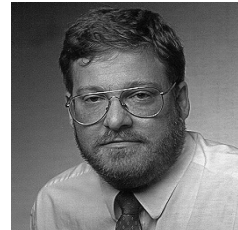


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COMPARISON OF GLIDE SLOPE PERFORMANCE AT A CHALLENGING SITE

ABSTRACT

The Federal Aviation Administration (FAA) is currently evaluating a new glide slope system configuration to be used at difficult sites characterized by rising terrain below the approach path. This system is the Model 107, upslope endfire glide slope system. The upslope system is currently being tested on runway 05 at the Columbus Metropolitan Airport (CSG), Columbus, Georgia. The upslope system was installed and a test program was initiated to evaluate the upslope for approval in the NAS. In addition, a site test was performed with the capture-effect, sideband-reference, and null-reference glide slopes to show a comparison between five glide slope systems given the same challenging siting environment. Data from the previous Model 105 endfire glide slope was added to the comparison. The paper provides an overview of the upslope system, status of the current upslope evaluation for use in the NAS, and comparison of performance of the various image and non-image glide slope systems. The comparison of performance will include mathematical modeling results as well as flight measurements to quantify signal-in-space quality.

PURPOSE

To provide a glide slope solution at Columbus, Georgia that will allow for airport expansion and to demonstrate performance of various glide slopes at a very poor siting location.

BACKGROUND

The Columbus Metropolitan Airport, Columbus, Georgia is served by runways 05/23 and 12/30. Runway 05 is the primary instrument runway and the only runway served by an Instrument Landing System. In the 1960's, the FAA tested an Australian Array designed by R.W. Redlich at this site trying to find a suitable glide slope. After the test, a capture-effect glide slope located on the northwest side of the runway was commissioned and provided satisfactory performance until 1990.

In the late 1980's, the Columbus Metropolitan Airport began planning for a taxiway expansion project. This expansion project would necessitate relocating the glide slope to the opposite or southeast side of the runway. Adequate real estate was not available to site an

image type glide slope outside the runway object free area, so a standard endfire glide slope was sited.

The standard endfire glide slope was installed in 1990 and commissioned with out of tolerance structure around ILS point B. This structure caused a facility restriction that both raised the decision height and disallowed coupled approaches. The high structure is a result of the standard endfire glide slope's inability to perform in an environment with up-sloping terrain located below the approach to the runway.

A developmental version of the endfire glide slope capable of performing in an upslope environment had been tested in 1980, but was not pursued when site requirements for this type of system could not be identified. A decision was made to test the upslope endfire glide slope at Columbus. These tests were completed in 1991 showing favorable improvement over the standard endfire glide slope. A decision was then made to move forward with the upslope endfire glide slope at Columbus. This decision would require the development of a monitor system as well as adequate testing of the system to approve its use in the National Airspace System (NAS).

A capture-effect glide slope system was again installed on the northwest side of the runway to allow for the permanent conversion of the standard endfire glide slope to an upslope configuration. The capture-effect performed only marginally and required antenna heights, which produced a 2.61° path angle. This lower angle resulted in optimum performance from the capture-effect system. An upslope endfire glide slope was permanently installed on the southeast side of the runway in 1997. This same location would later serve to conduct site testing of image type glide slopes for performance comparison.

SITE

The area of consideration for a glide slope installation on the southeast side of the runway is described as having a truncated ground plane both laterally and longitudinally. The runway shoulder gradually slopes downward until about 400 feet from centerline, and then quickly drops off about 40 feet in elevation. The terrain in front of the glide slope antenna area gradually slopes downward. This downward slope continues past the threshold for about 1500 feet where elevation is about 25 feet below threshold elevation. At this point, the terrain begins to rise upward until about 2400 feet from threshold where elevation is about 18 feet above threshold elevation. Figure 1 illustrates the Columbus, GA site looking from the glide slope shelter toward the approach. Figure 2 is a graphical representation of a side cut view of the terrain toward the approach region.



Figure 1: Columbus site viewed from shelter toward approach.

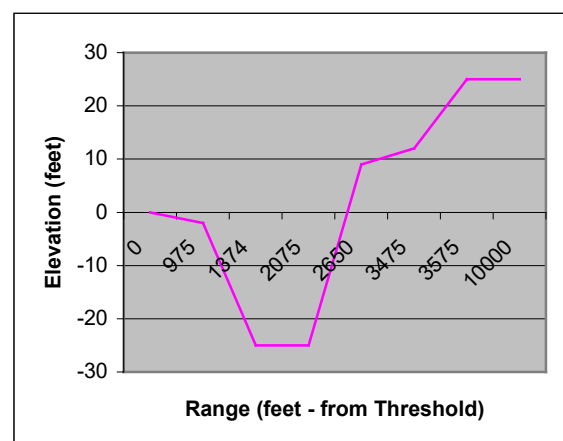


Figure 2: Graphical representation of terrain at Columbus.

UPSLOPE OVERVIEW

Upslope Description

Transmitting Subsystem. The Upslope Endfire Glide Slope (UEFGS) consists of front, middle, and rear main transmitting antennas along with a single clearance. The front and rear antennas consist of eight slotted-cable sections, each 15 feet long with 12 radiating slots in each section to produce a 4.0° path angle and a very sharp path width. The rear antenna is positioned to form a concave shape with a 445-foot radius. Similarly, the front antenna forms a convex shape with a 445-foot radius. These two antennas are 120-feet long with a separation distance of 890 feet in the dimension parallel to the runway.

In conjunction with the front and rear antennas, the middle antenna, consisting of four-slotted-cable sections each 15-feet in length with 12 radiating slots in each section, produces the below path cancellation to suppress the multipath and form the proper glide path angle and width.

The clearance antenna consists of one-slotted cable section, 15-feet long with 12 radiating slots. In conjunction with the front and rear antennas, the clearance antenna provides the necessary 150-Hz fly-up signal below and to the sides of the glide path proportional guidance sector. The phasing of the clearance signal is such that the clearance signal is substantially reduced in the vertical proportion sector. The clearance in the UEFGS performs in both the vertical and horizontal planes. This is different than the standard endfire glide slope, which provides off-azimuth, horizontal plane, clearance and the capture-effect in the vertical plan, below path. Table 1 contains a summary of the signals in each antenna.

Antenna	Signals
Front	CSB, SBO, CLR
Rear	CSB, SBO, CLR
Middle	CSB, SBO
Clearance	CLR

Table 1: UEFGS Transmitting Parameter List.

Monitoring Subsystem. The UEFGS monitor system consists of the following components:

1. Three field monitors
2. Components for integral monitoring of the front, rear, middle, and clearance antennas

The field monitoring antennas consist of one slotted-cable section 8-feet long with 6 slots. The locations of the three-field monitors (M1, M2, and M3) were chosen to monitor the glide slope path angle, which correspond to ILS Point A, B and C.

The UEFGS system also uses integral monitoring. The residual signals from the ends of the transmitting antennas are fed back into the Amplitude and Phase Control Unit (APCU). These four signals are combined to produce readings of path angle, path width, Rf signal-level, and percent modulation of the course signal as well as the clearance Rf level and percent modulation.

The most unusual feature used in the endfire glide slope is the snap-down technique which uses a synchronized pulse to control two Rf switches in both the front and middle antennas. During the snap-down pulse time, an attenuator and specified length of delay line is electronically switched into the front and middle antenna feed lines. These changes in the phase cause the path to shift or snap-down where the monitors, M1, M2, and M3 can evaluate the signal, i.e. path angle in various azimuth locations. At the same time the path is lowered the clearance signal is routed to a dummy load. This insures that the M1, M2, and M3 antennas will not be affected by the clearance energy during the sampling of the on-course signal. The attenuators placed in

the antenna feed lines are used to compensate for the unequal signal levels in the front, middle, and rear antennas as measured at the three field monitors. The snap-down pulse has a duration of 100-microseconds and occurs 60 times a second. Because of this short duration, the airborne course deviation indicator is not affected.

A total of seven monitor lines are routed into the APCU. These signals originate from the front, middle, and rear main antennas, clearance antenna and three field monitors. From these sampled signals, the UEFGS monitoring unit evaluates 13 different parameters. Table 2 provides a list of the monitoring parameters and the corresponding monitor signals.

Monitoring Parameter	Monitor Signal(s)
Path	F,M,R,C
Percent Modulation	F,M,R,C
Rf-Level	F,M,R,C
Width	F,M,R,C
CSB-SBO Phasing	F
Clearance Modulation	F,R,C
Clearance Rf-Level	F,R,C
M1 Transverse Structure	M1 Monitor
M1 Rf-Level	M1 Monitor
M2 Transverse Structure	M2 Monitor
M2 Rf-Level	M2 Monitor
M3 Transverse Structure	M3 Monitor
M3 Rf-Level	M3 Monitor
Notes: F, M, R, and C corresponds to the integral monitor from the front, middle, rear, and clearance antennas respectively.	

Table 2: UEFGS Monitor Parameters verses Signals.

UPSLOPE EVALUATION

The upslope endfire glide slope was installed by the FAA at Columbus, GA in 1997. Work continued from August 1998 through March 2001 to optimize the transmitting operation of the upslope system, develop a monitor system that properly tracked the performance of the transmitting subsystems, and redesign the clearance radiated signal – which resulted in a single-clearance antenna with integral monitoring. In late 2001, optimization and monitor development work was completed. The system still exhibits a close-in path reversal, but was deemed optimized. The transmitting and monitoring subsystems are currently operating in a test configuration. The

system is operating on a non-published, non-localizer paired frequency. The system is operating to evaluate signal in space as well as monitor stability. The intent of this testing is to evaluate the system for long-term performance, system stability in a wide range of weather conditions, and overall maintainability of the system. Currently, the upslope endfire glide slope is operating in a test configuration with monitor data as well as environmental data being recorded. Figure 3 is recorded data of the upslope endfire system showing the variation of the executive monitor parameters with respect to environmental conditions including temperature, precipitation, wind speed, and barometric pressure.

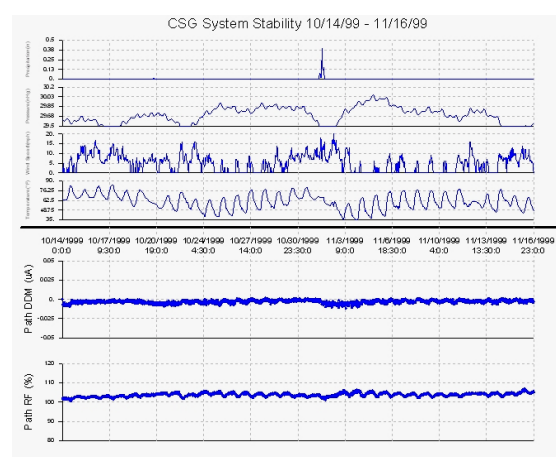


Figure 3: Recorded monitor and environmental data of upslope endfire glide slope system.

GLIDE SLOPE COMPARISON

Site Test

System Setup. For comparison purpose, and to determine if another type of glide slope would be suitable to provide the desired service, a site test was performed using an image system on the same side as the installed upslope. While performing this site test, all three image glide slope systems currently in service in the National Airspace System were evaluated. Specifically, the null-reference, sideband-reference, and capture-effect glide slope configurations were tested. A portable glide slope mast was used to mount the antennas, figure 4 and a Wilcox Mark 1F

transmitter with Mark 1C distribution units were placed in a van to drive the antenna arrays, figure 5. The site test used the same frequency as the upslope system, 329.45 MHz.



Figure 4: Image Glide Slope Test Setup.



Figure 5: Image Glide Slope Transmitter and Distribution.

The portable mast was located 232 feet offset from the runway centerline and setback 877 feet, resulting in a Threshold Crossing Height of 50 feet with a 3° path angle. This location was next to the existing shelter. The antenna heights were established to obtain a 3° path angle. In the cases of the sideband and null-reference, the theoretical heights were set since the structure roughness from the multipath biased the angle and limited time did not allow multiple adjustments. Table 3 contains the final antenna heights and offsets used in the site test for the three glide slope configurations evaluated.

Antenna	Null-Reference		Sideband-Reference		Capture-Effect	
	Height (ft)	Offset (in)	Height (ft)	Offset (in)	Height (ft)	Offset (in)
Lower	13.76	12.77	6.92	7.84	13.67	7.84
Middle	N/A	N/A	N/A	N/A	27.42	0
Upper	27.52	0	20.61	0	41.83	(22.56)

Table 3: Antenna Positions of Glide Slope Configurations Tested.

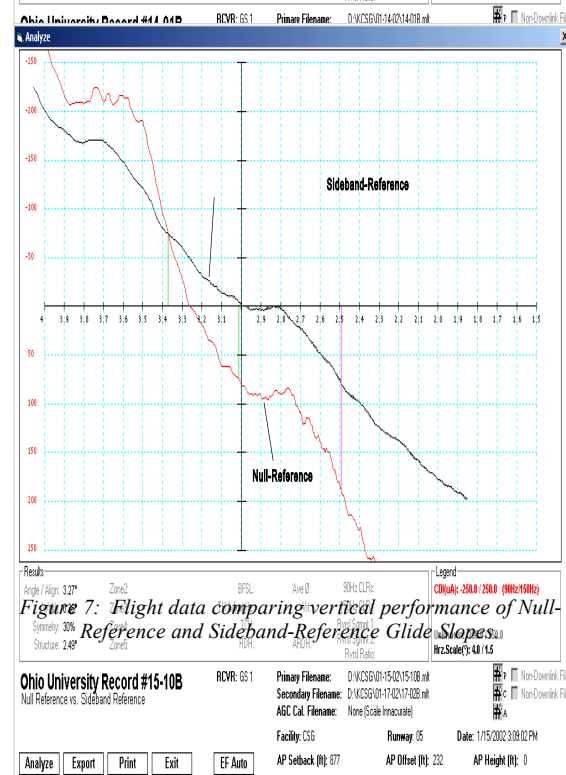
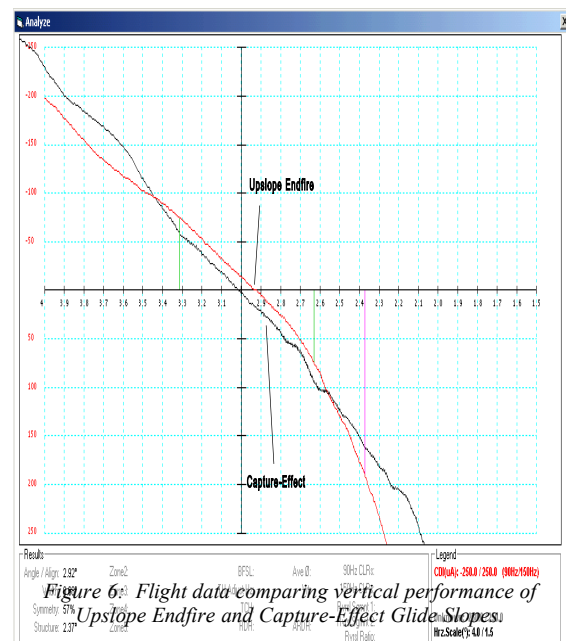
Test Results

Upslope Endfire Glide Slope. Since the upslope had previously been optimized for the test, periodic measurements were performed on this system prior to any setup of the image systems. These results include verification of the proportional guidance sector, approach, and transverse structure. These results showed no difference to previous measurements collected in August 2001. In fact, the upslope system provides for a very smooth and straight path between ILS Point A and B, as shown in figure 9. There is, however, a quick change of path direction, 150 Hz predominance, at ILS point B. This change of direction as evaluated using current reversal criteria would qualify as a path reversal and the location at this point would determine the minimum altitude to which coupled approaches would be authorized. FAA Flight Inspection determined that coupled approaches would not be authorized below 260 feet AGL.

Endfire Glide Slope. The endfire system was installed before the upslope and currently commissioned capture-effect system. A review of past measurements was performed and included in this paper for completeness. The endfire system allows for adjustment of support pedestals to shape the path. Attempts were made to do this, but in all cases the structure roughness remained out of tolerance because of reflections. The level run had significant steps, which resulted in higher than normal sideband power to obtain the desired path width. By using the mean width method, the sideband power was reduced significantly for the structure roughness to be within tolerance.

Image Glide Slopes. After the test configuration was setup and aligned using standard phasing procedures, level run measurements were performed on each configuration to measure the width, symmetry, structure angle, and path angle on centerline and at the edges of both sides of the localizer course (tilt). For the null-reference, sideband-reference, and standard endfire, the level runs exhibited steps in the vertical proportional guidance sector which was caused by the upsloping terrain under the approach path as seen in figure 2. Only the upslope and capture-effect systems showed a linear glide slope crossing, indicating reflections from the terrain are minimized with the below-path cancellation provided by these two systems. The sideband power was not adjusted to tighten the width since with previous tests, the endfire indicated that the single point method of evaluating the width would give broader than normal widths resulting in more roughness. The sideband powers used for the site test were set for typical values used in sites with adequate ground planes.

Flight measurement data comparing vertical performance of the upslope endfire and capture-effect glide slopes is provided in figure 6. Flight measurement data comparing vertical performance of the null-reference and sideband-reference glide slopes is provided in figure 7. Flight measurement data illustrating the vertical performance of the standard endfire glide slope is provided in figure 8. A summary comparing vertical performance for all glide slope configurations is provided in table 4.



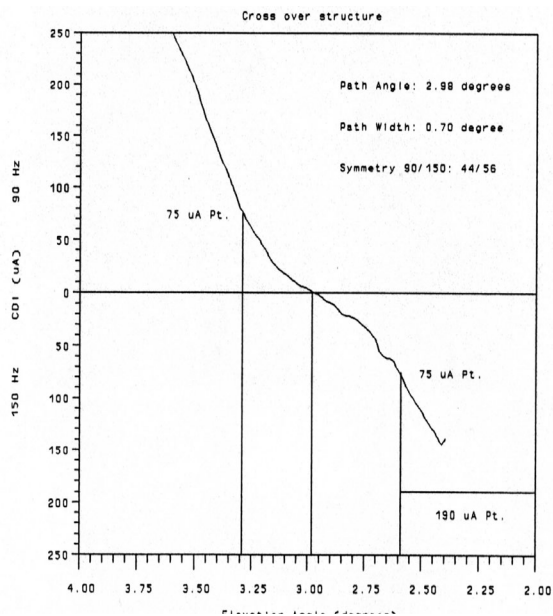


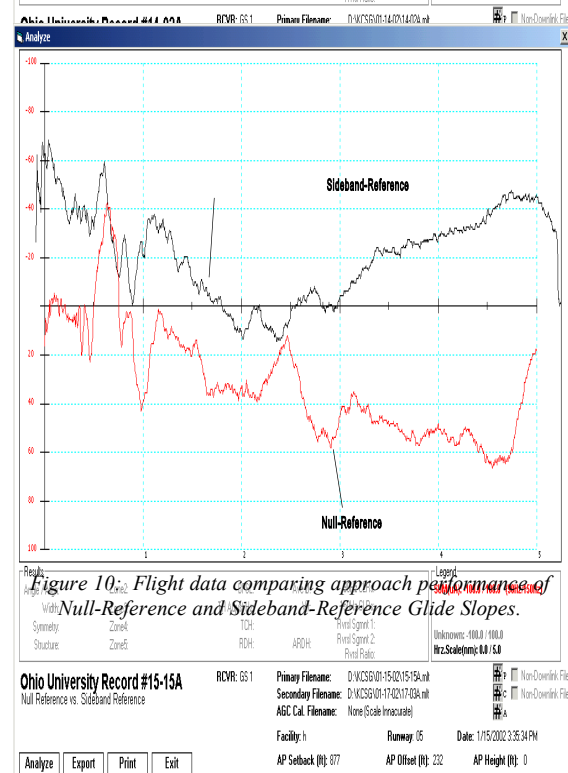
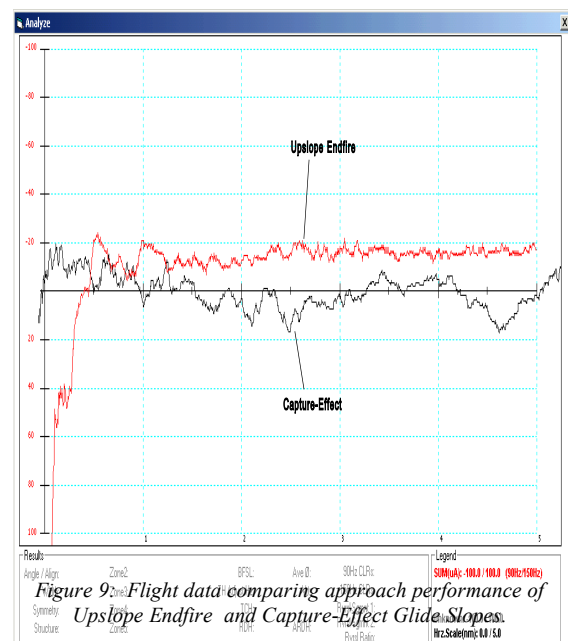
Figure 8: Flight data illustrating vertical performance of Standard Endfire Glide Slope.

Glide Slope Configuration	Path Angle (°)	Width (°)	Symmetry (%)	Structure Angle (°)	90 Hz Tilt (°)	150 Hz Tilt (°)
Null-Reference	3.23	0.79	26	2.21	3.44	3.28
Sideband-Reference	2.83	0.87	62	1.90	2.88	2.90
Capture-Effect	3.02	0.69	49	2.26	2.92	2.68
Standard Endfire	2.98	0.70	44	2.59	N/A	N/A
Upslope Endfire	2.97	0.68	52	2.37	3.19	2.85

Table 4: Flight measurement results comparing vertical performance of all glide sloped considered.

As one would expect, based on the limited lateral ground plane, the path angle at the edge of the 150 Hz localizer edge is low for all image systems. In fact, the path angle for the capture-effect system is out of tolerance. Approaches were made on path on the 150 Hz localizer edge, and found to be just in tolerance at 2.78°. In addition, the level runs also indicated that the below path clearances were soft on this side as well. Further investigation revealed that the course signals were reflecting up into this area resulting in low clearances. Increasing clearance power helped, but caused unsatisfactory conditions with the symmetry of the proportional guidance sector. Initial measurements of the capture-effect system on centerline indicated out of tolerance

conditions, requiring adjustments to the middle and upper antenna phasing to improve the path structure. These adjustments caused additional problems on the 150 Hz tilt. Flight measurement data comparing approach performance for the upslope endfire and capture-effect glide slopes is illustrated in figure 9. Flight measurement data comparing approach performance for the null-reference and sideband-reference glide slopes is illustrated in figure 10. Flight measurement data illustrating approach performance for the standard endfire glide slope is provided in figure 11. Table 5 illustrates comparative results of structure roughness of all glide slopes considered.



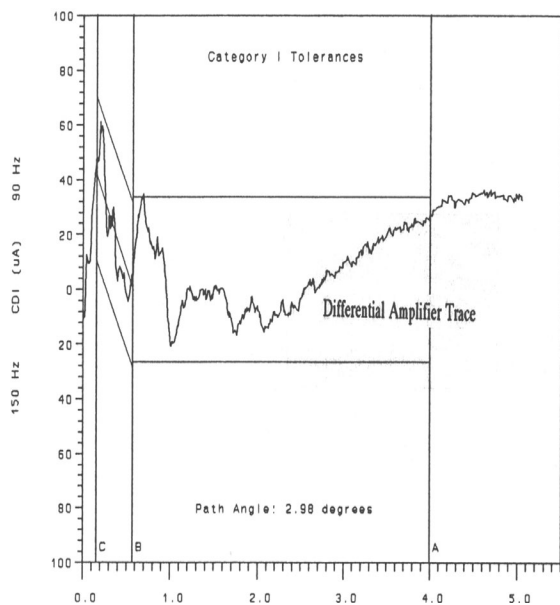


Figure 11: Flight data illustrating approach performance of Standard Endfire Glide Slope.

Glide Slope Configuration	Measured Structure Roughness			
	Zone 2		Zone 3	
	μA	% Tol	μA	% Tol
Null-Reference	73.6	245	22.1	74
Sideband-Reference	47.6	159	11.9	40
Capture-Effect	16	53	5.8	19
Standard Endfire	31	103	26	87
Upslope Endfire	10.2	34	17.4	58

Table 5: Flight measurement results comparing structure roughness of all glide slopes considered.

Vertical sideband patterns have been used in the past to show the roughness factor based on the elevation of the offending source. The roughness measured for each system type was used to validate this factor. Table 6 shows a comparison between the theoretical and those measured at this challenging site.

Glide Slope Configuration	Roughness Factor (%)	
	Measured – Zone2	Theoretical - 1° Elevation
Null-Reference	100	100
Sideband-Reference	65	79
Capture-Effect	22	16
Standard Endfire	42	59
Upslope Endfire	14	4.9

Table 6: Comparison between measured and theoretical roughness factor.

Modeling Results

Theoretical vertical sideband radiation patterns for each of the glide slope systems considered are plotted in figure 12. This figure compares relative sideband

amplitude verses elevation for the glide slope systems evaluated.

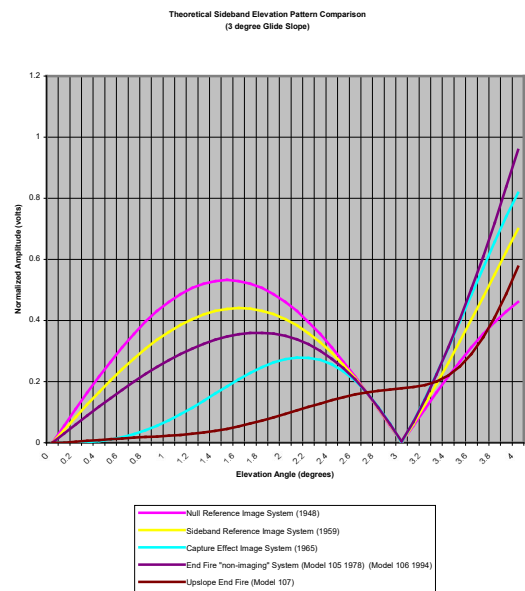


Figure 12: Comparison of theoretical sideband radiation patterns of glide slope considered.

The terrain for this site as previously described was included in the FAA/Ohio University geometric of diffraction model (OUGTD) to provide a comparison between the predicted and measured performance. Figure 13 compares the modeled vertical performance of the image glide slopes evaluated. Figure 14 compares the modeled approach performance of the image glide slopes evaluated. Figure 15 illustrates the design approach performance of the upslope endfire glide slope. A summary of the results is contained in table 7 and table 8. The upslope modeling did not include terrain, but only the antenna locations.

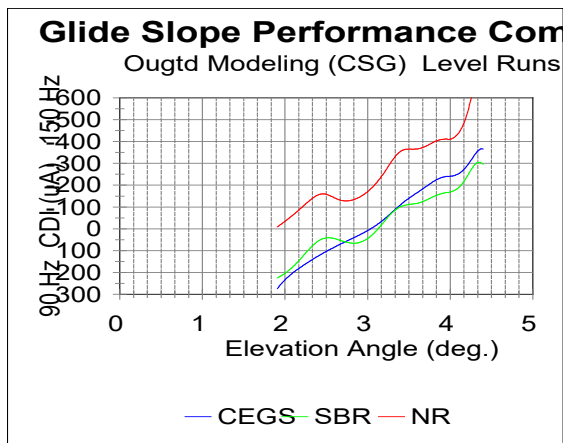


Figure 13: Modeled vertical performance of image glide slopes tested.

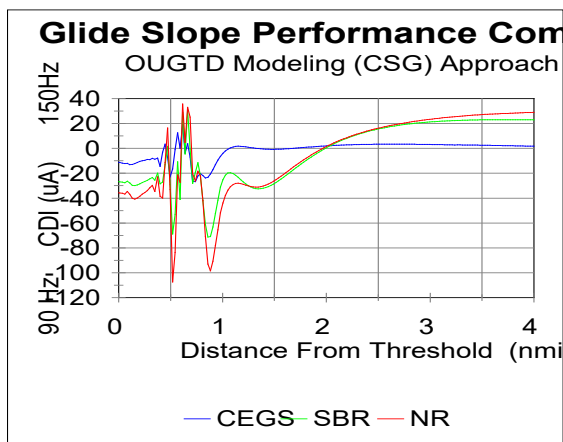


Figure 14: Modeled approach performance of image glide slopes tested.

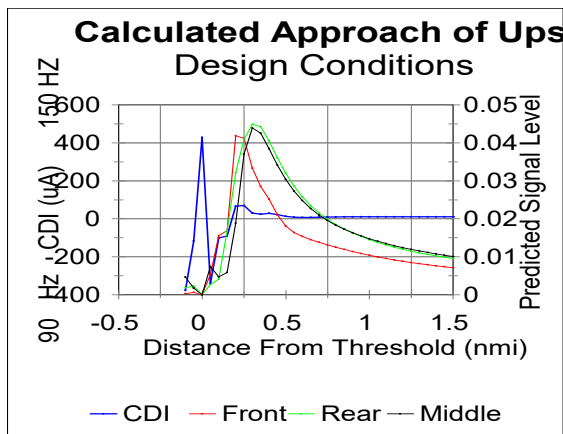


Figure 15: Design approach performance of the upslope endfire glide slope.

Glide Slope Configuration	Modeled Structure Roughness			
	Zone 2		Zone 3	
	μA	% Tol	μA	% Tol
Null-Reference	35	118	23	76
Sideband-Reference	31	103	20	66
Capture-Effect	19	63	3	10

Table 7: Summary of modeling results for structure roughness.

Glide Slope Configuration	Path Angle (°)	Width (°)	Symmetry (%)	Structure Angle (°)
Null-Reference				
Sideband-Reference	3.13	0.96	69	2.08
Capture-Effect	3.04	0.64	53	2.17

Table 8: Summary of modeling results for vertical performance.

As seen by figure 15, the characteristics of the path are similar to those measured. Further investigation has indicated that this is caused by the large separation between the antennas and is caused by the power imbalance with the receiver in the near field of the antenna system.

CONCLUSION

Based on the site testing of five glide slope configurations at a challenging site, one with limited terrain along the approach path as well as laterally, the following conclusions are reached:

1. Glide Slope systems with cancellation of the course signal at low elevations provide for a smoother glide path.
2. To obtain satisfactory performance throughout the service area, the capture-effect principal should be used in both the vertical and horizontal planes.
3. The performance obtained from the various system types is consistent with the modeling and the glide slope selection criteria contained in siting orders.

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