LAAS Reference Antennas - Circular Polarization Mitigates Multipath Effects

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BIOGRAPHY

Alfred R. Lopez is a Life Fellow of the IEEE. He received a BEE from Manhattan College in 1958 and an MSEE from the Polytechnic Institute of Brooklyn in 1963. He is a Hazeltine Fellow at BAE SYSTEMS Advanced Systems. ARL Associates is his private consulting practice. He started his career at Wheeler Laboratories in 1958 as an antenna design specialist. He has made contributions to the theory and practice of electronic scanned antennas. From 1969 to 1990 he was involved with the development of the Microwave Landing System. He has published extensively in IEEE publications, has been issued 36 US Patents, and has received several IEEE and BAE SYSTEMS Awards.

ABSTRACT

Early in the development of the local Area Augmentation System, LAAS, vertical linear polarization was selected for the low-elevation-angle antenna of the two-antenna reference antenna system. The initial LAAS development concentrated on ground reflected multipath. Polarization was not an issue; the level of radiation in the lower hemisphere was specified such that the ground-reflected multipath error was within acceptable limits. However, as LAAS approaches the deployment phase, other siting issues are coming to the forefront, and, polarization selection can make a significant difference.

This paper reviews the issue of polarization with regard to multipath performance, and in particular, it considers the performance with respect to lateral multipath (reflections from airport objects not including ground reflection). It presents some theoretical models and past experience that demonstrate that, lateral multipath for the case of linear polarization, can cause large errors, and in some cases, can capture the receiver with an associated outlier-type error. It is concluded that if both linearly and circularly polarized antennas can satisfy the ground reflection performance requirements then circular polarization is advantageous since it provides substantial suppression of lateral multipath effects.

INTRODUCTION

Signals from satellites at low elevation angles will reflect off lateral multipath (typically vertical surfaces such as aircraft fuselages and tail fins, hangars, terminal buildings, control towers, maintenance vehicles, etc.). In addition, some multipath reflector geometries or possible shadowing by objects near the horizon, can amplify the multipath (indirect) signal. This can result in the LAAS reference receiver locking on and tracking the multipath signal, with an associated large error. This condition may be steady state or transient in nature. Circular polarization mitigates the situation, since reflections nominally have the opposite handedness of circular polarization.

Basically, reflections off of lateral multipath are specular in nature, and a right circularly polarized signal is reflected as a left circularly polarized signal. If the omni-directional reference antenna has right circular polarization for all directions in the upper hemisphere, then significant suppression of lateral multipath errors can be expected. (Circular polarization with an axial ratio of 1dB can provide 25 dB suppression of the reflected signal.) There are several situations in which lateral multipath can capture (multipath signal greater than the direct signal) the reference receiver. Some of these are:

- Reflector Size – In electromagnetics and optics it is well known that a Fresnel zone circular plate can cause a reflection that is 6dB stronger than the direct signal. A reflecting surface with a size that exceeds ½ Fresnel Zone has the potential to cause a reflection the amplitude of which exceeds that of the direct signal.
- Ground Profile Difference Between Direct and Indirect Signals – At low elevation angles, the ground profile, such as rising terrain in the direction of the satellite, can suppress the direct signal with respect to the indirect signal. This is in essence, partial shadowing of the direct signal.

- Shadowing of Direct Signal – An object, such as a light pole, directly in the line-of-sight of the direct signal, can cause sufficient shadowing such that the amplitude of a reflection from an object that is normally less than that of the direct signal, now, because of shadowing of the direct signal, exceeds that of the direct signal.

This paper describes the severity of the lateral multipath problem and suggests that polarization discrimination be incorporated in the design of the reference antenna to mitigate the problem. A circularly polarized LAAS reference antenna provides significantly better multipath performance, especially for satellites at low elevation angles. A circularly polarized antenna with good ground-reflection performance has been described [1], [2], [3].

AIRPORT LATERAL MULTIPATH

In this paper, lateral multipath is defined as all multipath sources excluding the ground reflection (see Figure 1). In the early 70's a good deal of work was done in analyzing and estimating the effects of lateral multipath for the then developing Microwave Landing System, MLS, [4], [5]. Much of that work is directly applicable and helpful in estimating multipath effects for the LAAS reference antenna system. In those days computer simulations were not readily available and analysis was used to estimate performance. The airport environment has not changed very much over the years and the findings of the studies in the 70's are still applicable.

Airport Multipath

- **Local Ground**
- **Lateral Multipath**
  - **Aircraft Tailfin**
  - **Aircraft Fuselage**
  - **Airport Control Tower**
  - **Hangars**
  - **Terminal Buildings**
  - **Buses**
  - **Maintenance Vans**
  - **Surrounding Skyline**

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Figure 1

Characteristic of lateral multipath phenomena is reflection and shadowing. In combination, a multipath reflection from one object and direct-signal blocking by another object can cause the reference receiver to track the delay of the reflecting object. In general, this is a gross error that would be detected by the integrity monitor. It could, however, affect the system availability. It is also possible that a reflecting object is large enough and close enough so that the reflected (multipath, M) signal is stronger than the direct, D, signal (M/D > 0dB). Another possible situation for an M/D > 0dB is when the direct signal is partially shadowed by a rising terrain in the direction of the satellite or by a small object, such as a light pole, directly on the line-of-sight. The M/D > 0dB situation is a significant problem that requires consideration in the LAAS operation.

A more typical situation is the case of M/D < 0dB. A reflector with an M/D of –30dB and a delay ranging between 30m and 270m can cause a psuedorange error of about 0.5m (see Figure 2, and [6], page 560). For LAAS this is a significant error (the LAAS total system accuracy is less than 2m, 2-sigma). The following section describes the characteristics of objects that can cause M/D ratios ranging from –30dB to +6dB. The objective is to indicate the severity of the lateral multipath problem and that mitigation is needed.

Weak Multipath Can Cause Significant LAAS Error

$\delta = \rho \, k \, D / 2$

δ = Peak code delay error
ρ = M/D (Multipath/Direct Signal Voltage Ratio)
D = Chip period = 293m
k = Receiver processing factor

For k = 0.1 (Narrow correlator receiver and delays of 30-270m)

$\delta = \rho$ 14.7m

For $\rho = 0.032$ (-30dB) $\delta = 0.47$m

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Figure 2

ESTIMATES OF M/D RATIO

In [4] a relatively simple model was developed for estimating the reflection factor, ρ (M/D voltage ratio), for a multipath object. At the point of reflection a reference reflector is located. The reference reflector is a very large flat specular surface that creates a perfect image of the antenna. As shown in Figure 3, a product of five factors gives the reflection factor for a multipath reflector: The factor, g, is the relative antenna gain in the directions of the satellite and the reflector. The factor, d, is a distance ratio factor, the ratio of the distance from the antenna to the satellite and the distance from the antenna image to the satellite. For GPS, d = 1. Three factors; size, curvature and reflectivity complete the model. This paper will concentrate on the size and curvature factors.

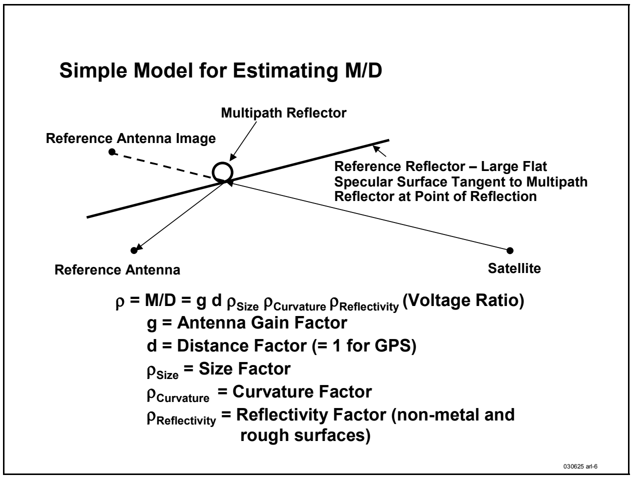

Figure 3

The Fresnel Zone Disc is an excellent example to illustrate the severity of the lateral multipath problem; it can create an M/D ratio of +6dB. Figure 4 defines the Fresnel Zone Disc. In general, a reflector with a projected area that exceeds the ½ Fresnel Zone area has the potential to create an M/D ≥ 0dB.

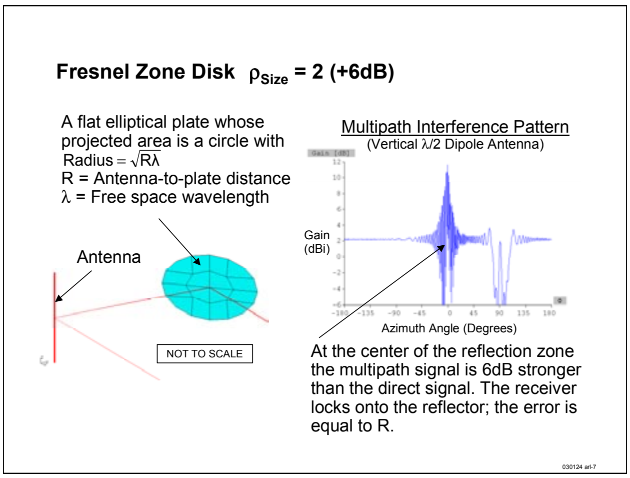

Figure 4

Figures 4 presents the results of a computer simulation demonstrating that, as predicted by theory, a Fresnel Zone Disc can produce a +6dB M/D. Detail of the interference pattern in the reflection zone is shown in Figure 5. Although a Fresnel zone reflector is highly improbable, the example demonstrates that a relativity small size reflector can create an M/D exceeding 0dB. At 1Km from the reference antenna a reflector with a projected area of 200m^2 could cause an M/D exceeding 0dB.

The maximum possible M/D for reflectors that have projected areas less than the Fresnel Area, Rλ, is presented in Figure 6. (Figure 7 presents a derivation of the equation, $\rho_{size} = A/R\lambda$.) Note that a 10m^2 reflector (a panel truck) at 1Km can cause an M/D exceeding –30dB.

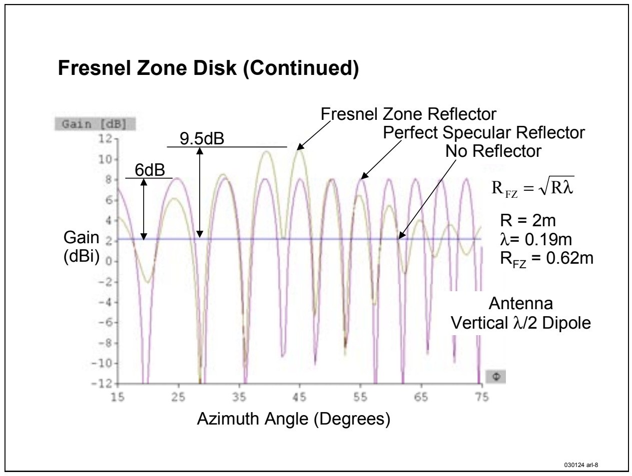

Figure 5

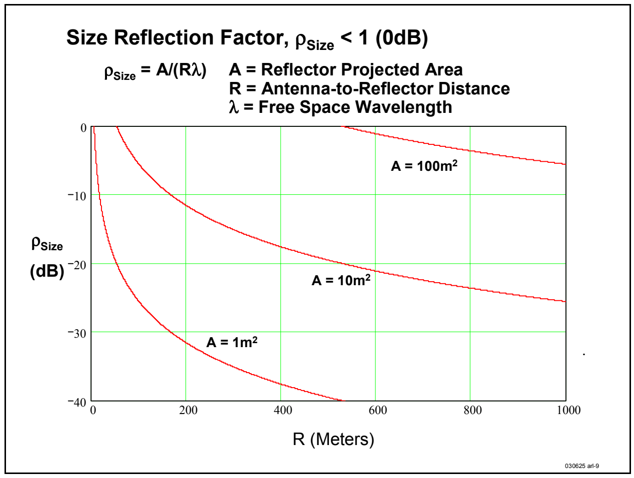

Figure 6

Derivation Of Multipath Formula For Small Flat Reflector

P = Power p = Power Density G = Antenna Gain A = Projected Area

$$p_{Direct} = \frac{P * G_{Direct}}{4\pi R^2} \qquad p_{Reflected} = \frac{P * G_{Reflected}}{4\pi R_1^2}\,\frac{A * 4\pi A/\lambda^2}{4\pi R_2^2}\left[\frac{R_1+R_2}{R_1+R_2}\right]^2$$

$$R_0 = \frac{R_1 R_2}{R_1+R_2} \qquad p_{Reflected} = \frac{P * G_{Reflected}}{4\pi(R_1+R_2)^2}\,\frac{A^2}{R_0^{\,2}\lambda^2}$$

$$\frac{p_{Reflected}}{p_{Direct}} = \frac{G_{Reflected}}{G_{Direct}}\left[\frac{R}{R_1+R_2}\right]^2\left[\frac{A}{R_0\lambda}\right]^2$$

$$\rho = \frac{V_{Reflected}}{V_{Direct}} = \sqrt{\frac{G_{Reflected}}{G_{Direct}}}\;\frac{R}{R_1+R_2}\;\frac{A}{R_0\lambda}$$

Gain Factor

Distance Factor

Size Factor

Figure 7

Aircraft surfaces are typically convex and reflections from these surfaces are reduced by the curvature of the surface. The curvature reflection factor was investigated during the development of MLS [4]. A relatively simple expression for this factor was derived and is presented in

Figure 8. This factor, in combination with the size factor, provides a simple means for estimating the M/D ratio for two of the most significant multipath objects in the airport environment, the aircraft tailfin and the aircraft fuselage. The size and radius of curvature for a 747 aircraft tailfin and fuselage are indicated in Figure 9.

An estimate of the interference caused by a 747 tailfin is shown in Figure 9. In Figure 9 the reference antenna is located 50 feet above the ground level (one approach to mitigation of the airport multipath problem is to locate the reference antenna above the local multipath such that the reference antenna up/down gain ratio suppresses the multipath level). The estimate indicates that even with the 50-foot height advantage, a tailfin at a distance of 200m can cause an error of about 1.5m.

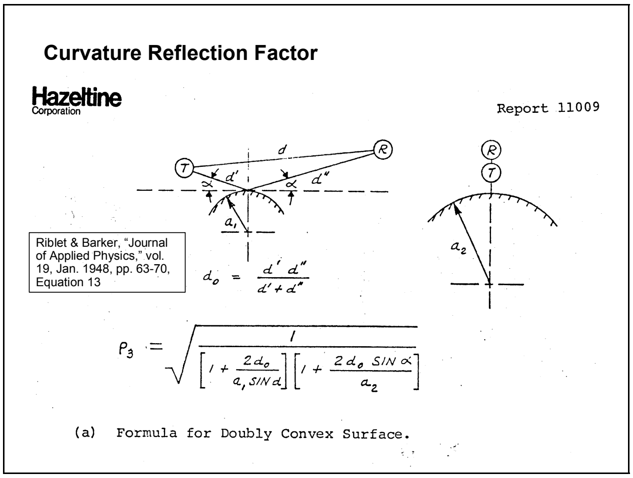

Figure 8

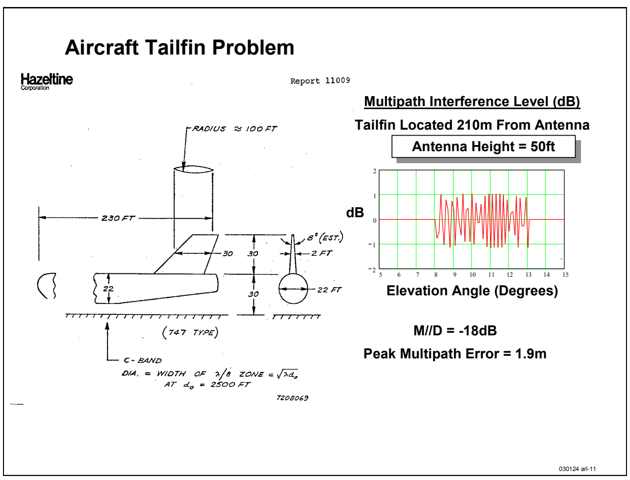

Figure 9

On the right side of Figure 9 is shown a geometrical-optics solution for the reflection from a 747 tailfin. The M/D ratio was estimated to be about –18dB, using the formula of Figure 3 and the curvature factor of Figure 8. The reflection zone extends from 8° to 13° in elevation and is about 30° wide in azimuth.

Figure 10 presents an example calculation of the M/D ratio. The case evaluated is for an aircraft fuselage with a radius of curvature of 3.3m. The evaluation is with respect to both the horizontal and vertical characteristics of the reflecting object. It is indicated that aircraft fuselages can cause M/D ratios of –30dB.

As noted in Figure 2, M/D ratios exceeding –30dB can cause errors that are large with regard to the LAAS accuracy requirement. It is argued that mitigation of the problem is required.

Evaluation of a Reflecting Object

Aircraft Fuselage, 3.3m radius, 300m from antenna, satellite at 5° elevation	Horizontal Factors	Vertical Factors	Product of Horizontal and Vertical Factors
Antenna Pattern	1	0.5	0.5
Surface Size	1	0.89	0.89
Surface Contour	1	0.07	0.07
Surface Reflectivity	1	1	1
		Product of Factors	0.031 (-30.2dB M/D)

Figure 10

MITIGATION OF AIRPORT LATERAL MULTIPATH PROBLEM

The traditional low-elevation-angle LAAS reference antenna [7] is linearly polarized. It is designed to have a large up/down antenna gain ratio to suppress ground multipath. One means for mitigation of the lateral multipath problem is to raise the antenna such that it is above the lateral multipath so that the large up/down antenna-gain ratio also suppresses lateral multipath effects. This is somewhat effective for close-in lateral multipath, but for a reflector at 300m a 12m increase in the antenna height only changes the elevation angle by a couple of degrees. Installing 3 or 4 reference antennas on 50ft (15m) masts with the required stability and constrained by airport safety requirements is difficult and probably not possible at some airports.

A circularly polarized LAAS reference antenna [3] provides a first level of lateral multipath suppression. In general, reflecting objects convert right circular polarization to a polarization ranging from left circular to linear. The polarization discrimination factor is typically greater than 6dB [6, p559] but can be as high as 30dB for flat metallic surfaces. The Fresnel Disc is used to illustrate the benefit of circular polarization.

The computer simulation that was used to get the results shown in Figure 4 for the Fresnel Disc was modified. A circularly polarized antenna replaced the linearly polarized ½ wavelength dipole antenna. Figure 11 shows that a circularly polarized antenna virtually eliminates the reflector-induced interference in the reflection zone.

The degradation in performance with increase in the polarization axial ratio is shown in Figure 12.

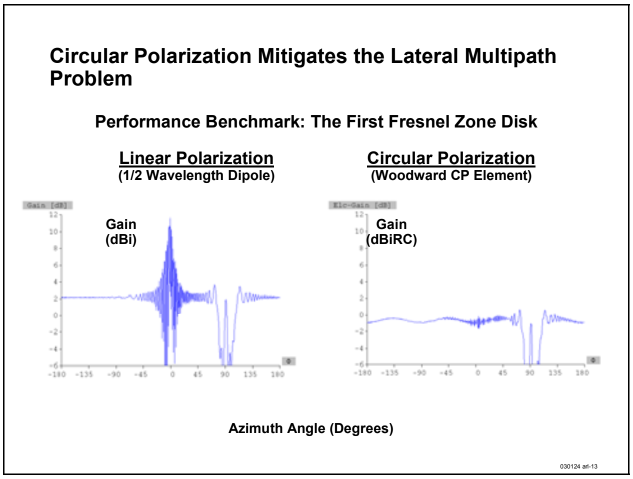

Figure 11

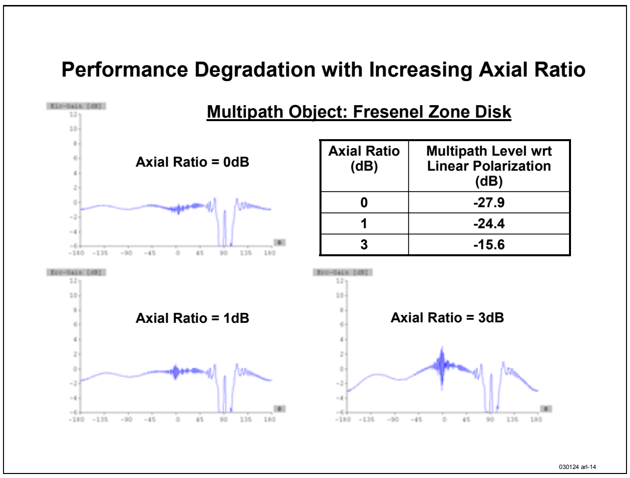

Figure 12

Circular polarization not only provides a benefit for the case of a direct reflection from an object, as summarized in Figure 13, it is also helpful for the case were the direct signal is reduced by shadowing caused by objects or the terrain. Polarization discrimination of the reflecting object can significantly reduce the M/D ratio. A question is raised as to whether or not circular polarization should be incorporated in the LAAS reference antennas. Braasch [6, p. 559] states, "Additional multipath attenuation by the antenna results from polarization discrimination ------------------ attenuation on the order of 10dB is typical." For aircraft surfaces, attenuation on the order of 20dB is typical. The argument for circular polarization is compelling.

LATERAL MULTIPATH IS A SEVERE PROBLEM

This section is intended to highlight the severity of the lateral multipath problem. It presents a computer simulation of a linearly polarized reference antenna that is designed with a sharp cutoff on the horizon. A Fresnel Disc is located on the horizon with its axis tilted up 10° from the horizon. Figure 14 shows the reference antenna, which is a collinear array of half-wavelength vertical dipoles, and the reflector. Figure 15 shows the unperturbed pattern of the reference antenna. The pattern has a cutoff of 2.6dB/° on the horizon. Figure 16 shows that a Fresnel Disc located 5m from the antenna can cause an M/D ratio of –2.2dB and an error of 7.7m. (The delay is 10m. The error, for small delays, is equal to the delay multiplied by the M/D voltage ratio, 10 x 0.77 = 7.7.)

Performance with Linear and Circular Polarizations

Reflecting Object	Peak Multipath Error (m)	
	Linear Polarization Ant. Height = 50ft	Circular Polarization 2dB Axial Ratio Ant. Height = 10ft
Fresnel Zone Disk (+6dB M/D)	Receiver loses track, may lock onto disk	3.0
747 Tailfin (-20dB M/D)	1.5	0.15
747 Fuselage (-30dB M/D)	0.5	0.05

Note: Satellite at low elevation angle

Figure 13

Figure 17 shows that a Fresnel Disc located at 15m from the antenna can cause an error of 18m. Figure 18 shows that a half-diameter Fresnel Disc at 15m from the antenna can cause an error of 10m. It is clear that the multipath problem associated with a linearly polarized reference antenna is severe.

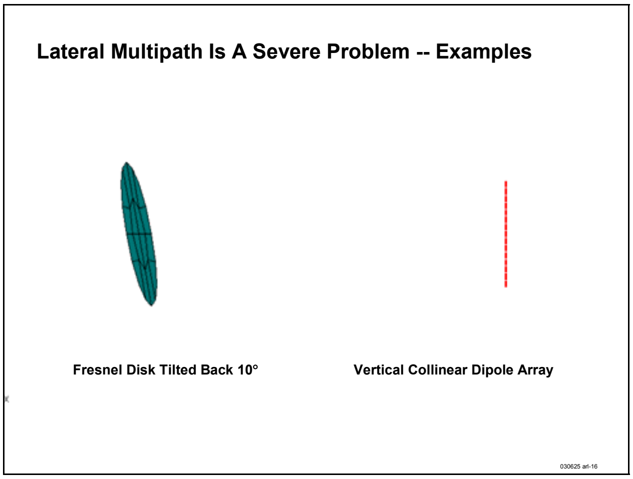

Figure 14

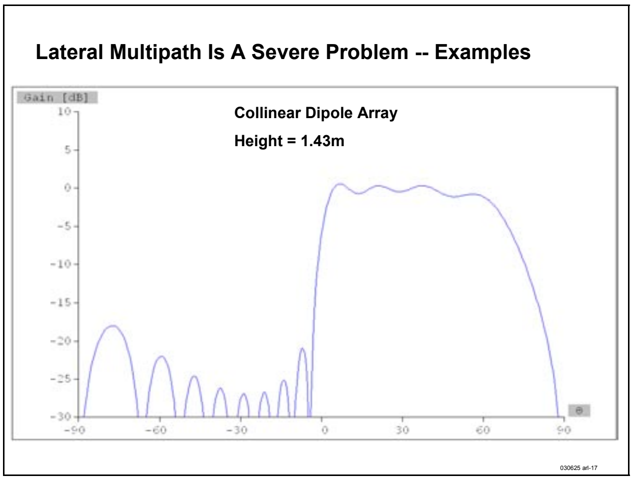

Figure 15

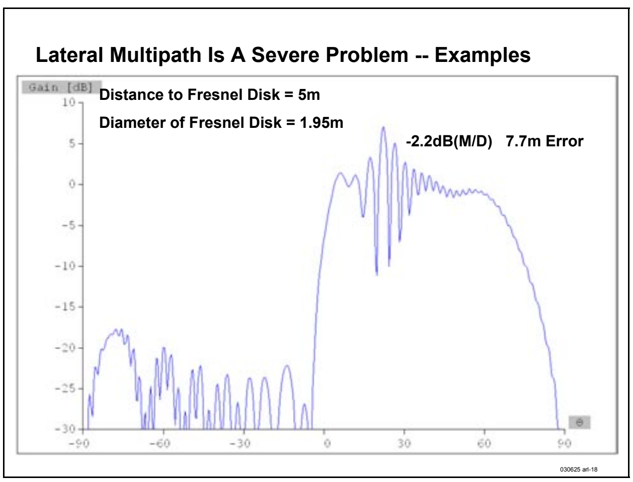

Figure 16

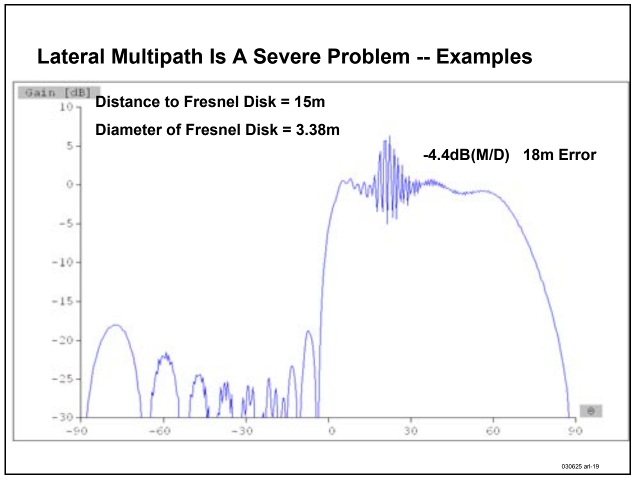

Figure 17

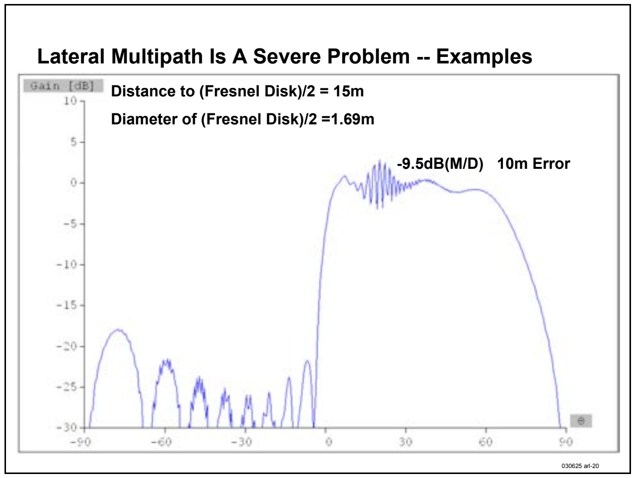

Figure 18

SUMMARY

This paper highlights the fact that lateral multipath is a significant problem for the LAAS reference antennas. The airport environment can create very high multipath signal levels for satellites at low elevation angles. Possible shadowing effects increases the severity of the problem.

Aircraft surfaces can cause significant multipath errors. The transient nature of these effects is of special concern and will affect the reference antenna siting criteria at many airports.

Some reflecting objects can cause M/D ratios that exceed 0dB. In other cases, shadowing of the direct signal can also cause M/D ratios that exceed 0dB. In both of these cases it is possible that the multipath signal will be acquired and tracked. This could impede the initial acquisition of satellites at low elevation angles.

Circularly polarized (as opposed to linearly-polarized) LAAS reference antennas can substantially mitigate the lateral multipath problem. Circular polarization should be incorporated in the design of the LAAS reference antenna.

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