the envelope of the nulls that would result from a water surface and a grass surface condition. These two surfaces represent opposite extremes in terms of the reflection coefficients likely to be encountered by the RBX. The position and spacing of the nulls are inversely proportional to the height of the antenna above the reflecting surface as illustrated in Fig. 3. For a given surface, a change in antenna height will cause the points of the nulls to follow the envelope curve depicted in Fig. 2. As seen from Fig. 1, antenna height will also determine the point at which the reflections occur. For example, an increase in antenna height will not only decrease the elevation angle at which a null occurs, but will also increase the range of the corresponding reflection point. Thus antenna height is an important consideration not only with regard to the position of the disruptive null, but also with regard to the location of the reflection point. In many instances an antenna height could be chosen such
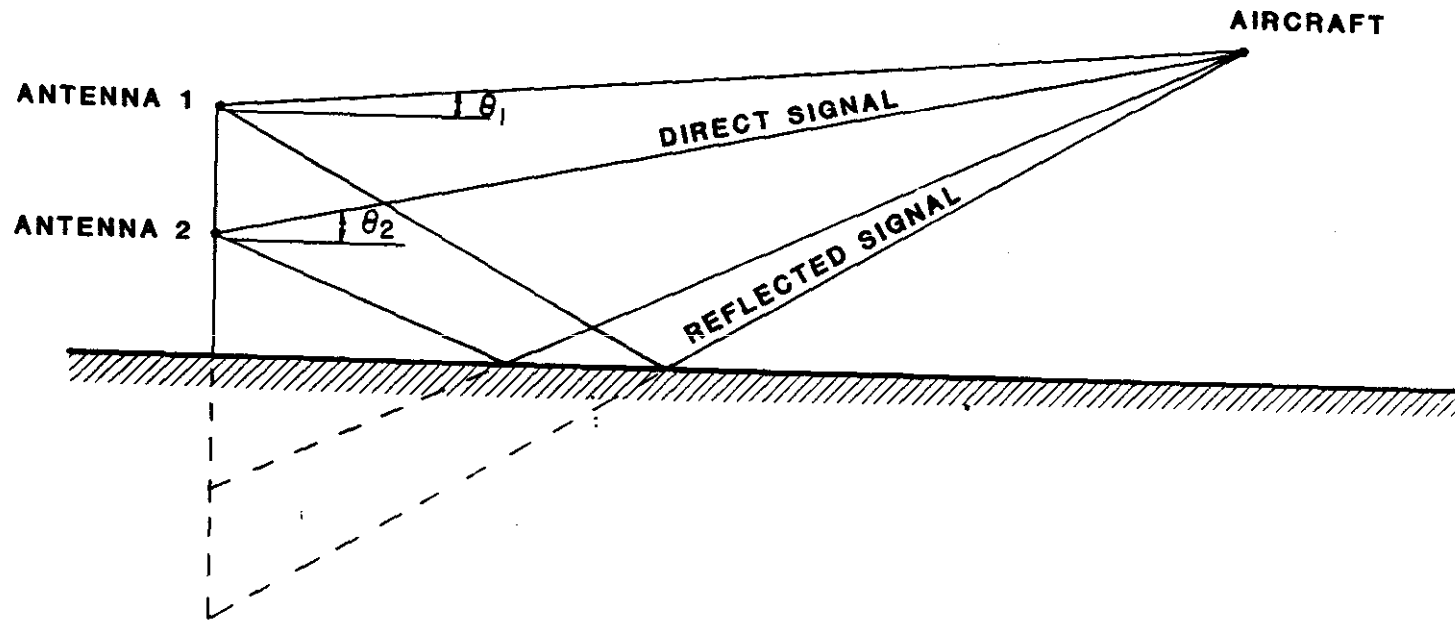
2

Fig. 1. Vertical lobing path geometry for two separate antenna heights.

3

FREE SPACE GAIN

ENVELOPE OF NULLS FOR A
WATER SURFACE

ENVELOPE OF NULLS FOR A
GRASS SURFACE

CONDITIONS: FLAT EARTH OF INFINITE EXTENT
ANTENNA HEIGHT 55 FEET
ANTENNA LOWER EDGE CUTOFF 2 dB/DEG.

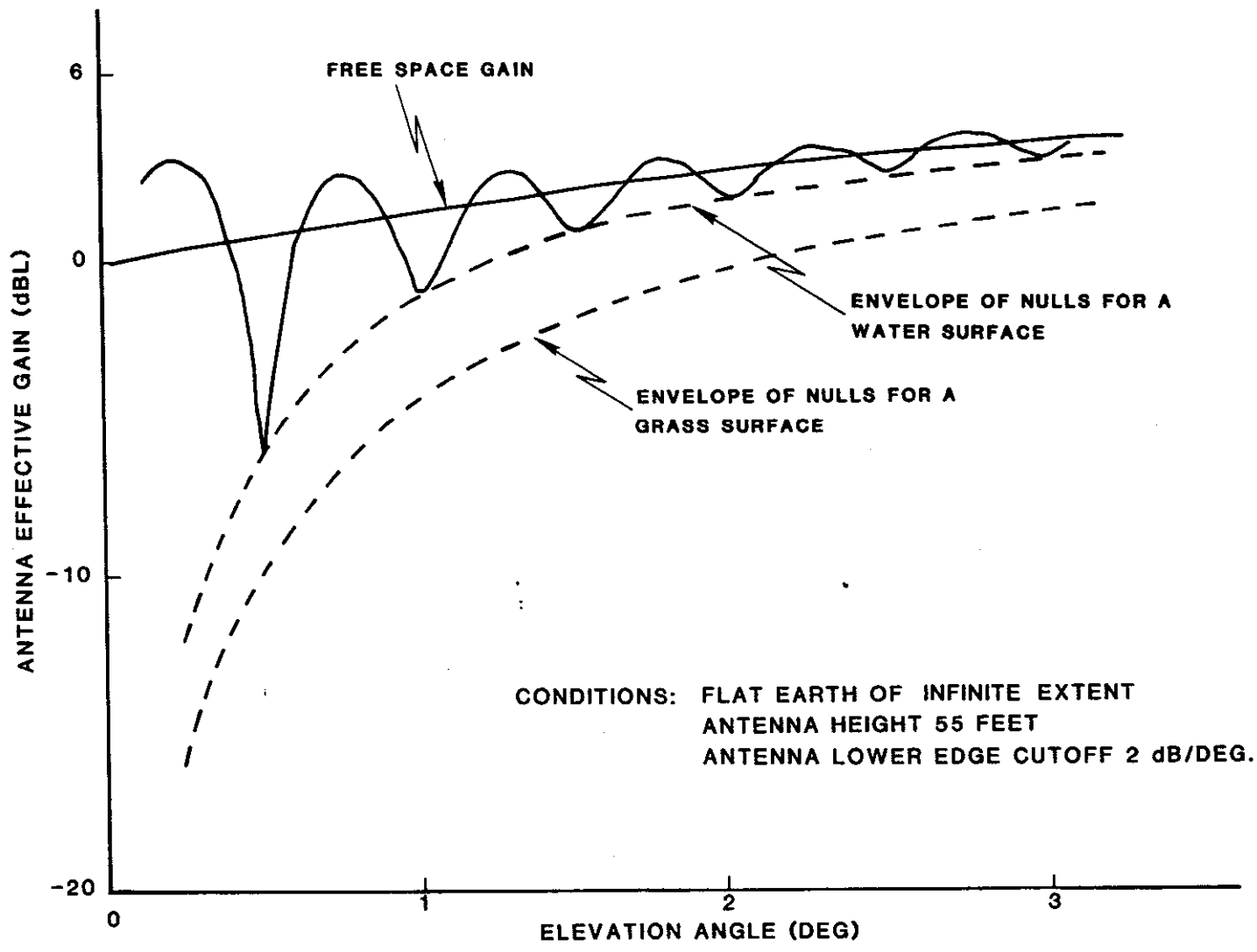ANTENNA EFFECTIVE GAIN (dBL)

ELEVATION ANGLE (DEG)

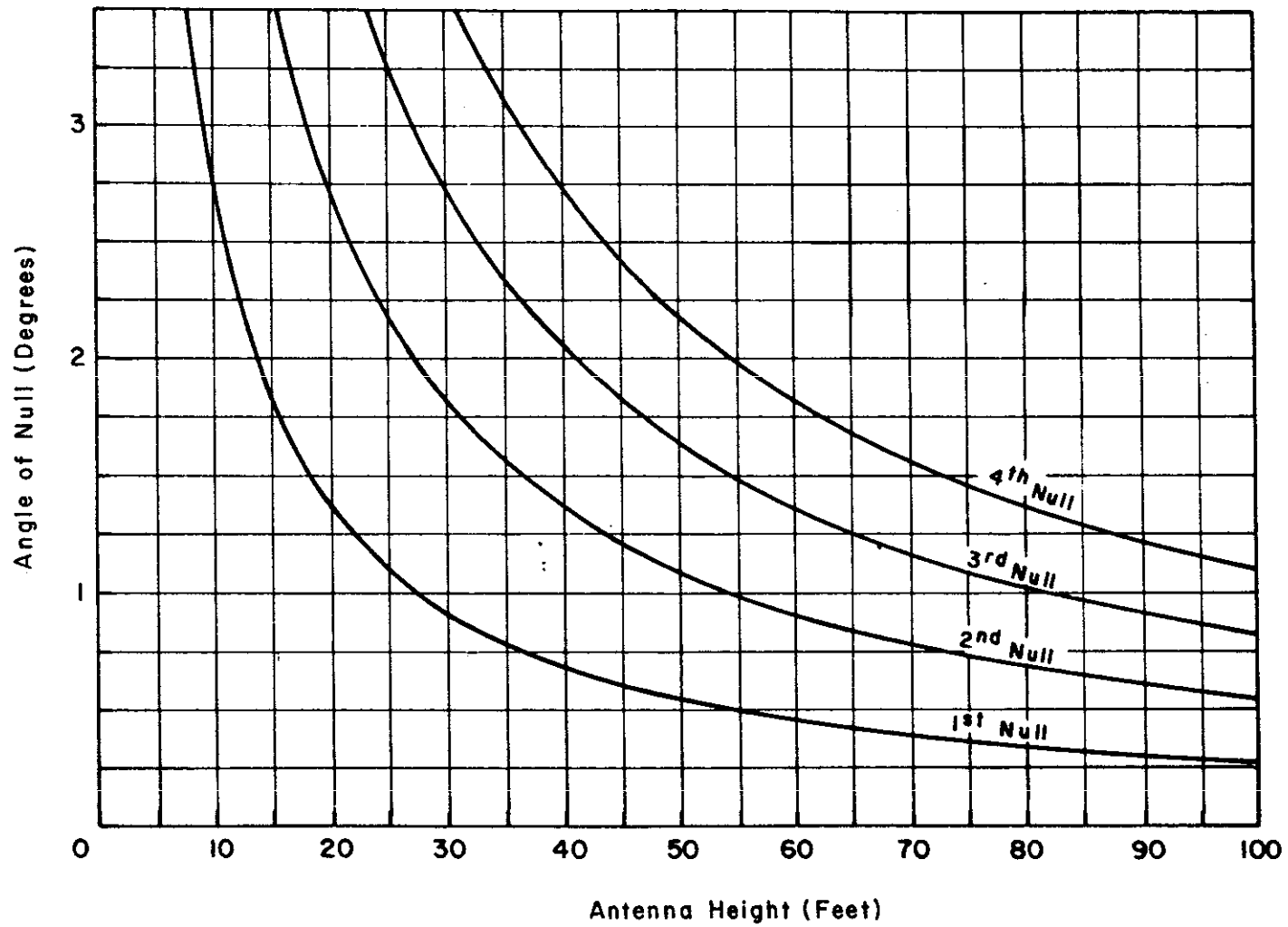Fig. 2. Effective gain of a 5-foot omni antenna.

Fig. 3. Position of null angles.

that the reflection point corresponding to the major null is in a region which causes little reflected energy.

Knowledge of the actual size of the surface area which contributes to the reflected energy is important in understanding the relationship between antenna location and height and the resulting pattern nulls. Instead of being generated from a single reflection point as depicted by the ray model in Fig. 1, most of the reflected energy along any given path is the result of a number of reflections over a finite area of surface called the first Fresnel diffraction zone. Contributions to the total energy are heaviest at the center of this area and diminish towards the edge. Reflections outside of this area contribute very little to the reflected wave front in question. The relationship between the location and dimension of the first Fresnel zone and the antenna height is plotted in Fig. 4 for the first null, and in Fig. 5 for the second null. As expected, the Fresnel zone moves away from the antenna as its height is increased. The severity of each null in the effective antenna pattern will depend on the characteristics of the surface (reflection coefficient) and on the size and number of irregularities or obstructions in the corresponding Fresnel region.

A smooth surface such as that assumed for the example illustrated in Figure 1, will generate a specular reflection due to the many individual coherent reflections within the Fresnel zone. A calm sea, a body of water, an expanse of desert or a runway area are obvious examples of smooth terrain that produce the largest specular reflections. The corresponding null depths are determined principally by the reflection coefficient of the surface and would fall somewhere between the two extremes illustrated in Fig. 1. In most cases the terrain surrounding an RBX will consist of irregularities such as buildings, trees and fences which tend to scatter the reflected signal and prevent the formation of a coherent wave front. A criterion for determining whether a surface is a specular (smooth) reflector or a diffuse (rough) reflector is based on the relationship between the extent of the peak-to-valley excursions of the surface and the reflection grazing angle. For targets at long range the grazing angle can be considered equal to the elevation angle of the target. If the peak-to-valley excursion for a given grazing angle is such as to produce a phase difference of more than 45 degrees between the reflection from the peak and the reflection from the valley, then the net reflection is incoherent, the net signal level is reduced, and the surface may be considered diffuse (rough). A net phase difference of less than 45 degrees will produce a wave front that appears to have been reflected from a specular (smooth) surface. The peak excursion (Δh) of a surface can be compared to a critical height (Δh_c) which just produces a net phase difference of 45 degrees at a given grazing angle (Ψ) to determine whether the surface is smooth or rough. The relationship between the critical height and the grazing angle is illustrated in Fig. 6. Note that, since the critical height is inversely proportional to the grazing angle (or elevation angle), an increase in antenna height will require a greater degree of surface roughness within the Fresnel zone to maintain the same level of reflection.
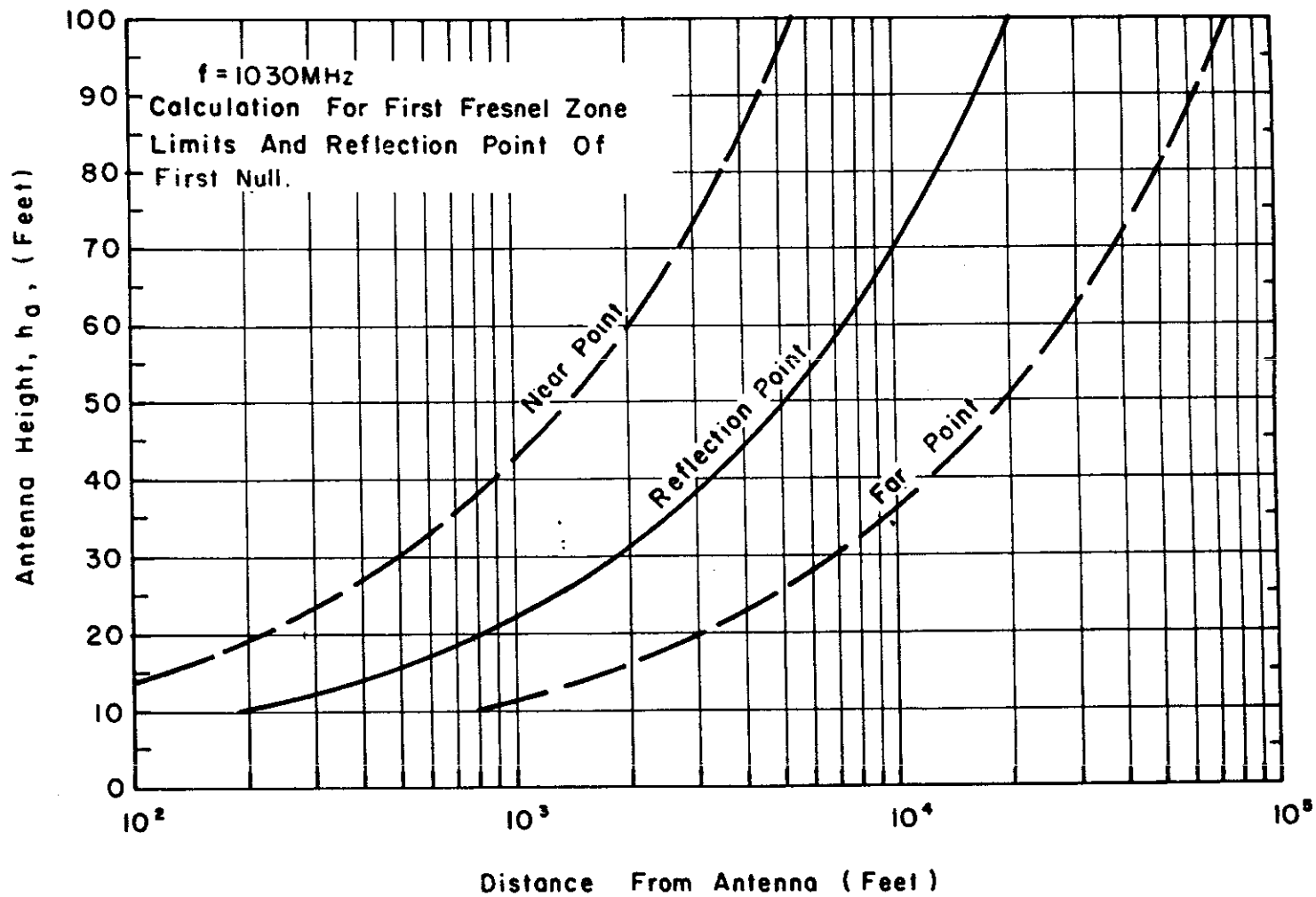
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The chart axes and labels read:

- Y-axis: Antenna Height, h_a , (Feet) — scaled 0 to 100
- X-axis: Distance From Antenna (Feet) — scaled 10^2 to 10^5

Text within the chart:

f = 1030 MHz
Calculation For First Fresnel Zone
Limits And Reflection Point Of
First Null.

Curve labels: Near Point, Reflection Point, Far Point

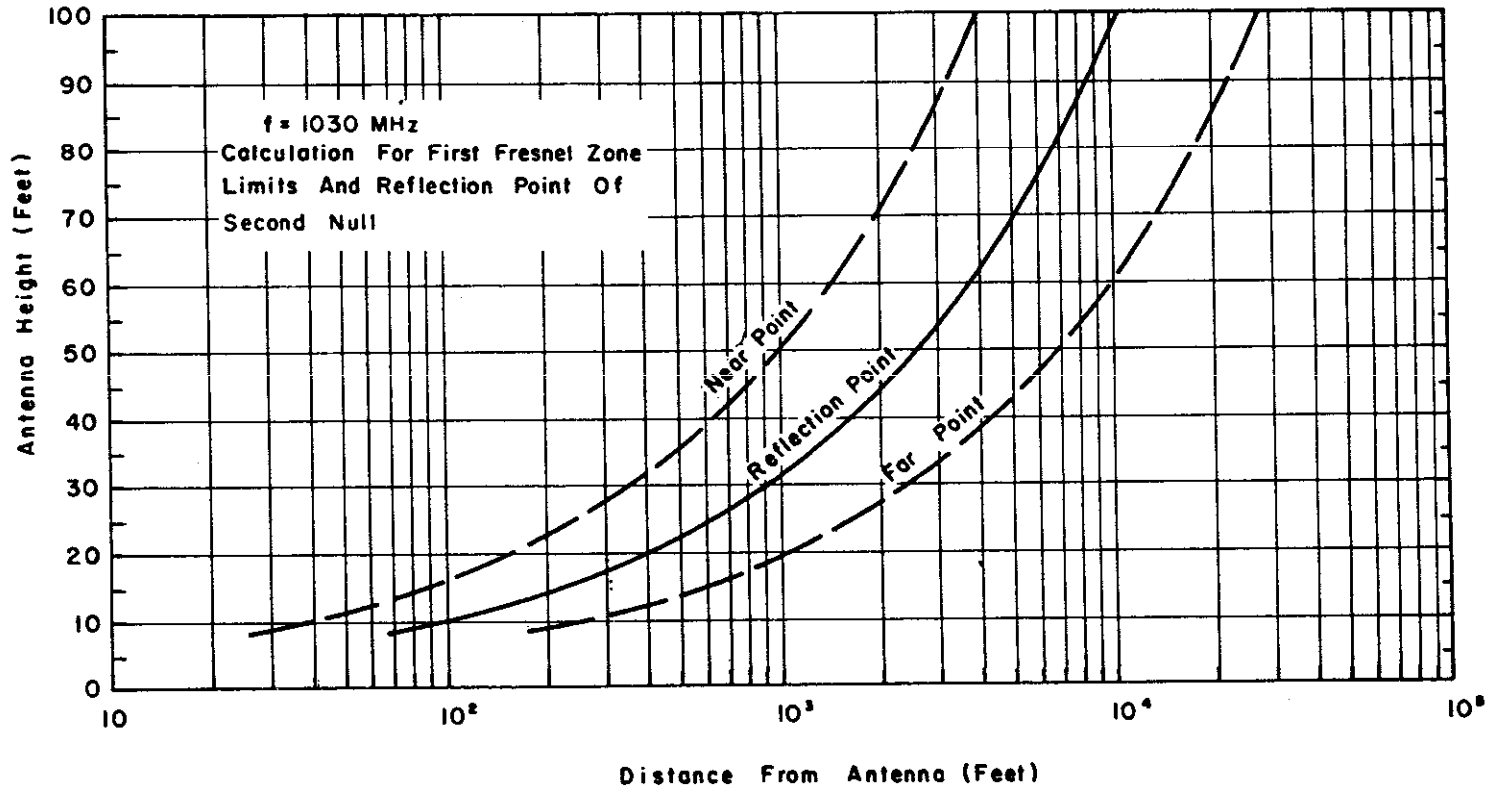Fig. 4. First null reflection point location.

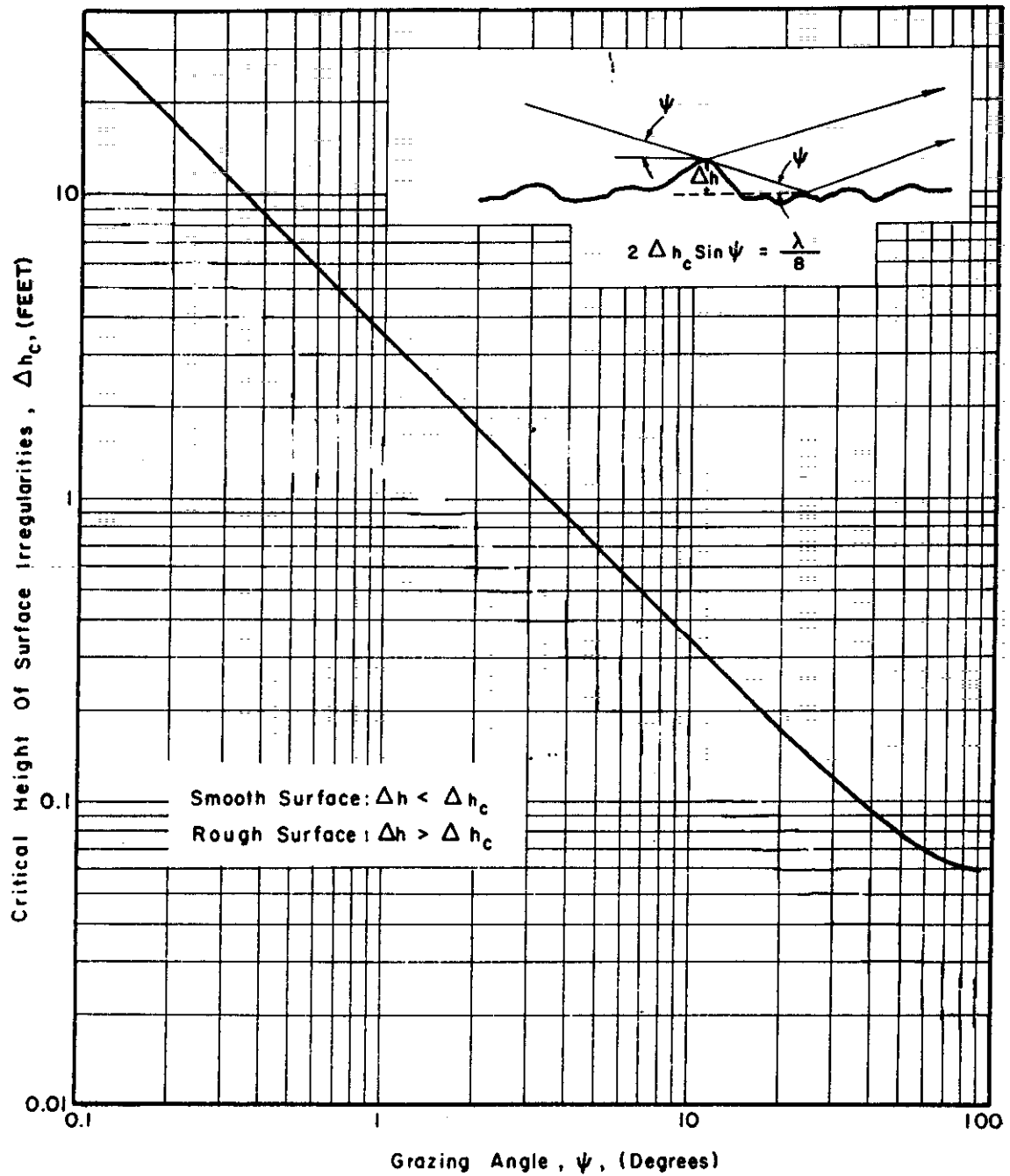Fig. 5.   Second null reflection point location.

Fig. 6. Surface roughness criterion.

9

In addition to the scattering properties of an intervening reflective surface, other terrain features such as hills, large structures and natural growth contribute to the reduction of reflected signals. The existence of hills and buildings within the Fresnel zone act to block the reflected signal and prevent the formation of nulls. Natural growth such as trees and tall grass tend to reduce the severity of the nulls by absorbing some of the reflected energy.

4. Effect of Shadowing on the RBX Signal Level

The low-angle coverage of the RBX will be affected by the existence of man-made obstructions within the direct signal line-of-sight. Obstructions of relatively simple geometric design such as buildings, towers and smokestacks, when situated in line with the direct signal path, will cause signal fades that can be reasonably well characterized.

The degree to which these obstructions impact the low-angle coverage of the RBX depends on their number, proximity, and vertical and horizontal dimensions. Many terminal airports in heavily populated urban areas are located near buildings and towers which extend to a few degrees elevation. As an example, Fig. 7 illustrates the Boston skyline as seen from the ASR at Logan Airport. Most of the buildings in one particular 11 degree azimuth sector exceed 1 degree elevation and some extend to 2.5 degrees. The low angle coverage of an airport-sited RBX could be severely compromised by such an environment.

The character and degree of signal fading that would be caused by an isolated building is illustrated in Fig. 8 (Ref.4). The value of fading is presented as a function of the lateral position of an aircraft well below and behind the building. In this example the signal fade is that which would be observed by an RBX at the Logan ASR site as a result of blockage by the Prudential Building in Boston. This building is 200 feet wide, 22,000 feet from the RBX and extends to 2 degrees elevation. The aircraft is assumed to be at a range much greater than the range to the building. The oscillatory nature of the fade verses aircraft position is due to the vector addition of signals diffracted by both edges of the building and is characteristic of all isolated and geometrically simple structures. The RBX azimuth angle subtended by an obstruction will determine the frequency of the oscillations in the pattern and the depth of the nulls. An increase in building width and/or a decrease in the RBX-to-building range will result in deeper fades and will increase the number of fade nulls. Figure 9 is a plot of the approximate relationship between the value of the deepest null and the building range for three different building widths. Generally the fade for a target line-of-sight midway between the edges of the building is approximately one-half the value of the deepest fade. For siting purposes this midrange fade value can be considered an average representation of the fade that would be encountered as a result of blockage by an isolated building.

5. RBX Siting Considerations and Recommendations

It is evident from the previous discussions that the 6 dB signal margin in the RBX link power budget will not be enough to compensate for
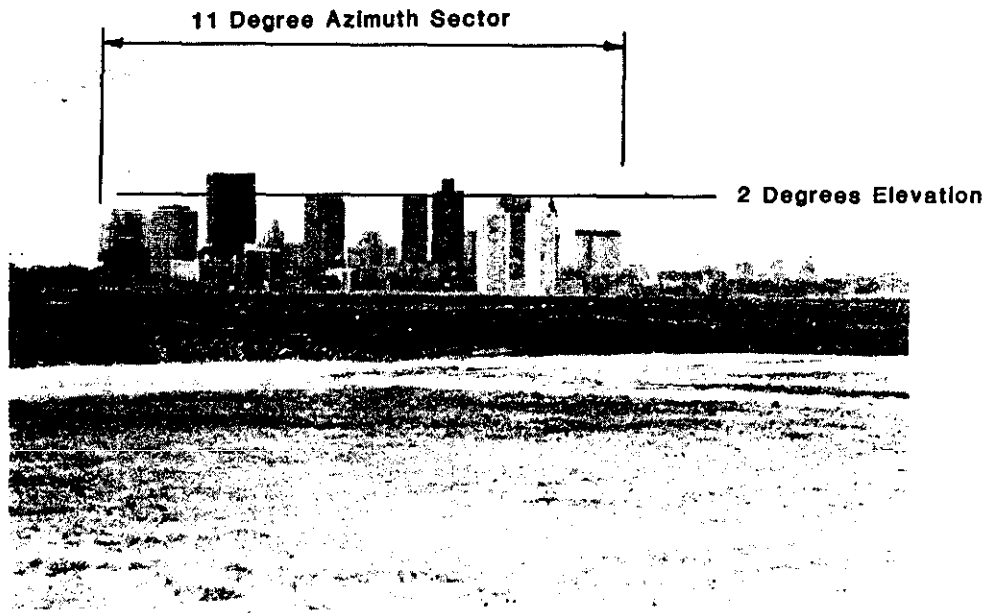
10

Fig. 7. Highrise buildings (part of Boston skyline as seen from Logan Airport).
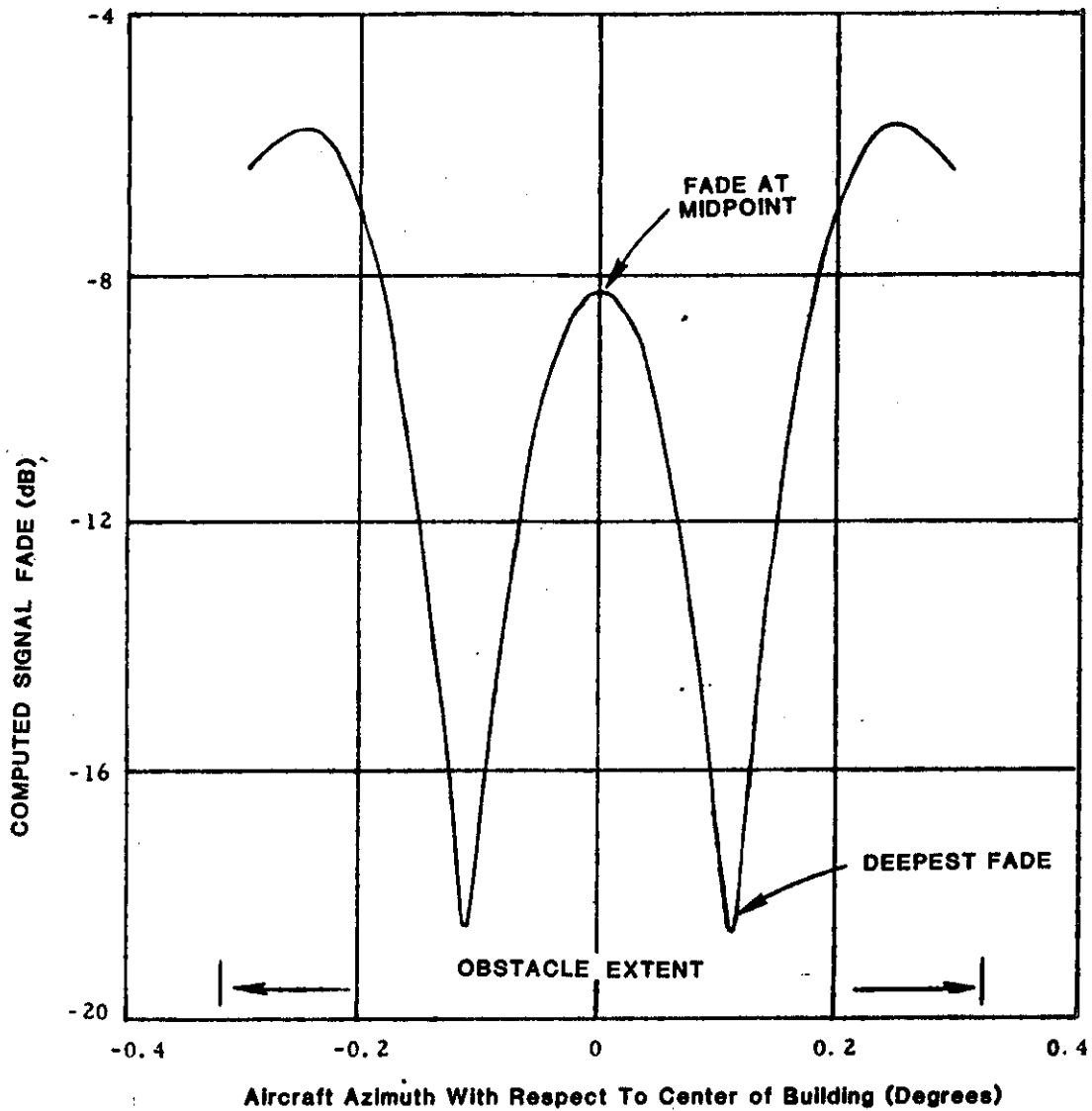
Fig. 8. Fade cast by the shadow of the Prudential Building as seen from Logan Airport.
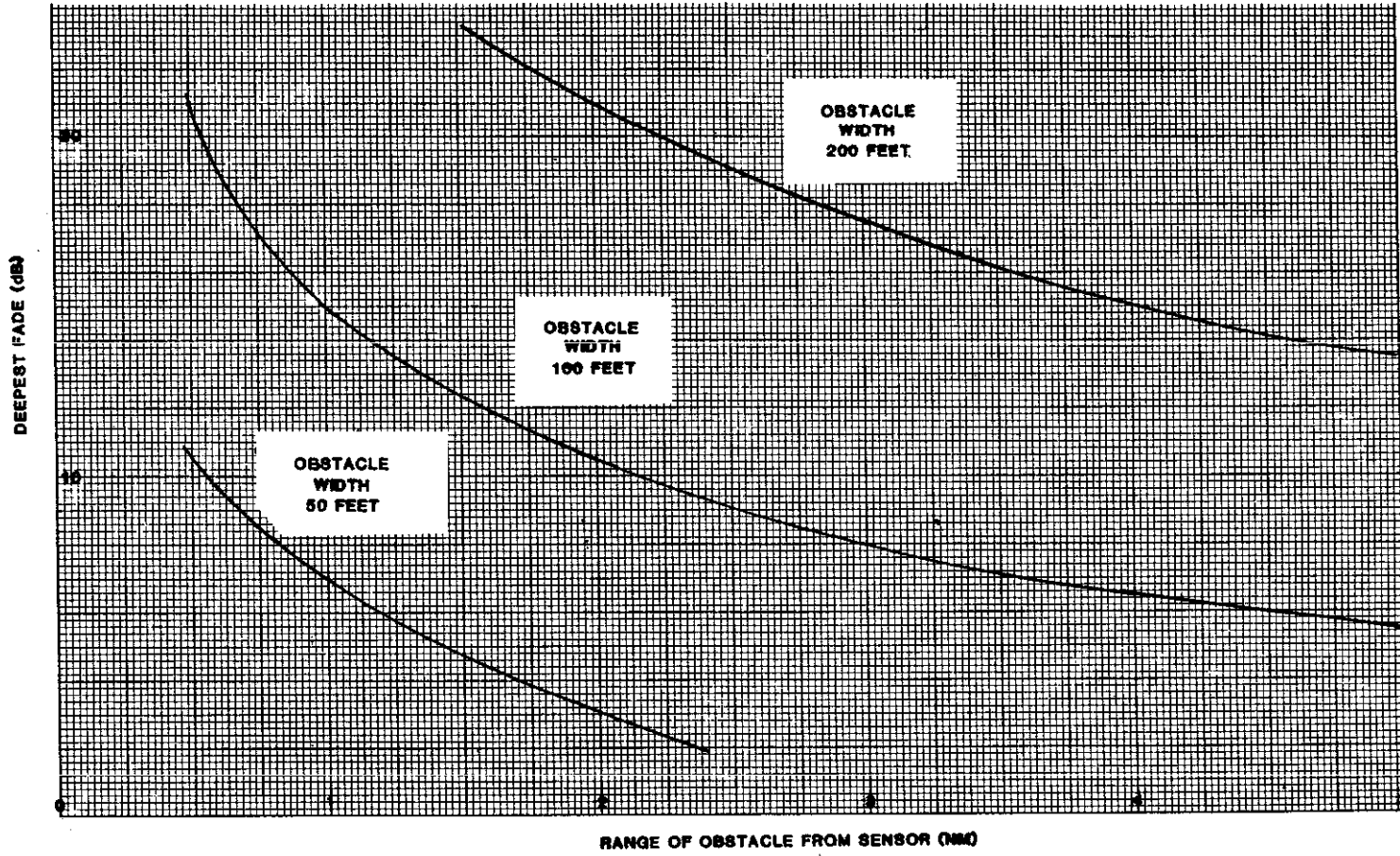
Fig. 9. Envelope of deepest fade nulls caused by an obstacle as a function of obstacle range.

lobing fades or signal blockage unless the RBX site is carefully selected. Occasionally an ideal location may not be available, or site selection may have to be based on non-environmental considerations such as cost or accessibility. In such cases the RBX performance may suffer depending on the character of the surrounding environment.

If the RBX is collocated with an ATCRBS terminal sensor in a heavily populated metropolitan area, it is likely to experience occasional link failures for long-range targets at certain azimuth angles. For instance, if a 40 foot high RBX antenna were situated adjacent to an expanse of flat runway surface extending out to 2 nmi, Figs. 2, 3 and 4 indicate that a lobing null of -8dB will occur at about 0.7 degrees elevation. This would result in a very marginal link reliability for an aircraft at 50-nmi range and 5000-foot altitude. Assuming that coverage below 0.5 degrees elevation is not an important requirement, the situation could be improved by raising the antenna height to 60 feet. This would position the first null slightly below 0.5 degrees elevation. Also the center of the Fresnel zone for the first null would be relocated approximately 1 nmi away and possibly in a region which is non-specular. Any additional increase in height would have to take into account the presence of the second null.

Tall metropolitan buildings in the vicinity of the airport-sited RBX could result in shadowing fades at elevations below 2 degrees that are severe enough to cause definite link failures. Unlike the situation with antenna lobing, it would be unrealistic to attempt to raise the antenna high enough to clear these obstructions. The duration of a particular link failure (i.e. how long the aircraft remains behind the building) depends on the elevation angle of the aircraft, its cross-range or altitude rate and the dimensions of the building. If a BCAS aircraft does not clear the obstruction within the 12-second coast period, it will drop its track on the RBX and the RBX will not be able to control the BCAS sensitivity level.

For an RBX whose location and height is not constrained by non-environmental factors, the principal siting considerations relating to antenna lobing nulls and shadowing is the angular position of the nulls, the area illuminated by the Fresnel zones and the relative distance and height of obstructions. The position of the nulls are determined by the height of the antenna which also determines the surface area causing the reflections. The characteristics of the reflecting surface, in turn, determine the depth of the nulls. In a region surrounded by terrain that can be considered flat according to Section 2, and which extends out for a considerable distance, the lobing structure will approximate that illustrated in Fig. 2. In this situation the only alternative is the selection of an antenna height that positions the first null either below the minimum elevation angle coverage requirement ($>$ 60 feet), or at an elevation angle that results in an acceptable null depth ($\approx$ 25 feet). Heights above 60 feet or below 25 feet should take into account the effect of the second null and of surrounding obstructions repectively. Most regions will consist of areas containing irregular terrain and/or obstructions which tend to break-up or disperse reflections. Site selection can take advantage of this by locating the

antenna position and height such that the first, and possibly the second-null Fresnel zones, fall within a non-specular surface area for most of the radials. Most metropolitan airport areas tend to become "non-flat" in all directions 20,000 feet from the airport sensor. An RBX located a few miles from the airport surface would have a distinct advantage in being able to reduce the depth of lobing nulls.

Serious fades caused by an obstruction can be reduced or eliminated by raising the RBX antenna to clear the obstruction or by locating the RBX at an appropriate distance from the obstruction. The range of an obstruction of given width is inversely related to the amount of shadowing it causes, thus the farther away the RBX can be located from an obstruction the less the signal fade. For example, in order to reduce the mid-range or likely fade from a 100 foot wide building to an acceptable value of 3 dB, the RBX would have to be located 4.5 nmi away.

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