MULTIPATH EFFECTS
IN
DOPPLER MLS

by

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Only Paragraphs 3 and 4 are included in this reprint. These paragraphs present details on airport multipath.

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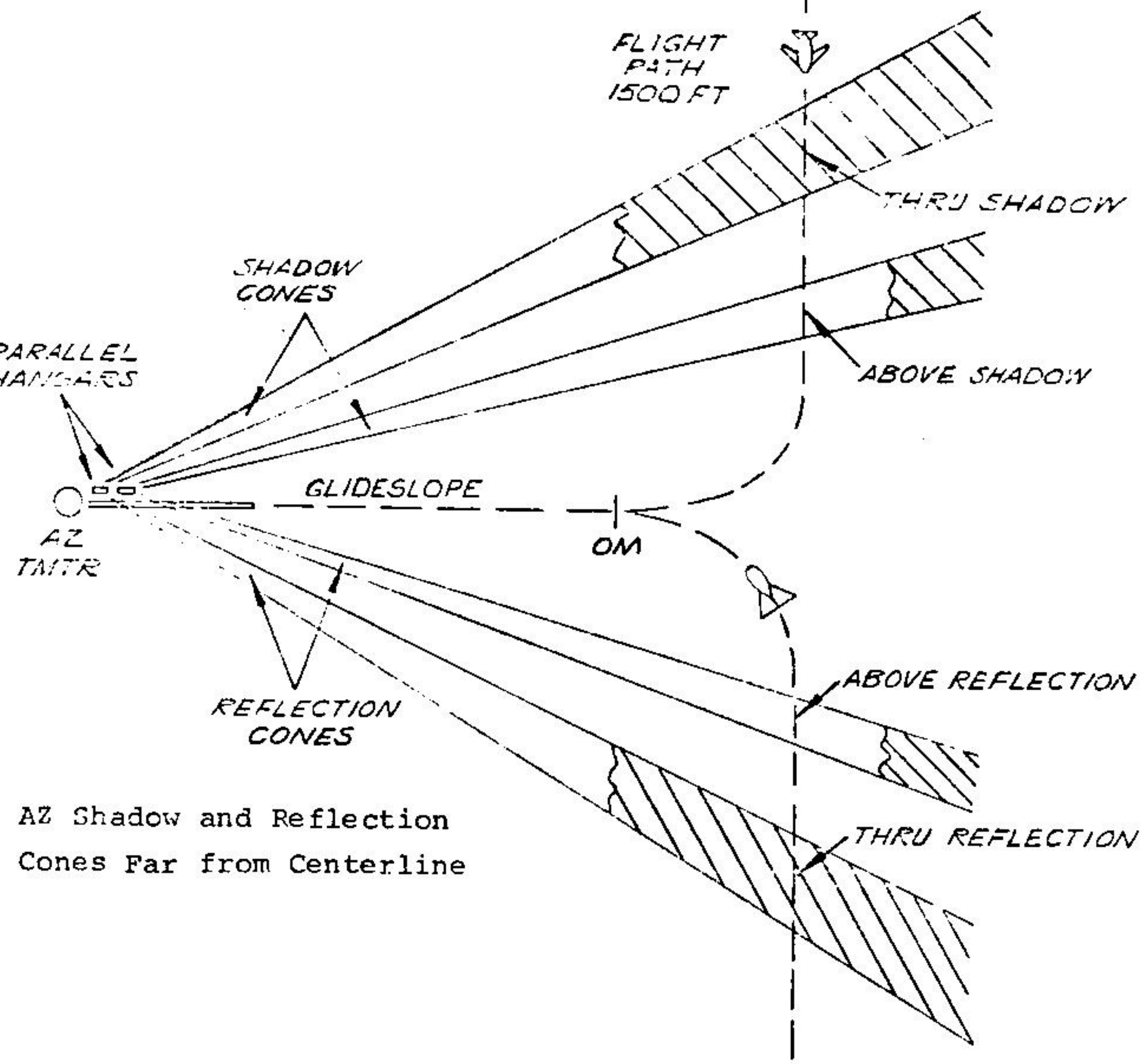
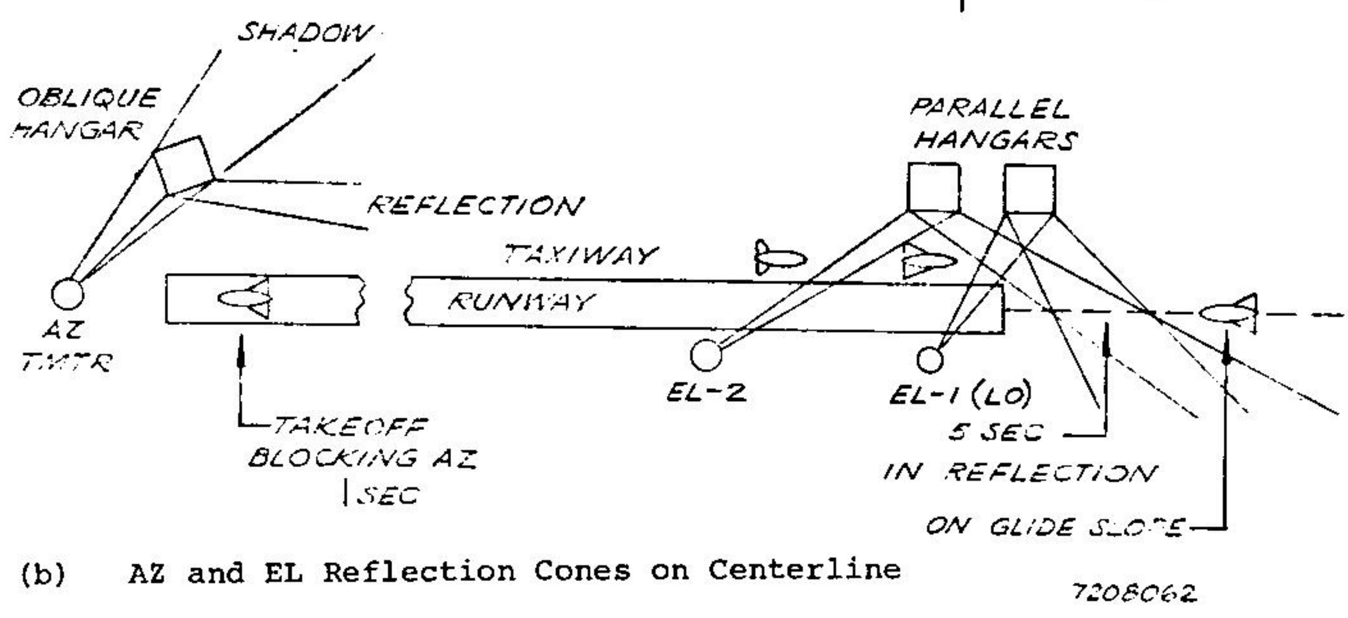


(a) AZ Shadow and Reflection Cones Far from Centerline



(b) AZ and EL Reflection Cones on Centerline

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Figure Q-1. Airport Runway Environment

3. Obstacles in an Airport.

In relation to the guidance system for one runway, any object above the ground is potentially a cause of multipath or shadowing. This is inherent in a microwave system. See figure Q-1. Location, size, shape and any motion are factors determining the effect of one object on the coding and decoding of angle from one transmitter. In this Section, various obstacles will be described and classified with respect to their potential to cause shadowing and multipath effects. The reflection from the ground, within and near the runway, is related mainly to the transmitter antenna properties, so it is not discussed here.

Characteristics of principal obstacles. There are several characteristics of an obstacle which determine whether it is a threat to the angle accuracy in the MLS system. The principal obstacles may be rated in the following terms, which will be discussed in more detail.

		Relevant to:	
		Shadowing	Reflection
(a)	Location relative to the runway	yes	yes
(b)	Size	yes	yes
(c)	Shape and material	no	yes
(d)	Direction of reflection	no	yes

The location. These are the principal considerations.

(a) Proximity to the runway.
(b) Proximity to the transmitter, which is near one end of runway.
(c) Proximity to the receiver, which is near threshold for a short time from the lower part of glideslope to the touchdown.
(d) Angle proximity to the runway centerline, as seen from AZ transmitter.

The size. The size of an obstacle has to be compared with some reference, such as the following:

(a) Relative to the first zone of diffraction as determined by the wavelength and the distances from transmitter and receiver.
(b) Relative to the distance from transmitter, which decreases the angle subtended in AZ and EL.

In either case, the reference size increases with distance or, conversely, the effect of a certain size is greater at a lesser distance, as would be expected.

The shape and material. An obstacle of a certain size has its reflection factor decreased by any of these properties.

(a) Convex curvature, causing divergence of the reflected radiation. This is typical of the tail fin of an aircraft (on a taxiway).
(b) Roughness, such as corrugation, causing some pattern of divergence.
(c) Absorption, reducing the amount of power in the reflected radiation. This may be associated with openings (windows) or lossy dielectric building materials (any except metal).

These are all compared with a perfect reflector, which is approximated by a flat smooth metal sheet.

The direction of reflection. As compared with a vertical wall parallel to the runway, these departures may be noted:

(a) Horizontal rotation of the reflector to an oblique angle. Some angle may direct the reflection into a sensitive area.

(b) Vertical tilt of the reflector, which is unlikely for a flat wall but is typical of the tail fin of an aircraft (on a taxiway). The tilt of the latter lifts the reflection above the horizontal to an angle where it may not reach the receiver or its effect may be transient. (The same is true of the height of the lower edge above ground.)

Examples of principal obstacles to be considered. In order to have a basis for evaluation of the effects, these two obstacles are defined as the closest and largest that may be encountered in conjunction with a long runway (14,000 ft):

(a) A large hangar with a vertical wall which is mostly made of corrugated metal doors.
    - Stationary and predictable
    - Height = 100 ft
    - Area = 500 × 500 ft
    - Width of reflecting wall = 500 ft

  Location relative to runway.
    - Offset 1000 ft
    - Opposite some point on the runway.

(b) A large aircraft (747). See figure Q-10 below. May be on a taxiway parallel to the runway.
    - Offset 500 ft
    - Tail fin (convex),
        - Height 30 to 60 ft from ground.
        - Width 30 ft
        - Thickness 0 - 4 ft
        - Radius of curvature 100 ft

  May intervene between T and R.
    - Fuselage (cylinder),
        - Diameter 22 ft
        - Length about 200 ft

In general, the hangar is expected to cause the greatest cone of shadowing and strong reflection, while the tail fin is expected to be the closest reflector. The fuselage is the main obstacle that may intervene during a centerline flight path.

Examples of lesser obstacles. The following obstacles in or near an airport have been considered but will only be listed here. Their effects have been estimated to be so small as to deserve little or no further discussion here.

(a) Terrain outside the airport. (A certain hill will be evaluated.)
(b) Large buildings outside the airport, water tower, radio tower, tall chimney.
(c) Large buildings far from the runway.
(d) Small buildings in the airport.
(e) Airport surveillance antennas.
(f) ILS antennas.
(g) Fuel trucks, panel trucks.

Some justification for this estimation will be found in the next section.

Motion of an obstacle. Because the receiver is moving at a high speed (taken to be 120 knots or 200 ft/sec during the approach) it is found that the motion of any mobile obstacle, such as another aircraft on a taxiway, is relatively negligible.

4. Shadowing, Reflection and Diffraction.

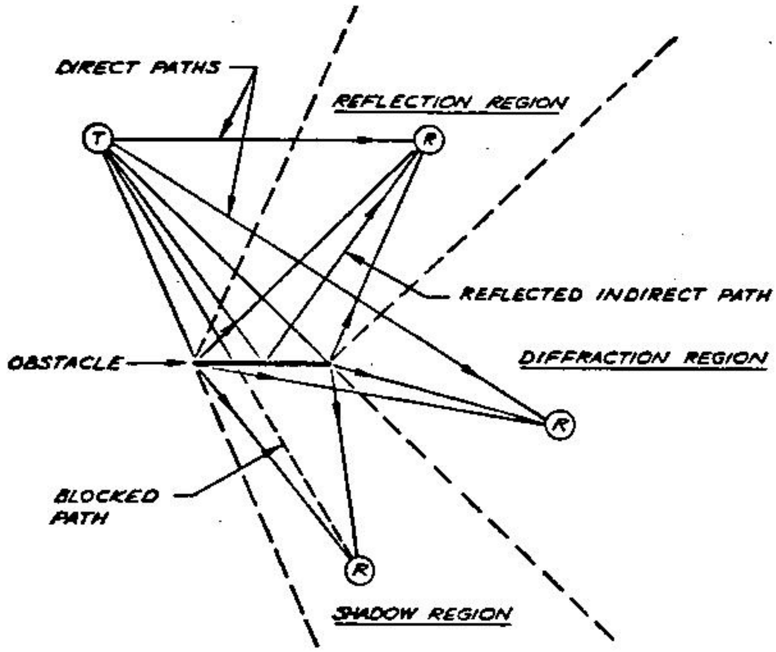
As shown in figure Q-1 an obstacle in an airport may be associated with well-defined regions of shadow and reflection. In the shadow region, the direct path is blocked and the signal at the aircraft receiver arrives only by diffraction paths. In the reflection region, a direct path is accompanied by indirect paths of both reflection and diffraction. This is shown in figure Q-5 in general terms, where a diffraction region is also defined. The multipath indirect signal is the combination of all reflected and diffracted signals.

For the MLS, the two cases that are most important are the blocked path in a shadow and the indirect path by reflection. Figure Q-6 summarizes the various characteristics of obstacles in the direct and indirect paths which are relevant to the AZ angle guidance in MLS. From these characteristics the magnitude, duration, and variation of the effects on angle decoding can be estimated.

Shadowing, which is the result of blocking of the direct signal path, poses two problems for the MLS. The greater problem is the predictable reduction in system coverage caused by the shadow of a large building near the transmitter. The lesser problem is the momentary blocking caused by an aircraft on takeoff, or conceivably by its tail fin while on a taxiway near the transmitter.

Figure Q-7 shows profiles of the risk of shadowing and reflection from buildings on one side of a long runway, for the AZ radiation. Figure Q-8 shows the conceivable shadowing of the AZ radiation by a hangar or tail fin on the ground in some areas.

From these figures, it is observed that shadowing by buildings is not a problem in the region between the outer marker and the



NOTE: ALL PATHS NOT LABELED ARE DIFFRACTED INDIRECT PATHS

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Figure Q-5. Shadow, Reflection and Diffraction Regions

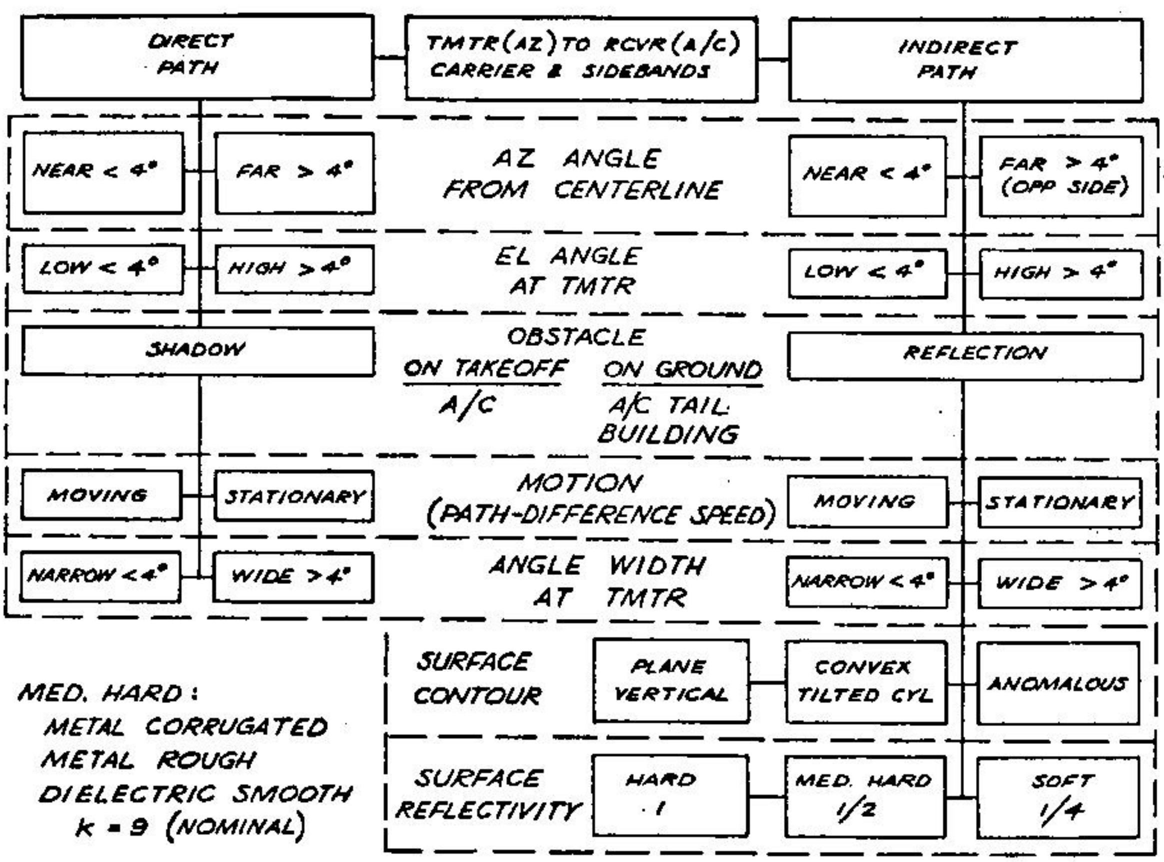

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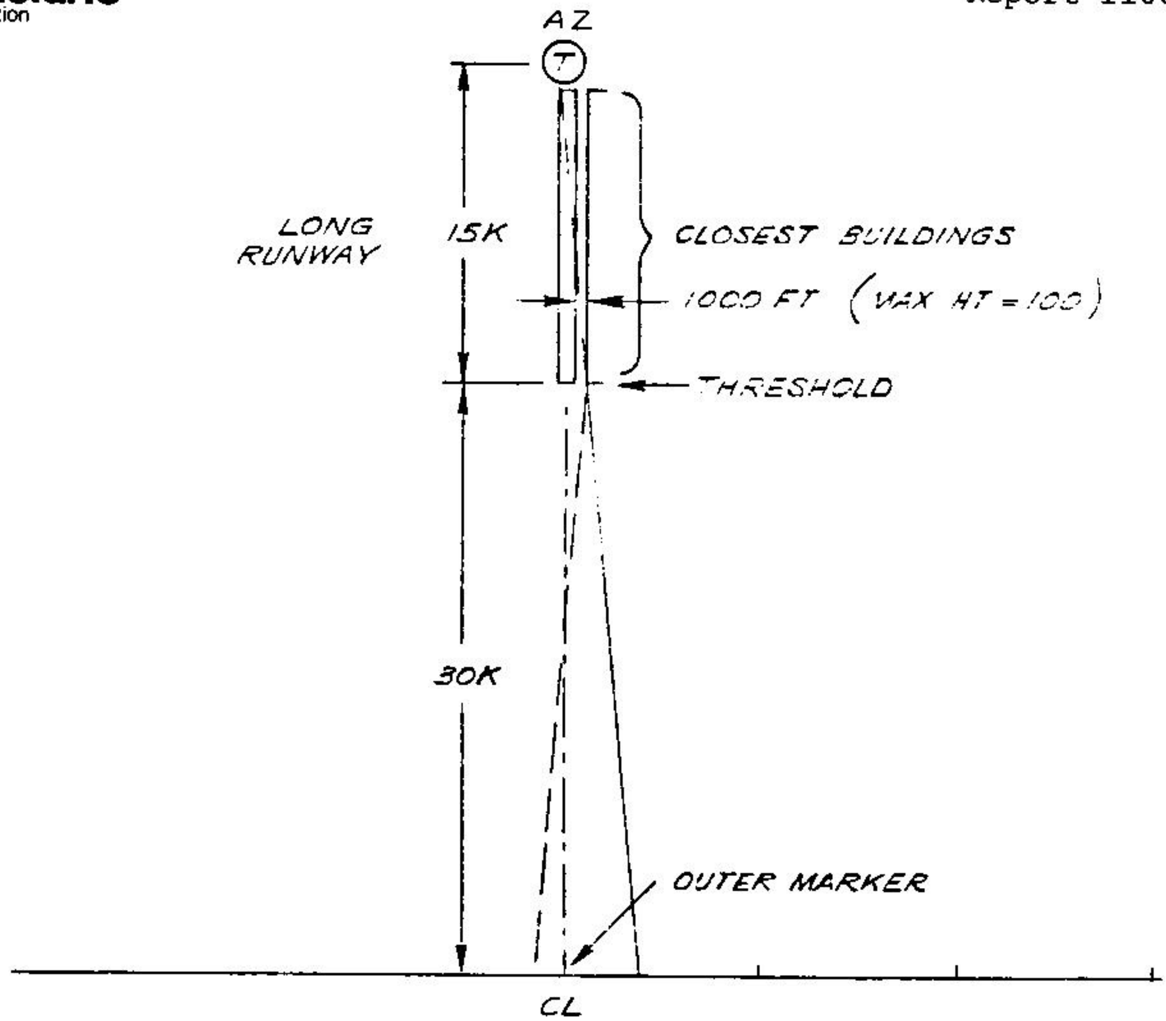
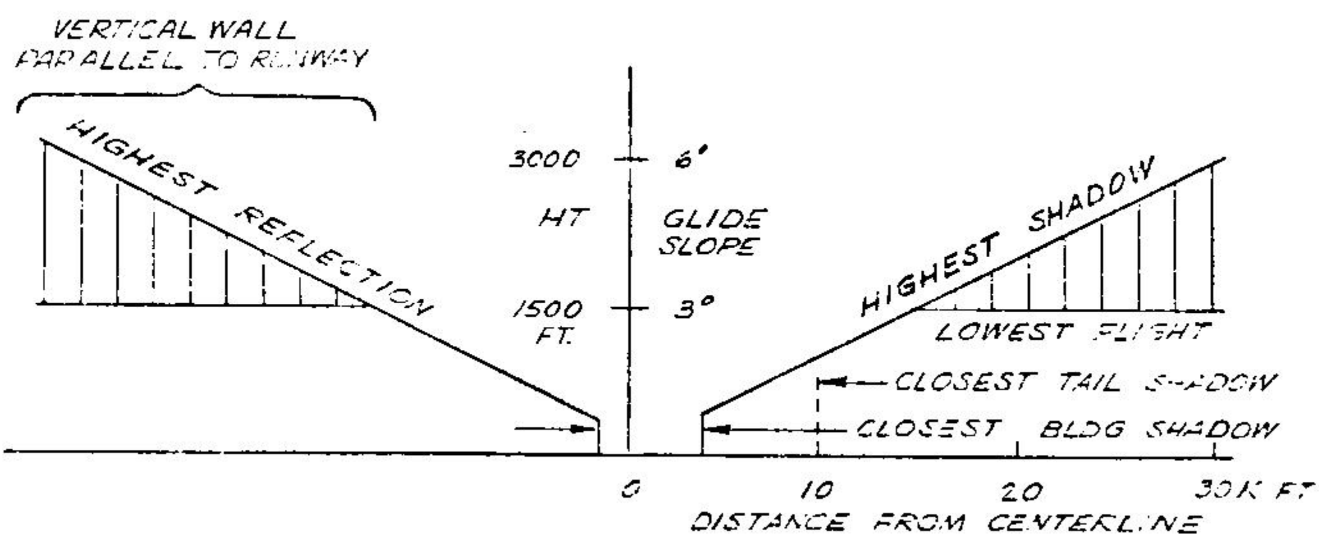
Figure Q-6. Characteristics of Obstacles in Direct and Indirect Paths



(a) Plan.



(b) Interception on Plane at Outer Marker.

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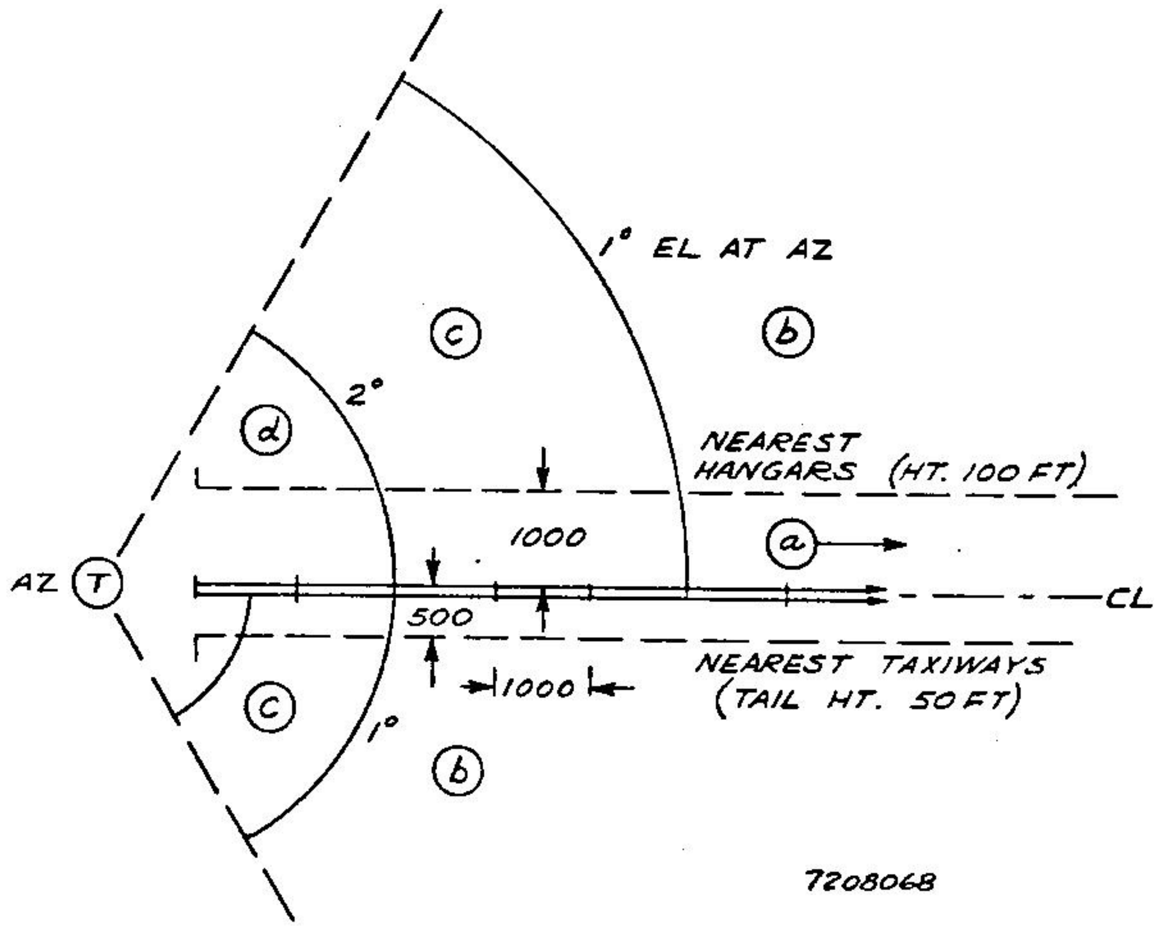
Figure Q-7. Profiles of Risk of Shadowing and Reflection From Buildings on One Side of Long Runway



(a) No shadow near CL.

(b) No shadow above 1°, or above 1500 ft at 15 nmi.

(c) No shadow above 2°, or above 1500 ft at 7.5 nmi.

(d) Hangar shadow above 2°, or above 1500 ft at 7.5 nmi.

Figure Q8. Shadowing of AZ Radiation by a Hangar or Tail Fin on the Ground in Some Areas touchdown. However, a flight path far from centerline may experience shadowing from a large building or a tail fin located near the AZ transmitter.

There will be given a few examples to illustrate some relations that are relevant to shadowing. Each is applied to:

AZ radiation, C-band, $\lambda = 0.2$ ft.

In each example, the size of the reflecting surface is compared with the diffraction zone. Here we use the $\lambda/8$ zone, whose width is

$$\sqrt{\lambda d_o}$$

This width is 1/2 of the $\lambda/2$ zone width, commonly termed the first Fresnel zone. It is chosen because:

(a) It is the minimum aperture width that will transmit a signal nearly equal to the free-space signal.
(b) The shadowing effect behind the center of a strip of this width reduces the signal to about 1/2 its free-space voltage.

The "effective distance" (d_o) is formulated in figure Q-9; it is somewhat less than the lesser of the distances between the obstacle and the transmitter or receiver. A typical value is 2000 ft, in which case the $\lambda/8$ zone width is 20 ft. This is somewhat smaller than a large tail fin and much smaller than a building. It is comparable with the diameter of a large fuselage.

<u>Example - Shadowing of AZ by a large building</u> (such as a hangar) located rather near the transmitter.

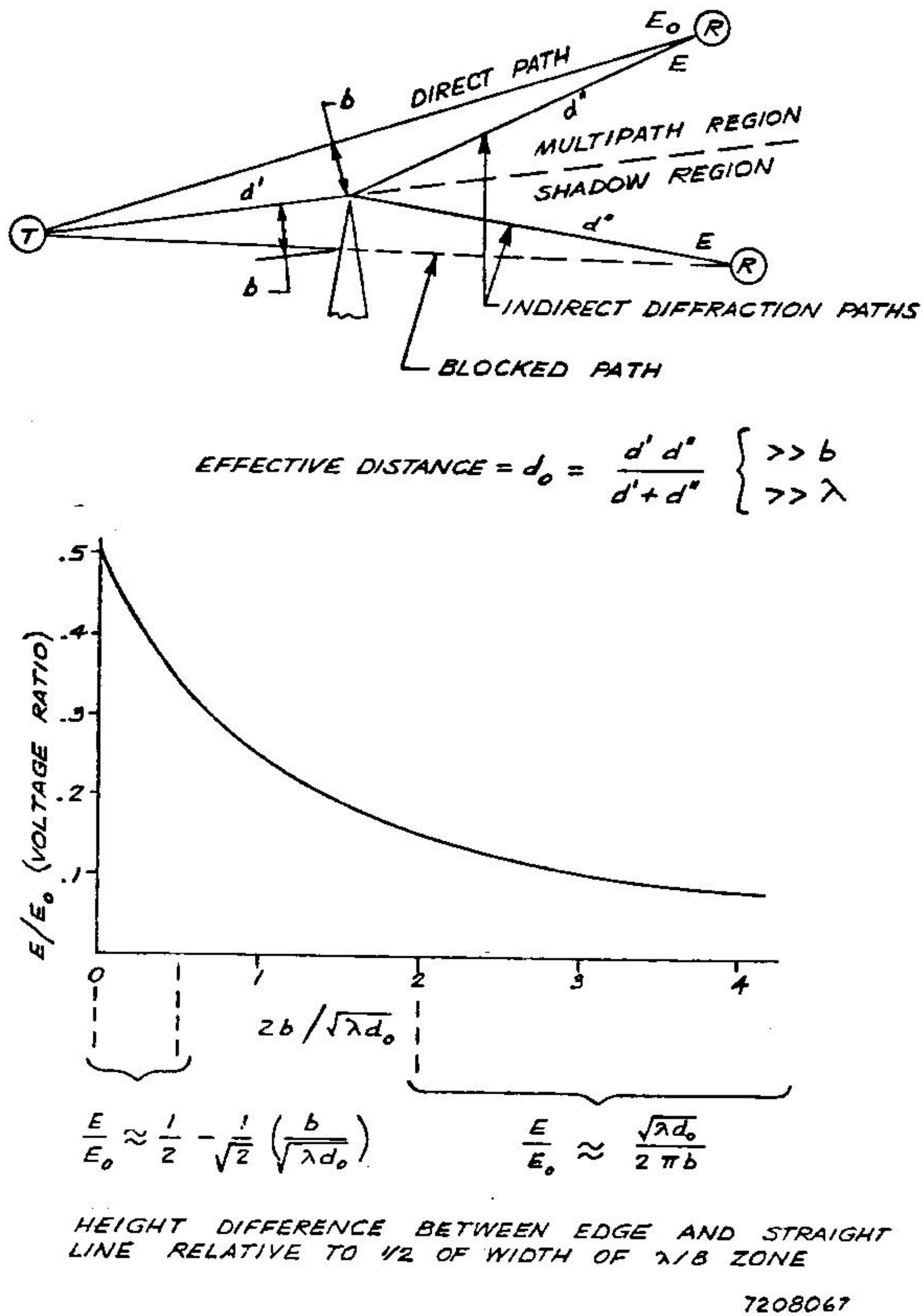


Figure Q-9. Forward Diffraction from Horizontal Edge, Downward in Shadow or Upward in Multipath Region

Building:

Direction - 45° off centerline

Distance - 1500 ft from transmitter

Height - 100 ft.

Projected width - 500 ft.

Receiver position:

Direction - 45° off centerline

Distance - 10 nmi from transmitter

Height - 1500 ft.

The decrease in signal level can be estimated from the results of the solution to the knife-edge diffraction problem. The formulas and a graph of signal ratio are presented in Figure 6-9. These formulas are valid when the projected width of the building, in a plane perpendicular to the direct line-of-sight, is greater than $2\sqrt{\lambda d_o}$, which is true here.

$$d_o = 1500 \text{ ft.}$$
$$\sqrt{\lambda d_o} = 17 \text{ ft.}$$
$$b = 62 \text{ ft.}$$
$$E/E_o = 0.044 \ (-27 \text{ dB})$$

Duration about 100 sec.

It is seen that this building is close enough to the transmitter, to cause a great reduction of signal strength for a long time.

Computation of signal in shadow behind a strip. Figure Q-9 can be used to evaluate the diffraction signal behind an aircraft on takeoff or by a tail fin while taxiing. In this case, the signal in the middle of the shadow region is the sum of two edge-diffracted components whose magnitude can be estimated from the strip-diffraction model. For this model, the ordinate of the graph in figure Q-9 is doubled for a strip of width w = 2b. From the middle toward either edge, the signal oscillates between the difference and the sum of the two edge signals. The formulas are valid if the projected length of the strip, on a plane perpendicular to the direct line-of-sight, is much greater than its width. Then this rule is found to be helpful:

> If the strip width is less than double the $\lambda/8$ zone width, the signal in the shadow region is between 1/2 and 1/4 of its value in free space.

The reduction by blocking is negligible if both width and projected length are less than one zone $\sqrt{\lambda d_o}$.

Shadowing by an intervening aircraft. Figure Q-10 shows some relevant dimensions of a large aircraft. These are to be used in examples of blocking by an intervening aircraft. Figure Q-11 shows some situations in which an aircraft A may intervene between T and R, all three being over the centerline. The signal reduction depends mainly on the fuselage width (22 ft for the 747). This is equal to double the $\lambda/8$ zone if

$$d_o = (11)^2/0.2 = 600 \text{ ft}$$

If T and R are separated by more than 2000 ft, the lesser distance is less than 1000 ft. Then we have this rule:

> If the intervening aircraft is more than 1000 ft from the closer of T and R, the received signal exceeds 1/4 the free-space voltage.

Referring to figure Q-11, the lesser distance would always exceed 1000 ft.

Example - Shadowing of AZ by an intervening aircraft on takeoff. Figure Q-11(b) shows the shadowing of AZ radiation by an aircraft on takeoff over the transmitter. The following case is calculated:

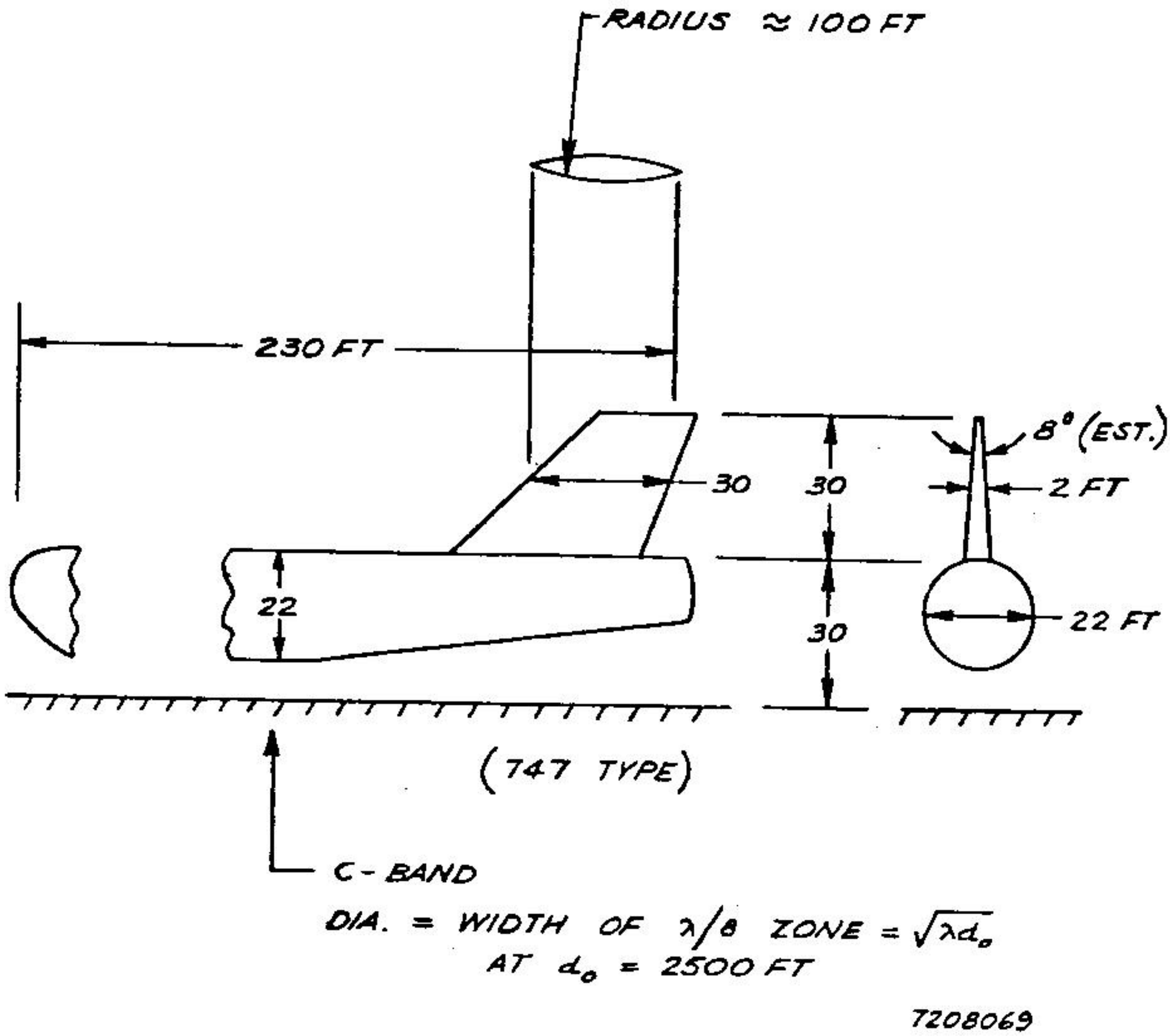
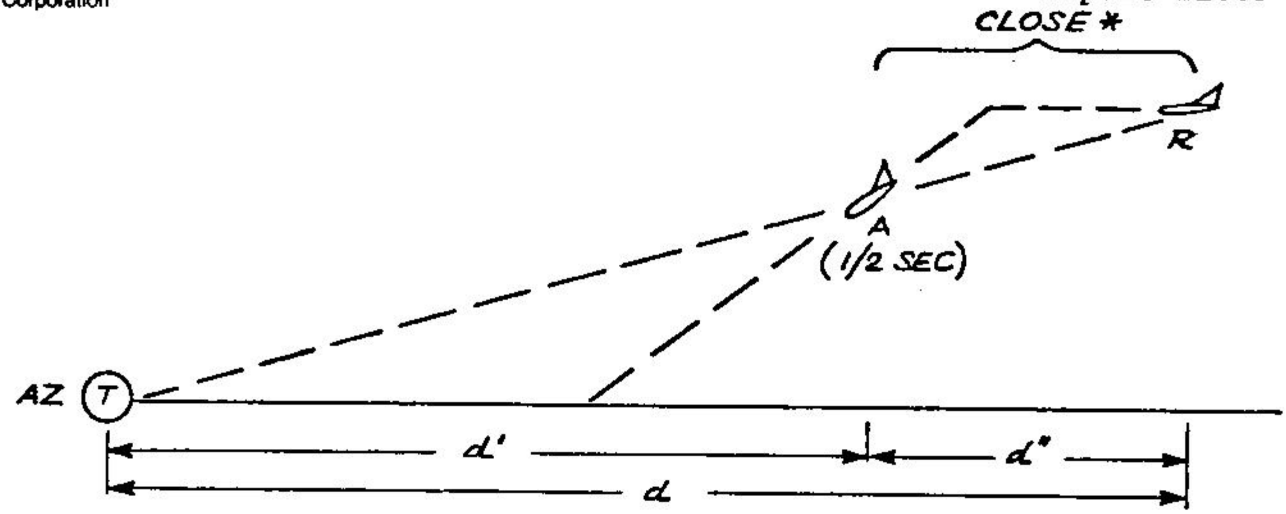
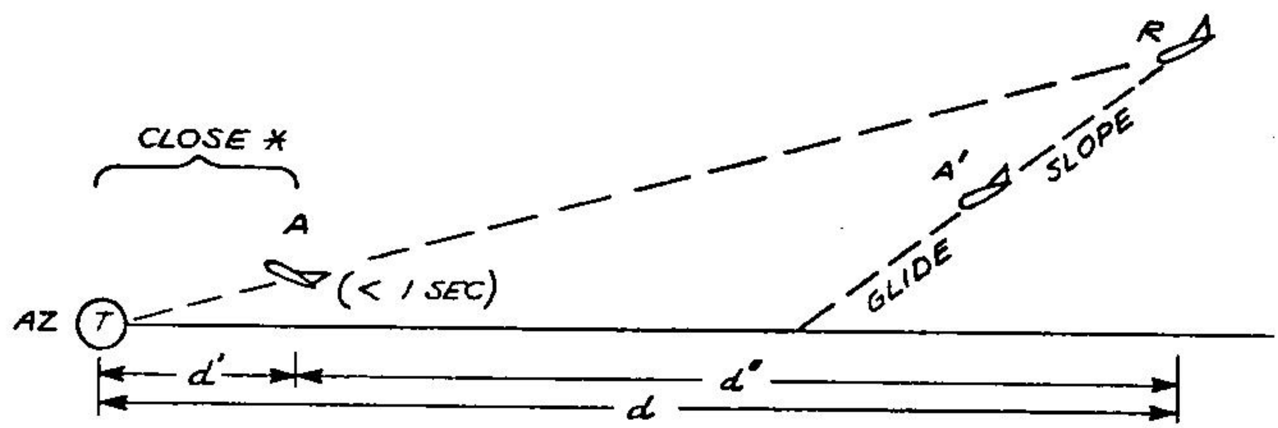


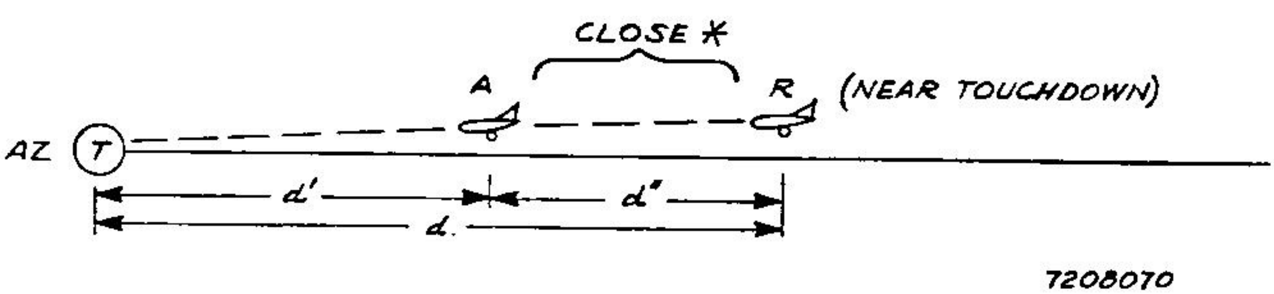
Figure Q-10. Some Relevant Dimensions of a Large Aircraft



(a) Shadow by Aircraft on Glideslope.



(b) Shadow by Aircraft on Takeoff.



(c) Shadow by Aircraft on Runway.

(*) If separation exceeds 3000 FT, the signal in shadow will exceed 1/2 and any angle error will be very small.

Figure Q-11. Shadowing of AZ Radiation by an Intervening Aircraft

Intervening aircraft (747) on takeoff:

Direction - on centerline

Distance - 1500 ft from transmitter

Height - 50 ft.

Fuselage width - 22 ft.

Fuselage length - 230 ft.

Receiver position:

Direction - on centerline

Distance - 45 Kft from transmitter (at outermarker)

Height - 1500 ft.

Computations:

d_o = 1500 ft.

$\sqrt{\lambda d_o}$ = 17 ft.

w = 2b = 22 ft.

E/E_o = 1/2 to 1/4

Duration about 1 sec.

This is not serious, considering that the receiver is in a non-critical time in the flight path (not too low or too far).

Example - Shadowing by a large tail fin. As seen in figure Q-8, a large tail fin near the AZ end of the runway might cast a shadow as high as a flight path.

Aircraft tail fin (747) on taxiway:

Direction - 20° off centerline

Distance - 1500 ft.

Height - 60 ft above ground

(about 20 ft above line-of-sight)

Width - 30 ft (perpendicular to line-of-sight)

Receiver position:

Direction - 20° off centerline

Distance - 10 nmi from transmitter

Height - 1500 ft.

Computations:

$d_o = 1500$ ft.
$\sqrt{\lambda d_o} = 17$ ft.
$w = 2b = 30$ ft.
$E/E_o = 1/2$ to $1/4$
Duration about 6 sec.

Here again, this is not serious, considering that the receiver is in a noncritical time in the flight path (not too low or too far).

From the examples above, it appears that the most serious shadow problem is caused by buildings. This effect is predictable and stable so regions could be defined in the terminal airspace where MLS receivers would not be operated. A secondary and less predictable problem is the momentary decrease in signal caused by an intervening aircraft near the transmitter, on takeoff or on taxiway.

Reflection deserves special attention in MLS. It is the multipath caused by radiation from a transmitter being reflected from a large obstacle toward the receiver. It is inherently a problem for any microwave system, especially for one covering a wide angle from the runway centerline. The MLS differs from ILS in that it covers a wide angle in some applications.

The occurrence of a reflected signal in some particular sector is indicated in figures Q-1, Q-5, Q-7 and some to follow. The principal reflecting obstacles are exemplified by a large hangar near the runway and the tail fin of a large aircraft on the parallel taxiway. The relevant qualities of these obstacles are noted above. The former has the greater effect, which occurs in a stable and predictable cone in space. Its effect is greater in AZ radiation, because this is utilized over a wide angle.

If the receiver traverses a cone of reflection, the indirect signal may be strong enough to approach the amplitude of the direct (perhaps 1/2 as great). Then it may cause an error in the angle decoding. In an extreme case, it is conceivable that it might temporarily exceed the direct and capture the limiter (as will be explained). The discussion here is directed to the occurrence of reflections and to the amplitude ratio of indirect/direct signal voltages as influenced by various factors. The reflection factors combine to give a reflection coefficient (ρ) which may be slightly less or much less than unity.

Table Q-1. Reflection Factors for Indirect Signals.

Reflection Factor	Phenomenon	Remarks
ρ_1 Path distance.	Distance ratio, direct/indirect.	Simple rule.
ρ_2 Surface size.	Relation to zone size, diffraction.	Surface is usually larger than $\lambda/8$ zone, so factor is near unity.
ρ_3 Surface contour (convex).	Reduction by divergence.	Locates image closer to reflector.
ρ_4 Surface reflectivity.	Reduction by diffusion and absorption.	Roughness, corrugation, materials, openings.
ρ = product.	Voltage ratio, indirect/direct.	Does not include radiation pattern and environment.

Table Q-1 describes several factors entering into the reflection coefficient for an indirect signal caused by one obstacle in an airport. Each factor is to be evaluated and all are multiplied to determine the relative amplitude of the indirect signal. The reference for all factors is a perfect plane reflector large enough to develop an image substantially like the transmitter. A conceptual example would be a large, flat, metal, vertical wall.

The path-distance factor (in table Q-1) gives the reduction factor resulting from the indirect path distance (d' + d") being greater than the direct (d). There are two situations which have different formulas for this factor.

(a) In free space, this factor would be

$$\rho_1 = \frac{d}{d' + d''}$$

This ratio is valid if the reflector is vertical and the receiver is high enough that the free-space field intensity is approximated. This height depends on the height and directional properties of the transmitter antenna.

(b) For a lesser height of receiver, the ground image causes the field intensity to be proportional to height. The path-distance factor becomes

$$\rho_1 = \left(\frac{d}{d' + d''}\right)^2$$

This ratio is valid for the AZ signal on a long runway, as the receiver approaches flareout and touchdown. This also is conditioned on a vertical reflector.

This factor is usually unimportant for the AZ transmitter, so the first form is usually valid and may be relevant to an EL transmitter.

The surface-size factor (in table Q-1) includes the effect of reflector size relative to the λ/8 zone defined above.

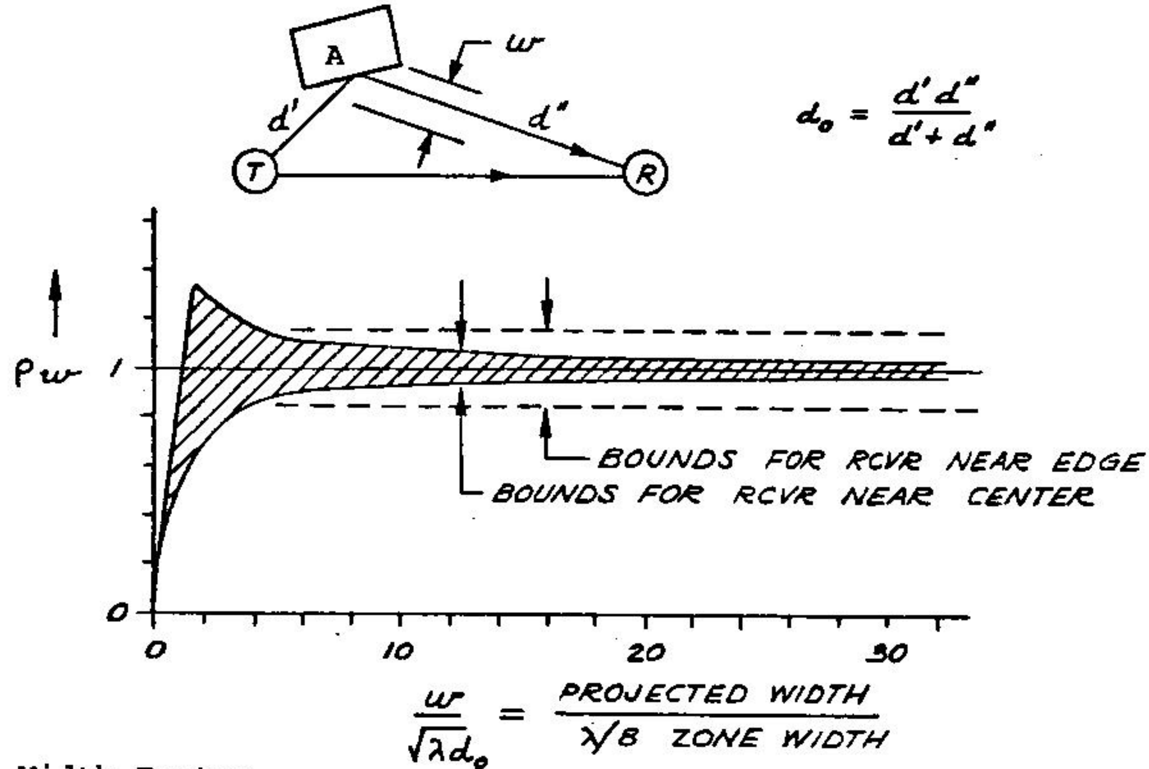
For a rectangular wall, figure Q-12 shows how this factor may be described in terms of two components depending respectively on width and height:

$$\rho_2 = \rho_w \rho_h$$

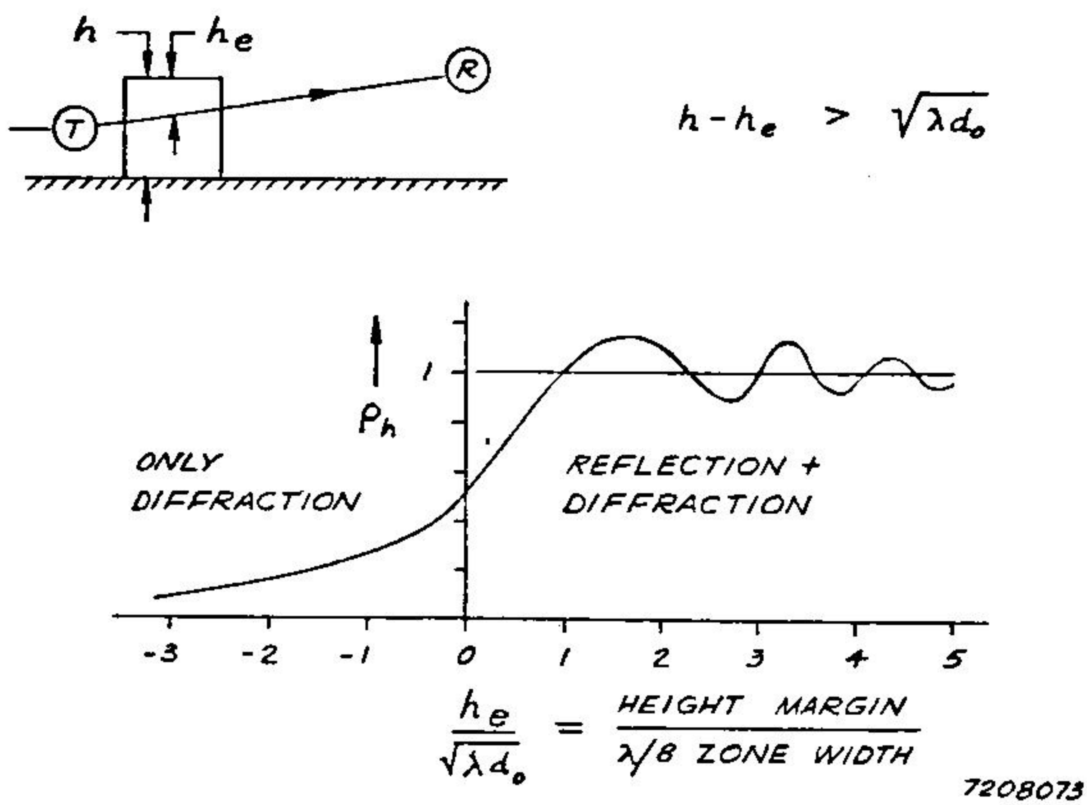
Figure Q-12(a) shows the projected width of a wall A acting as a reflector between T and R. The "effective distance" d_o and the $\lambda/8$ zone width $\sqrt{\lambda d_o}$ are formulated as above. If the projected width exceeds the zone width, ρ_w is near unity. The difference from unity is caused by edge diffraction, as indicated for the receiver location near the middle or one edge of the reflection sector (Figure 6-5). In practice, the width of a hangar wall is usually many times the zone width, so this factor is near unity.

Figure Q-12(b) shows the effect of the height of a vertical wall located on the ground. The height is taken to be much greater than the $\lambda/8$ zone width. The reflection point on the wall is identified, and the excess height above that point is denoted h_e. The graph shows the height factor ρ_h to be near unity if the excess height exceeds the zone width. This is true if the receiver is within the reflection cone by some margin.

<u>The surface-contour factor</u> (in table Q-1) gives the effect of divergence in reflection from a convex surface. This is relevant especially to the tail fin of a large aircraft, also to its fuselage and to other obstacles such as a fuel truck or a water tower. It is assumed that the surface extends more than one $\lambda/8$ zone width (with due regard for the curvature) in all directions from the point of reflection. This effect is expressed in terms of ρ_3 , the ratio of reduction of field intensity at the receiver. The reference is a perfect plane reflector located at the point of reflection.



(a) Width Factor.



(b) Height Factor.

Figure Q-12. Reflection Factors for a Rectangular Plane Vertical Wall

Figure Q-13(a) gives the general formula for curvature in either or both of the horizontal and vertical planes ($1/a_1$ and $1/a_2$).

Figure Q-13(b) gives another formula for the case of most interest here. It is a large thin tail fin with a convex surface of width w and thickness t. If T and R are on centerline (as in the AZ function on approach), c is approximately the offset of a taxi-way from the centerline. (For a horizontal cylinder, just change b to a.)

Example - Reflection of AZ by a large tail fin (747) located on a taxiway near the threshold.

$d' = 13500$ ft, $d'' = 1500$, $d_o = 1350$
$c = 500$ ft, $w = 30$, $t = 2$
$\rho_3 = 0.09$ (-21 dB)

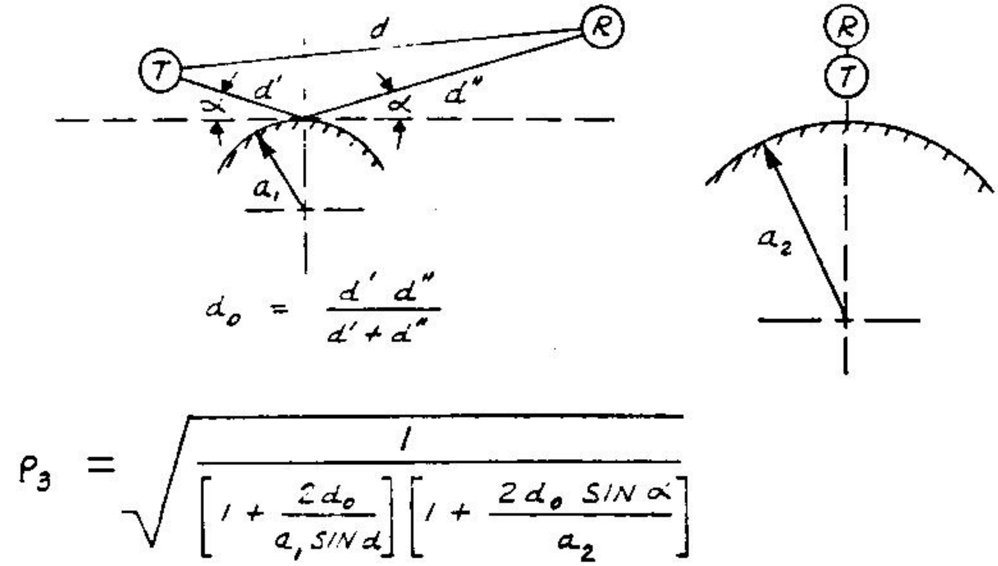
This illustrates the great reduction of the indirect signal by the curvature of the tail fin.

Example - Reflection of AZ by a hill located on one side of center-line, under the glide slope. This is an extreme (conceptual) case, included as another illustration of the effect of convex curvature. Figure Q-14 shows a configuration chosen to emphasize any detri-mental effect and thereby to indicate the improbability of appreci-able error from this cause. The curvature gives

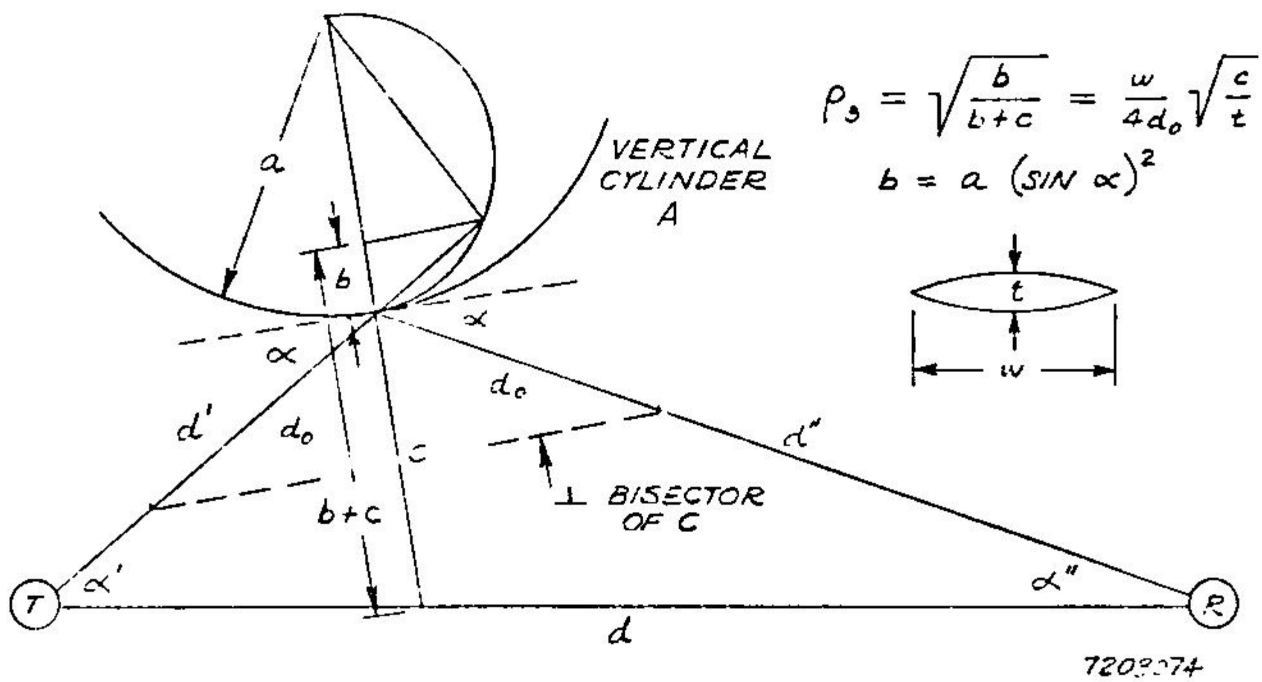
$\rho_3 = 0.06$ (-24 dB)

The indirect path is coded 0.5° (1/2 beamwidth) from centerline (T to R), which would give "in-beam" error of decoding, but it is too small to be noticeable.

The surface-reflectivity factor (in table Q-1) gives the effective reflection coefficient ρ_4 of the surface. It includes scattering



(a) Formula for Doubly Convex Surface.



(b) Geometrical Evaluation for Convex Tail Fin.

Figure Q-13. Reflection Factor for a Convex Surface

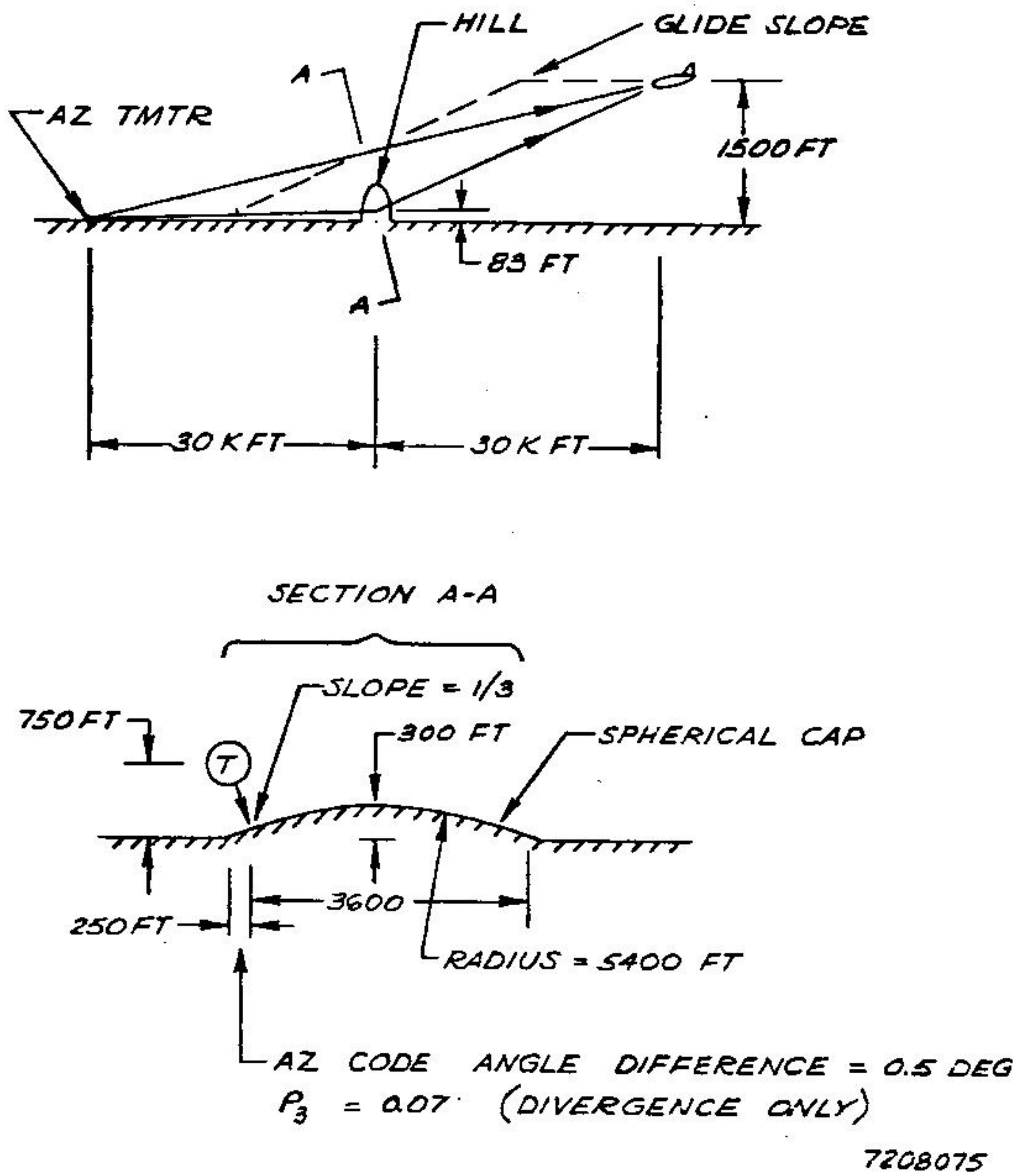


Figure Q-14. Reflection from Hill on one Side of Centerline, Showing Indirect Path with Different Angle Coding by corrugation or roughness, and absorption by the material or openings. The following are some estimated values for a few cases:

Surface	Reflectivity (ρ_4)
Smooth metal tail fin of an aircraft	1
Flat metal door of a hangar	1
Corrugated metal door of a hangar	1/2, 3/4
Nonmetal side of a building	1/4

The tail fin has its reflection reduced by convex curvature, as discussed above. The flat metal door is believed not to be typical of a large hangar of recent construction. If it should appear in a critical situation, it might be necessary to reduce the reflection, as by applying a corrugated face.

The corrugated metal door of a large hangar deserves special attention because it is typical of the largest vertical wall to be encountered. Being metal, it re-radiates, in some directions, most of the incident-wave power. AZ and EL radiation is at C and Ku-bands, where the wavelength is less than the corrugation period, perhaps much less. Therefore the power is divided between equal-angle reflection and grating-lobe scattering in a number of other directions. A few corrugation contours have been noted, which are estimated to give a reflection coefficient (ρ_4) of about 1/2. Reference [4] reports measurements of one contour (not detailed) giving about 3/4 to 1/2 at 15-30° from grazing incidence for vertical ridges of corrugation. The computation and measurement of this effect on practical surfaces will receive more attention.

Table Q-2. Reflection Factors for Some Airport Obstacles.

OBSTACLE		(a) HANGAR DOOR				(b) BUILDING WALL				(c) AIRCRAFT TAIL FIN			
ANGLE CODED		AZ		EL -1	EL -2	AZ		EL -1	EL -2	AZ		EL -1	EL -2
RECEIVER LOCATION	AZ	0	30°	0	0	0	30°	0	0	0	30°	0	0
REFLECTION FACTORS													
SPACE PATTERN	ρ_x	1	1	0	$\frac{1}{3}$	1	1	0	$\frac{1}{3}$	1	1	0	$\frac{2}{3}$
PATH DISTANCE	ρ_1	1	1	$\frac{3}{4}$	$\frac{3}{4}$	1	1	$\frac{3}{4}$	$\frac{3}{4}$	1	1	$\frac{3}{4}$	$\frac{3}{4}$
SURFACE SIZE	ρ_2	1	1	1	1	1	1	1	1	1	1	1	1
SURFACE CONTOUR	ρ_3	1	1	1	1	1	1	1	1	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$
SURFACE REFLECTIVITY	ρ_4	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	1	1	1	1
PRODUCT	ρ	$\frac{3}{4}$	$\frac{3}{4}$	0	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	0	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{8}$	0	$\frac{1}{16}$

A summary of reflection factors is given in table Q-2 for three cases of particular interest. They are estimates of typical cases, based on the preceding discussion. The receiver location is in terms of AZ angle from centerline (0 or 30°). It is noted that this table does not include other factors such as space patterns or frequency filters. The zero values for EL-1 indicate that these are nominally outside the AZ coverage angle of the fan beam. The AZ reflection from the corrugated metal door of a hangar (a) is the only case where ρ might be greater than 1/2.

The cone of reflection. Just as important as the reflection factor is the location of the cone of reflection. This determines whether a particular flight path will traverse the cone, and during what time in its approach pattern. The practical effect of this transit may be inferred in some typical cases. The practical effect is different for typical cases of reflection of AZ and EL radiation.

Parallel wall, AZ reflection. Figure Q-1(a) and Q-7 show this case. The reflection cone is on one side of centerline, opposite from the shadow cone and similar in shape. There is no reflection cone along the centerline. There is only a small chance that one cone will be traversed, requiring that it include the flight path in one of two locations:

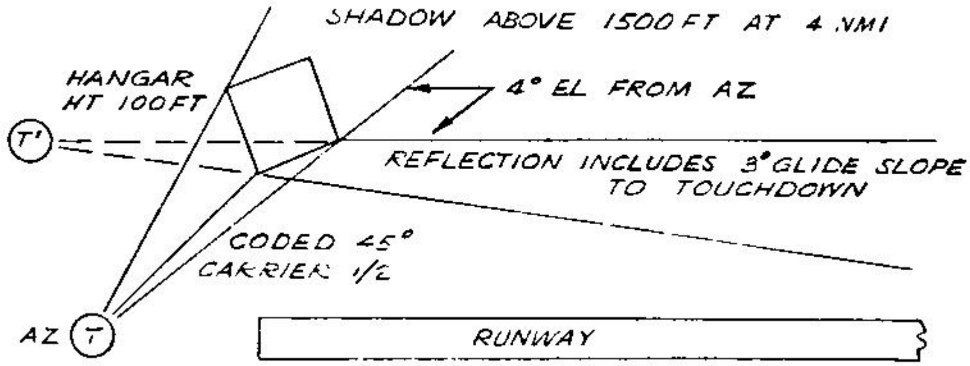
(a) At a great distance and far from centerline; and/or
(b) Below 200 ft and before touchdown.

Only in the latter case is it critical, and then the duration may be about 5 sec. In either case, the angle coding of the indirect and direct paths is much different, so the multipath error may be removed by frequency filtering.

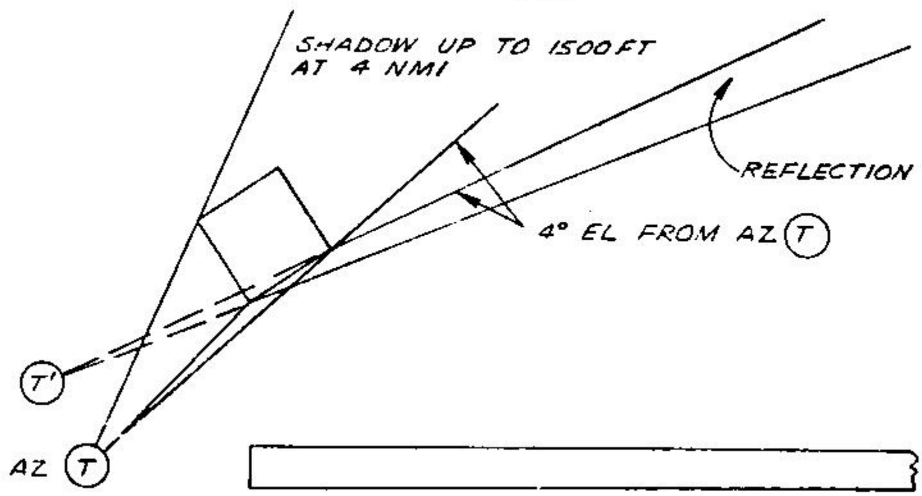
Oblique wall, AZ reflection. Some examples are shown in figure Q-15. The reflection cone may include:

(a) The centerline over the entire glide slope and flareout to touchdown.
(b) A cone on the same side of centerline.
(c) A narrow, low cone near threshold, traversed during the flareout.

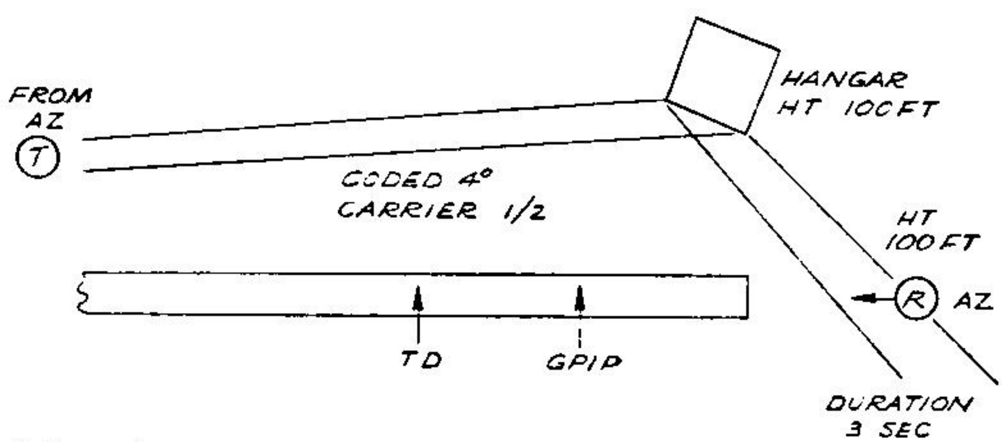
The relative angle coding of indirect and direct paths can be inferred in each case. Only one (b) has both angles far from centerline and on the same side, so they are not separated by the fixed prefilters discussed elsewhere herein.



(a) Reflection Toward Glide Slope.



(b) Reflection in Same Half-Sector.



(c) Reflection toward Transition From Glide Slope to Flareout

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Figure Q-15. Reflection of AZ Radiation from Oblique Vertical Wall

Nearby wall, EL reflection. Figure Q-16 shows some peculiarities of reflection cones in the vicinity of the EL radiators and the approach to touchdown. The hangar location illustrates two cases:

(a) The flight path traverses the EL-1 cone, but only during flareout after handover to EL-2;
(b) The flight path passes over the EL-2 cone, and before handover to EL-2.

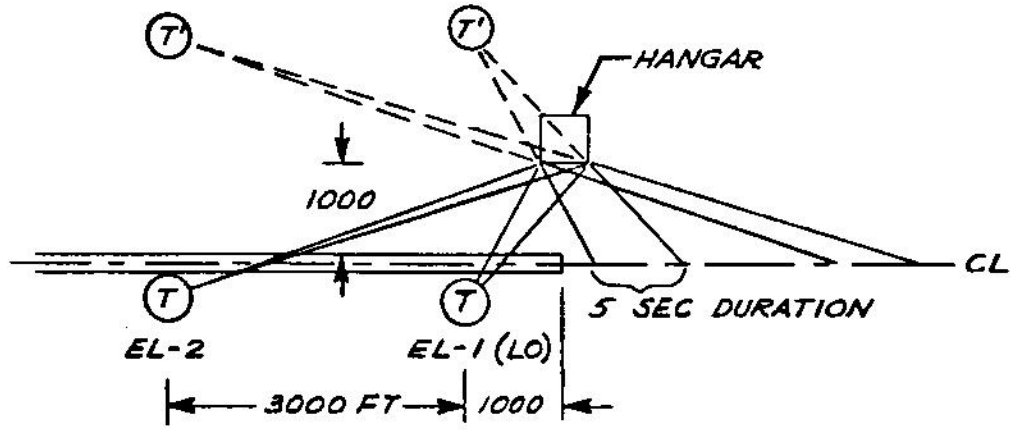
Therefore both of these reflection cones happen to be harmless.

Nearby tail fin on parallel taxiway. The cone of reflection has these peculiarities:

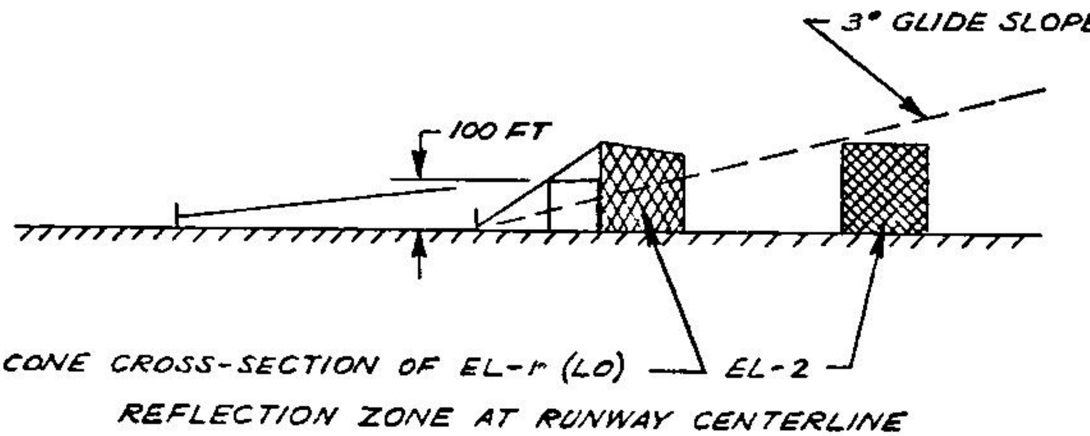
(a) It is spread in width by the convex curvature, so it covers a horizontal angle of about 30°.
(b) The vertical angle subtended at the transmitter is small (less than 3°) and is lifted both by the height of the fin above ground and also (about 8°) by its taper.
(c) The face is similar to a cylinder tilted both laterally and longitudinally, so there are components of curvature in both horizontal and vertical planes, see figures Q-10 and Q-13(a).

The cone of reflection tends to be tilted upward, away from the flight path near touchdown. However, the double curvature makes it difficult to describe. Since the reflection factor is reduced by convex curvature, this reflection has little effect on angle guidance.

Diffraction is the cause of multipath outside the regions identified with shadowing and reflection, as indicated in figure Q-5. The relative strength of the indirect signal is appreciable if the line-of-sight is separated from the obstacle by only a few times the zone width, as appears in figures Q-9 and Q-12(b). This is associated with a well defined cone of shadowing or reflection.



(a) Plan



(b) Elevation

Figure Q-16. Reflection of EL Radiation from a Vertical Wall

One line-of-sight is unlikely to be close to more than one such cone at a time.

There are many objects on the ground which are illuminated by any one transmitter, especially the AZ. There is no realistic model that seems to give diffraction paths of appreciable strength, individually or collectively.

(a) A horizontal edge at the top of a high building gives diffraction mainly in line with the building and far beyond it. One or very few such edges would be in the same line, and typically much below the line-of-sight.

(b) Corners at the top of high buildings give diffraction in all directions but much weaker, even in the aggregate.

(c) Anomalous obstacles in or near the airport would contribute more numerous signals but so much weaker that their aggregate is hardly appreciable.

The RMS value of diffraction indirect signals, or the value of one principal component, is estimated to be around 0.01 of the direct. Also their contribution to the residual error is reduced by the AZ prefilter or the EL space patterns. They are regarded collectively as a low level of background noise.

Conclusions. Relative to these three phenomena, the following are the principal conclusions.

(a) Shadowing is unavoidable in a microwave system, but a deep shadow is caused only by a large building that happens to be located within some small fraction of the airport area. Its effect is stable and predictable.

(b) Reflection, in various amounts, is the principal cause of multipath effects. A large hangar door or a large tail fin is a reflector of some concern. An appreciation of the properties of reflectors forms a basis for evaluating and reducing the problems, as described in other sections.

(c) Diffraction, as separated from shadowing and reflection, does not cause appreciable multipath effects.