

# An Overview of End Fire Glide Slope System Characteristics and Flight Inspection Methods

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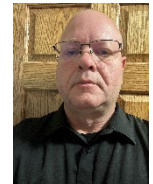
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## ABSTRACT

End Fire Glide Slopes (EFGSs) are specialized Instrument Landing System (ILS) components installed at locations where a standard image array glide slope cannot be accommodated due to terrain, space limitations, or other site constraints. Because of these restrictions, EFGS configurations are considered a last-resort solution and are relatively uncommon. Unlike conventional glide slopes, EFGS systems transmit the course signal using a pair of long (> 75 feet) slotted cable antennas positioned horizontally near the runway to project the glide path along the runway centerline. Precise alignment of these antennas is critical to ensure a uniform glide slope signal across the service volume, and novel monitoring techniques are used to detect adverse environmental effects. To validate lateral consistency of the glide slope signal, flight inspection includes a transverse structure run, which measures signal performance to the left and right of the course. These evaluations confirm that the glide slope provides accurate and reliable guidance for aircraft during approach. This document outlines the operational principles, major system components, typical facility layout, antenna installation and alignment considerations, and verification methods associated with EFGS systems, emphasizing their role in maintaining safety and compliance in challenging environments.

## INTRODUCTION

The main challenge for the glide slope (GS) component of the ILS is the presence of irregular and/or rising terrain in front of the glide slope. In traditional image-type GS systems, glide path formation uses both the direct and ground reflected (image) RF signals. This requires a sufficiently sized and reasonably smooth ground plane for optimum performance. There are three types of image GS systems; Null Reference (NR), Sideband Reference (SBR), and Capture Effect (CE). The specifics of the terrain and antenna mast height constraints generally dictate which system is selected.

At most airports, an adequate ground plane can be constructed with minimal grading that will enable one of the three commonly available image GS systems to be used. However, an ILS precision approach could not be established at some airports because of two terrain issues that could not be accommodated by any of the image system variants.

- 1) Short (less than 800 ft) or non-existent ground planes in front of the GS antennas
- 2) Insufficient land alongside the runway to meet the runway safety area (RSA) offset requirements for installation of a 20- to 45-foot-tall GS antenna mast

The non-image EFGS system offers a solution to these issues. When compared with the image GS systems, EFGS performance is similar to the SBR GS in that it can accommodate a short ground plane. Like image systems, its performance can be impacted if the terrain is too irregular or if terrain farther out in the approach area rises too steeply.

Although the EFGS system makes an ILS precision approach possible at those airports where this would not be otherwise achievable, the system design, tune-up procedure, and operational needs significantly differ from those of the image GS system. Thus, this situation requires installers, maintenance personnel, and flight inspection crews to have specialized EFGS knowledge.

### SYSTEM COMPONENTS

The nine components of the Models 105/106 EFGS systems produced by the Watts Antenna Company are shown in Figure 1, and their descriptions follow:

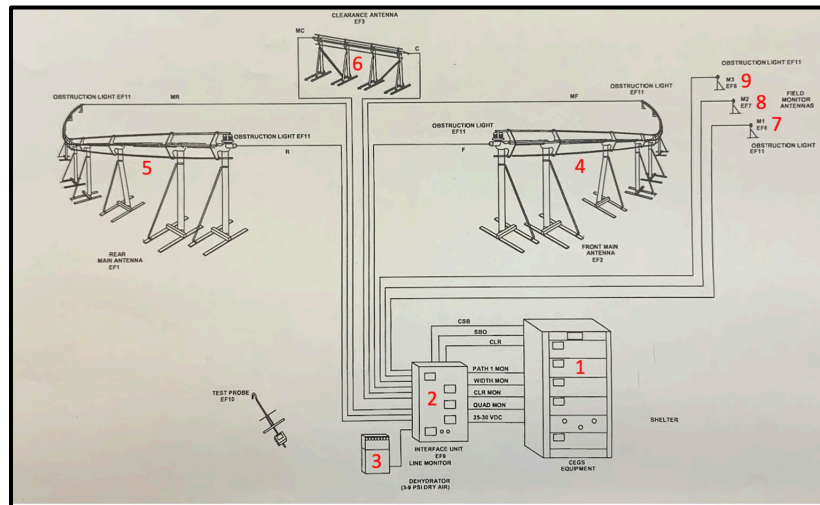


Figure 1. The Components of the EFGS System [1]

1. Dual-Frequency ILS GS Transmitter Station – includes course and clearance transmitters, integral monitor with executive shutdown function
2. Interface Unit (EF9) – Contains the RF distribution/combining networks, multi-input wattmeter, snap-down monitor circuitry with field monitor meters
3. Automatic Air Dehydrator Pump and Line Monitor – Provides dry air at 3 to 9 psi to pressurize the air-dielectric RF cable and antennas with the ability to read the pressure in each line
- 4-5. Front/Rear Main Antennas – Each composed of five (Model 106) or eight (Model 105) slotted-cable sections, each 15 feet in length, with 12 radiating slots in each section, erected in convex/concave shapes of 220-foot radius; monitored integrally and by field monitor antennas M1, M2, and M3
6. Clearance Antenna – Composed of a slotted-cable antenna with 12 radiating slots; provides “fly-up” clearance guidance signal to the sides of the main beam and is integrally monitored
- 7-9. M1, M2, M3 Field Monitor Antennas - Located 600 feet forward of the phase center and positioned to sample three distinct azimuth points, provides signals for channels 1, 2 and 3 snap-down monitor

## UNIQUE SYSTEM CHARACTERISTICS

The basic principles of the EFGS are like those for image-type glide slope systems in terms of signal radiation. That is, the EFGS radiates the same type of signals, including the Carrier and Sideband (CSB), Sideband Only (SBO) and clearance signals. However, the radiation patterns produced are unique to the EFGS. This uniqueness results from using two antennas separated horizontally instead of the vertical stack used in image-type systems. In its simplest form, two antenna elements (e.g., dipole) can be used for the antenna array - one element for the front and the other for the rear antenna. The azimuth pattern of this simple EFGS produces a glide path in the shape of a narrow cone with an axis horizontal to the approach region as shown in Figure 2a while the image systems produce a wide cone with an axis vertical to the approach region as shown in Figure 2b. The danger of the narrow cone is that a deviation by the pilot at the edge of the cone can cause a hard fly down signal to be received.

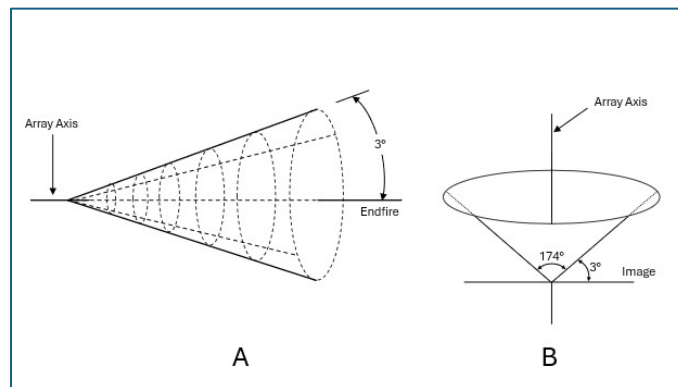


Figure 2. Glide Path Cone for EFGS and Image Type GS

Chester Watts, founder of the Watts Antenna Company, broadened the azimuth coverage of the EFGS path by using two curved arrays made of long (> 75 feet) slotted cable antennas for the front and rear antennas. The rear array has a focal point in front of the antenna while the front antenna has its virtual focal point located behind it. The separation between the rear and front arrays is selected such that the two focal points are at the same location. The front antenna is typically located about 775 feet from the threshold, while the rear antenna is located 1225 feet from the threshold. Figure 3 illustrates the basic Watts EFGS configuration. The role of the clearance antenna is discussed in the following section.

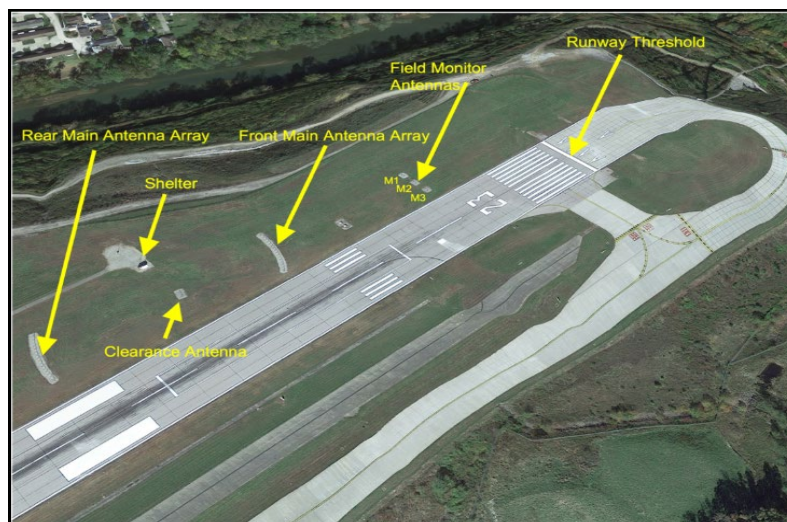


Figure 3. Example EFGS Configuration

## Antenna Radiation Patterns

The effect of making the focal points converge to the same point is that in the far-field region, the path appears to originate from a common phase center between the two arrays. This characteristic results in fewer variations in path angle over a change in azimuth, thus providing wider azimuth coverage. Figure 4 shows an example of far-field patterns for an EFGS as a function of azimuth angle. Note that the CSB signal is relatively flat with a sharp drop-off at the edges of the coverage sector. That is, the radiation pattern of main antennas results in an indicated 90-Hz fly-down on the Course Deviation Indicator (CDI) at the edge of the proportional guidance sector.

To remedy this situation, a clearance antenna radiating a 150-Hz ("fly-up") signal was added to provide protection outside of the achieved azimuth coverage sector. The clearance signal is minimum where the CSB is maximum, while it peaks at the edge of the coverage sector to provide the necessary hard fly up outside of the coverage sector. The addition of the clearance signal adds approximately 4 degrees to the transverse structure width. The CDI traces with and without the clearance signal represent the transverse or azimuth structure of the EFGS system. Lateral deviations by the pilot can cause the path angle to change due to the roughness of the transverse structure. The transverse structure roughness is a consequence of slot excitations or pedestal location errors. The transverse structure region produced by the EFGS provides the GS proportional guidance sector.

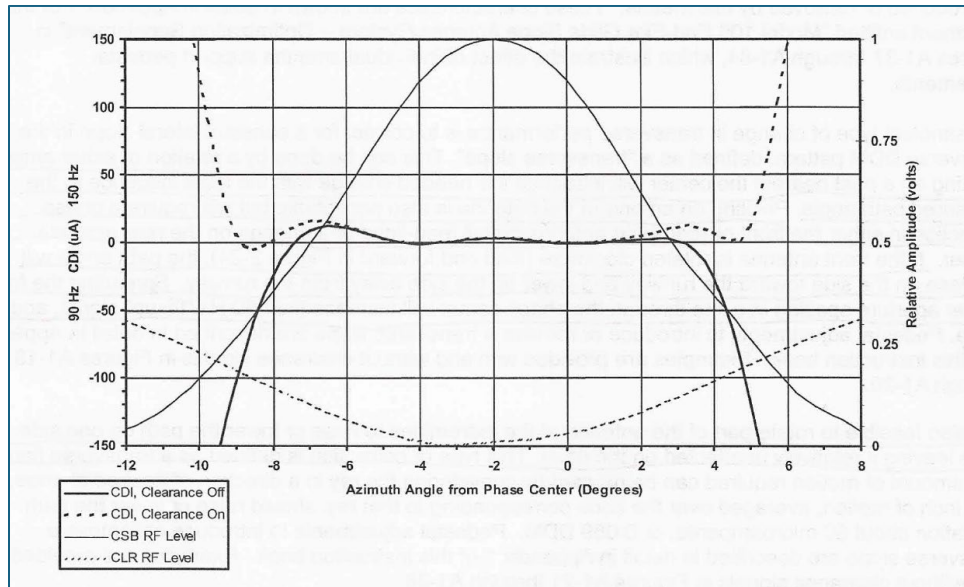


Figure 4. Theoretical main antenna patterns [1]

Other unique EFGS system characteristics include the following:

1. Because the main transmitting antennas cannot be located on the runway centerline, and glide slope coverage is needed out to the edges of the localizer course, using only a few single radiating elements for each antenna will not provide suitable coverage. The use of an RF slotted-cable antenna array that contains a multitude of radiating elements (see Figure 5), with the capability to adjust the RF energy output at each radiating slot, is the only practical way to achieve the necessary glide slope azimuth coverage. The length of the main transmitting antennas is dependent upon the amount of azimuth coverage needed and how close the array is to the centerline of the runway.



Figure 5. Rear Main Transmitting Antenna of the EFGS

2. A separate clearance transmitter and antenna is required to mask the natural presence of the hard 90 Hz fly-down in the azimuth regions outside of the proportional EFGS coverage area. This would be a dangerous and inappropriate indication for pilots that are in the process of intercepting the localizer course. A clearance antenna is therefore properly aimed and fed with a 150 Hz fly-up signal to eliminate this issue.
3. The RF phase relationship between the main transmitting antenna arrays must be strictly maintained to keep the glide path angle at three degrees. The portion of the two RF cables feeding the antennas that are buried in the ground must be the same physical length and experience an identical environment (e.g., temperature). These cables are each approximately 250 feet in length, and only a two-degree difference in the electrical path lengths will cause a measurable change in the glide path angle. For this reason, and to reduce RF signal loss, large-diameter (7/8-inch) air-dielectric RF cables are used to feed the antenna arrays. These cables require dry air pressurization and use a pump/dehydrator system to achieve the needed phase stability.
4. The main transmitting antenna arrays are also lengthy and can be a source of phase instability. The antennas are fitted with radomes that have air-tight O-ring end seals. Special end-adapter connectors that mate the antenna ends to the air-dielectric RF cables are manufactured to allow the air in the cables to pass through to the antennas.
5. The individual slots that radiate RF energy from the slotted cable require precise physical positioning to assure that the glide path angle remains constant over the edge-to-edge localizer coverage. The main transmitting antennas need to be firmly supported to prevent unwanted movement and yet have complete adjustability over the entire length of each antenna. The adjustability must be in both the vertical direction (to follow the contour of the terrain) and in the longitudinal direction (towards/away from the array phase center).
6. Airborne flight measurements are required to fine-tune the position of the main transmitting antennas to achieve optimal azimuth (transverse structure) and low-approach performance. The antenna movements can be minute; moving a portion of a main transmitting antenna just  $\frac{3}{4}$  of an inch can have a measurable effect.
7. In addition to the use of integral monitoring, the EFGS system must employ field monitors to verify that the RF phase relationship (i.e., glide path angle) between the main transmitting antenna arrays does not deviate outside of an allowable range. Also, more than one field monitor is needed to sample the glide path angle near the edges of the azimuth coverage to verify that the physical positioning of the front/rear antennas, or even a portion of those antennas, has not changed.
8. Field monitoring the path angle of a GS system requires careful consideration because the glide slope on-path indication is not observable at ground level. This would normally require the monitor antenna to be some distance in front of the main transmitting antennas and elevated 20-40 feet to coincide with the glide path angle, which is impractical primarily due to obstacle clearance considerations. A novel

monitoring strategy was implemented wherein the field monitor antennas are installed at ground level and electronic circuitry is used to momentarily “snap” the glide path down for field monitor evaluation. The filtering time constant of the aircraft receiver CDI needle is such that the operation of the glide path snap-down function is undetectable to the user.

9. The field monitors also assure that asymmetrical snow/ice accumulation on or underneath the antennas is detectable as such conditions can cause undesirable path angle variations in the transverse structure.

## SYSTEM TUNING

Optimizing the EFGS transverse structure is paramount to achieving a high quality low-approach path structure. In the EFGS system, any skew in the glide path, a flare near the threshold and/or to some extent the path structure roughness itself is directly attributable to the shape of the transverse structure. The reasons for needing to optimize the transverse structure range from minute errors in pedestal positioning during installation to manufacturing variations in the amplitude/phase distribution of the slotted array.

The support pedestals of the EFGS system can be moved to optimize the transverse structure. Each pedestal produces a different effect in the transverse structure that is a function of the magnitude and phase of the slot currents in the area of the adjusted pedestal. Because the slot amplitudes at the ends of the main arrays are tapered to reduce sidelobes, movement of pedestals near the ends of the antennas minimally affects the transverse structure. Conversely, if a pedestal is moved near the middle of the main array where slot excitations are maximum, significant effects to the transverse structure result. Pedestal adjustment only affects the phase of the radiated signal relative to the other slots. Although slot amplitude could be adjusted for transverse optimization, slot excitations are determined by the manufacturer and not intended to be a system adjustment.

As an ILS receiver-equipped aircraft tracks inbound on the ILS towards the runway threshold, the azimuth angle of the aircraft relative to the EFGS is constantly changing because the system is offset from the runway. Flight inspection low-approach path structure tolerances are dependent on the distance from the threshold and each discrete distance from the threshold corresponds to some azimuth angle on the transverse structure. The entire approach transitions through approximately 5 degrees in azimuth for Category I operation. Should Category II operation be desired, the angles are changing quickly in close and the additional 1000 feet traveled to qualify the system to the threshold transitions through 5 more degrees.

In addition to this center area of the transverse structure that correlates to the low approach, still more azimuth coverage on the ends is required to assure that the glide slope is still usable on the edges of the localizer. The GS tilt checks assure that the vertical structure and below path structure are satisfactory in the proportional guidance region of the localizer.

Individual pedestal adjustments as well as a complete or partial main antenna rotation are the tools used to optimize the transverse structure. The main antenna rotations are used to remove a sloping trend across the entire transverse structure or an inappropriate flare at the coverage edges. Individual pedestal adjustments are used to attain “flatness” across the central portion. Clearance antenna rotation is used to obtain symmetrical clearance capturing on the edges of the coverage and clearance RF output power is set to maximize the width of the transverse structure.

As the pedestal movements are made to bring the shape and width of the transverse structure to a near-optimum looking state, it is the low-approach quality that is the real indicator of success. It may be helpful to have a less-than-optimal looking transverse structure if the low-approach path structure improves or it offsets the effect of an environmental issue.

## FAA FLIGHT INSPECTION - EVALUATING THE TRANSVERSE STRUCTURE

End Fire Glide Slopes require a check known as transverse structure. Transverse structure evaluates the glide slope across the lateral service volume. Glide slope angle varies laterally due to the antenna being offset from the runway centerline, and this check ensures the angle remains within tolerance across the lateral service volume. The reference point for transverse structure measurement is a point on runway centerline abeam the glide slope phase center.

ICAO Annex 10 and Doc 8071 do not specify transverse structure tolerances or procedures. The United States Federal Aviation Administration (FAA) Order 8200.1 provides both the limits and the flight inspection maneuver.

### Transverse Structure Limit

Transverse structure verifies that the GS angle remains within the monitor tolerance of

- plus  $0.10 * \theta$
- minus  $0.075 * \theta$

Where:  $\theta$  is the commissioned or the nominal GS angle (typically 3.00 degrees)

To determine the limits in DDM:

$$DDM \text{ Limit} = (\text{Angle Monitor Tolerance} * 0.0875)/0.35$$

Determining the limit in DDM is setting up a proportional relationship of 0.0875 DDM is equal to 0.35 degrees and the DDM limit is equal to monitor tolerance in degrees.

A 3.00 degree nominal GS angle has the following limits:

- Positive monitor tolerance: 0.30 degrees/0.075 DDM/64 $\mu$ A in the 150 Hz
- Negative monitor tolerance: 0.225 degrees/0.056 DDM/48 $\mu$ A in the 90 Hz

FAA Order 8200.1 lists the limits in microamps ( $\mu$ A).

### Transverse Structure Maneuver

Transverse structure is completed by:

- An arc maneuver 12 degrees either side of localizer centerline
- At a distance of
  - Equal to the final approach fix (FAF) distance or
  - Five (5) nautical miles (NM) from the runway centerline abeam the GS if the FAF is less than 5 NM.
- At the on-path altitude at that distance.

The  $\pm 12$  degrees of arc ensures data is collected beyond the coverage limits, capturing the full lateral service volume. The FAF distance is typically used because it represents the farthest operational use of the GS. If the FAF is closer than 5 NM, completing the maneuver at 5 NM or greater improves the measurement accuracy. Finally, the on-path altitude ensures the GS trace remains close to the baseline, improving measurement repeatability.

### Measurement Analysis

Step 1. Set the commissioned GS angle.

Step 2. Set the nominal GS displacement sensitivity (path width).

Step 3. Perform a transverse structure maneuver.

Step 3.a. Place a line parallel to the baseline, tangent to GS cross-pointer at the localizer centerline (see Figure 6).

Note. This becomes the reference baseline and compensates for not being on the angle.

Step 3.b. Place a parallel line -0.075 DDM (-64 $\mu$ A) below the reference baseline (see Figure 7).

Step 3.c. Place a parallel line +0.056 DDM (+48 $\mu$ A) above the reference baseline (see Figure 8).

## Acceptance Criteria

The GS cross-pointer should:

- Remain within the  $-0.075$  DDM and  $+0.056$  DDM ( $-64\mu\text{A}$  and  $+48\mu\text{A}$ ) within the localizer proportional guidance region (see Figure 9) and
- Not exceed  $+0.056$  DDM ( $+48\mu\text{A}$ ) beyond the localizer proportional guidance region to the lateral service volume (see Figure 10).

## Out-of-Tolerance Procedures

If maintenance personnel are present:

- Provide a description or image of the cross-pointer behavior
- Maintenance adjusts antenna pedestals accordingly
- Repeat transverse structure run
- Reanalyze using Steps 3.a., 3.b., and 3.c.

If maintenance personnel are not present:

- Within the localizer proportional guidance region:
  - Perform a level run (one or both sides as required)
  - Perform an obstruction clearance run
  - If both are satisfactory then the GS is satisfactory
  - If either is unsatisfactory then the GS is unsatisfactory
- Beyond the localizer proportional guidance region:
  - Perform an obstruction clearance run
  - If satisfactory then the GS is satisfactory
  - If unsatisfactory then the GS is unsatisfactory

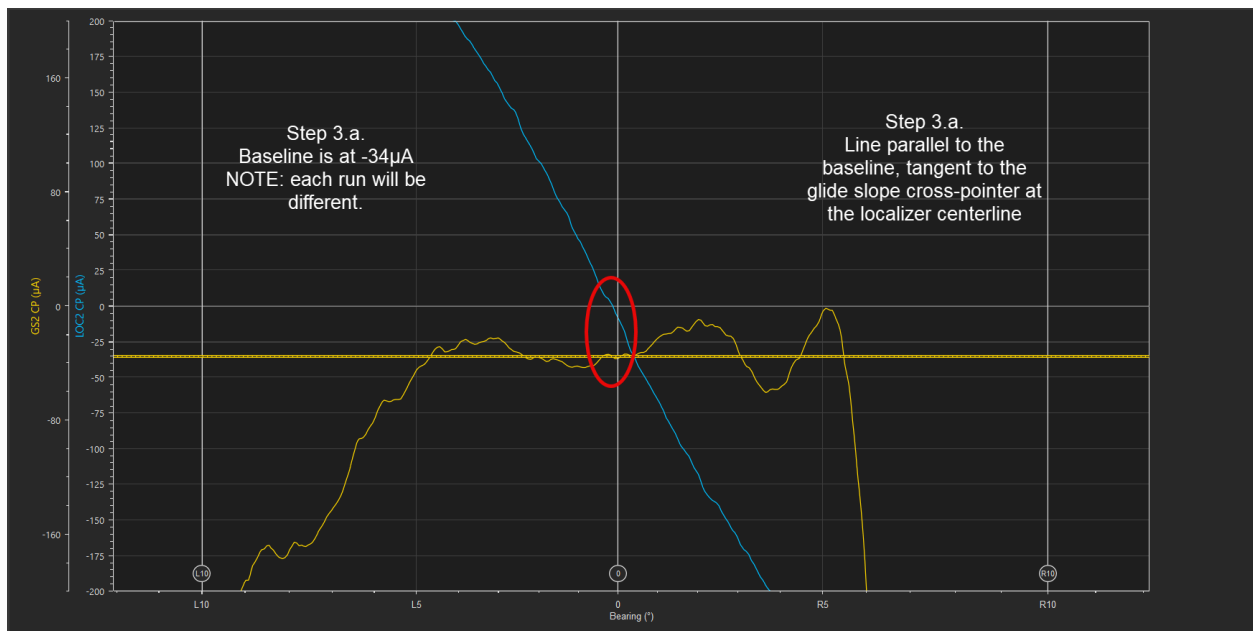


Figure 6. Example Flight Recording for Step 3a, Establishing Baseline Value

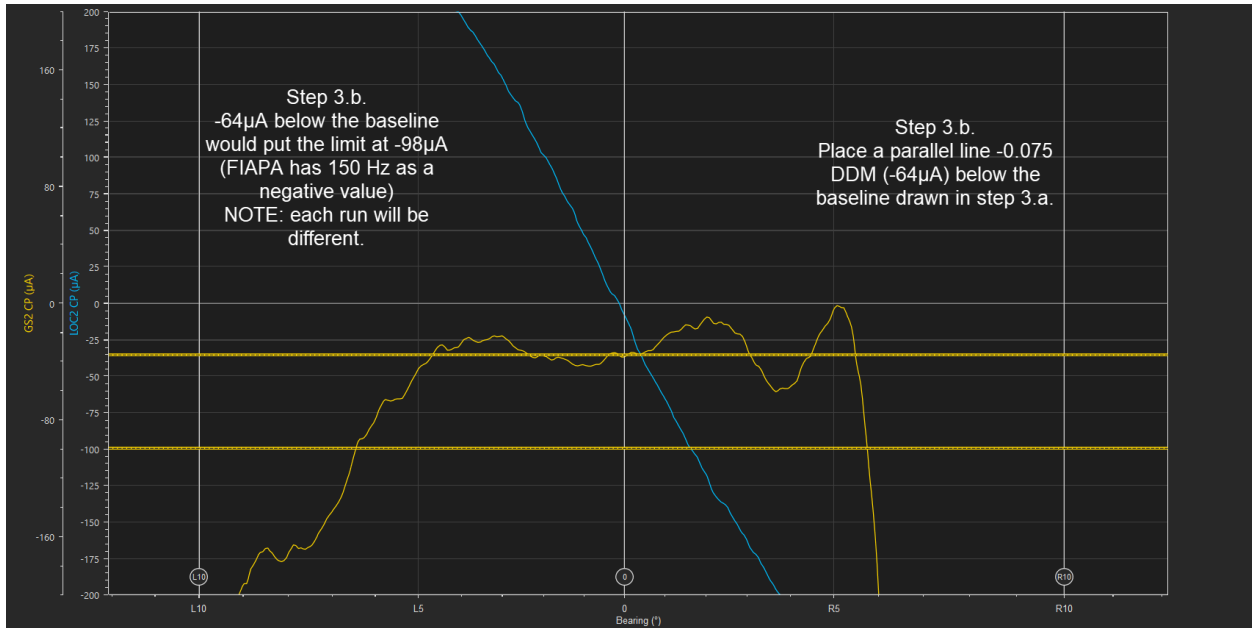


Figure 7. Example Flight Recording for Step 3b, Establishing the  $-0.075$  DDM ( $-64\mu\text{A}$ ) Limit

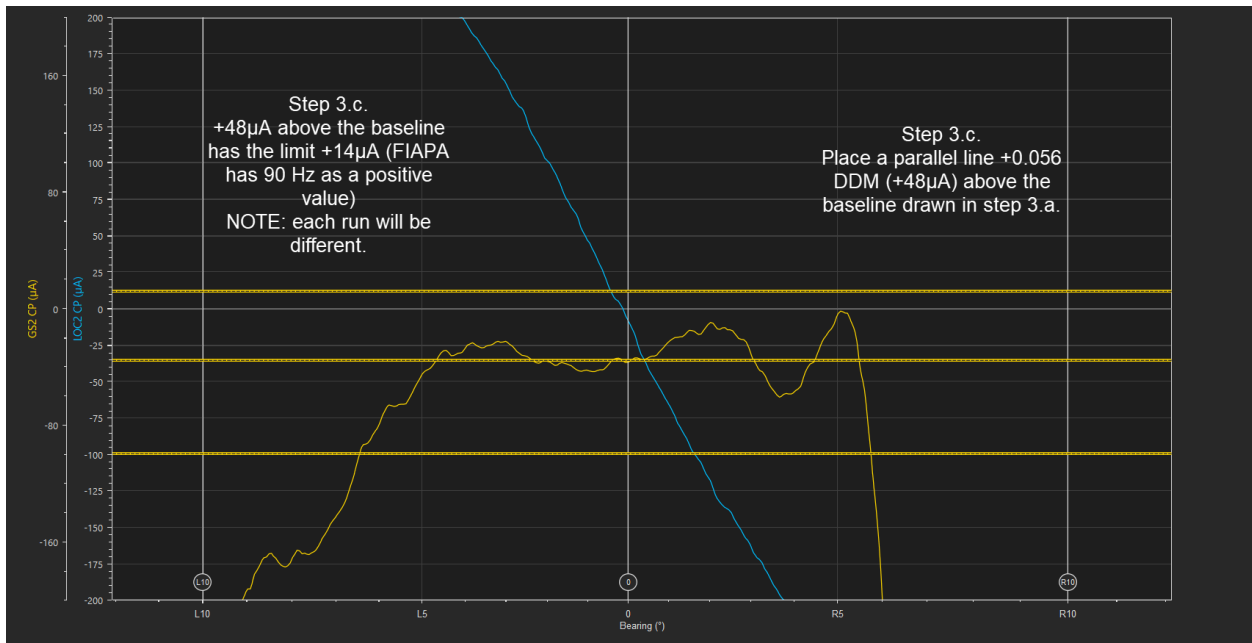


Figure 8. Example Flight Recording for Step 3c, Establishing the  $+0.056$  DDM ( $+48\mu\text{A}$ ) Limit

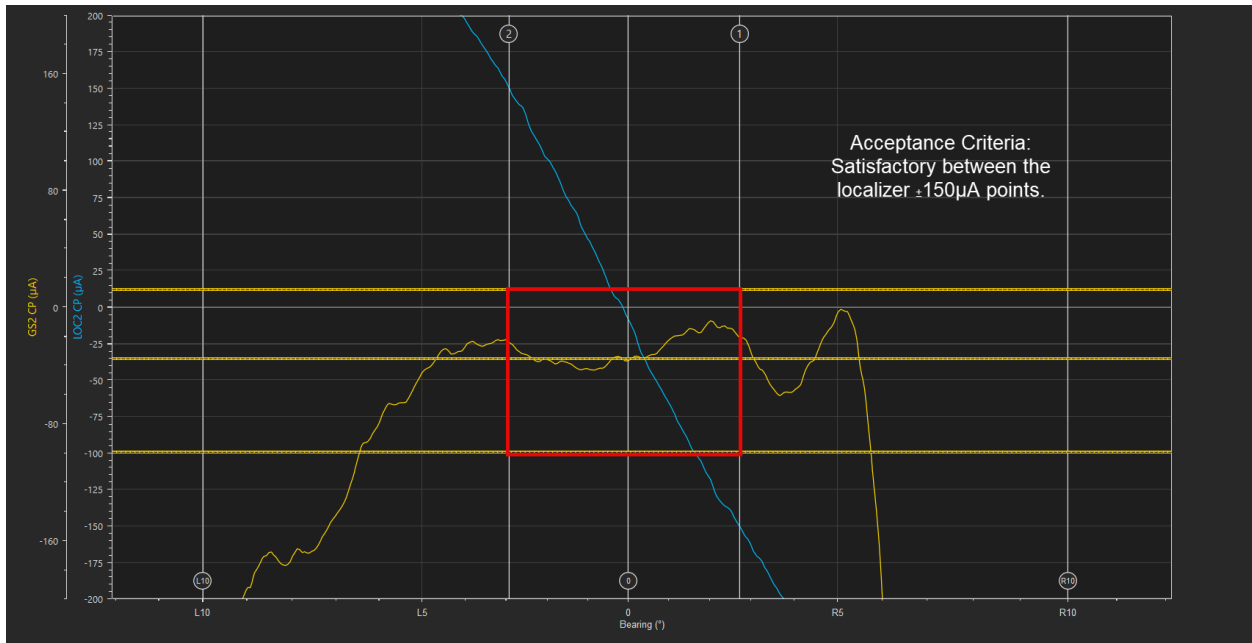


Figure 9. Example Flight Recording Illustrating the Inside Localizer Boundaries of the Assessment Zone

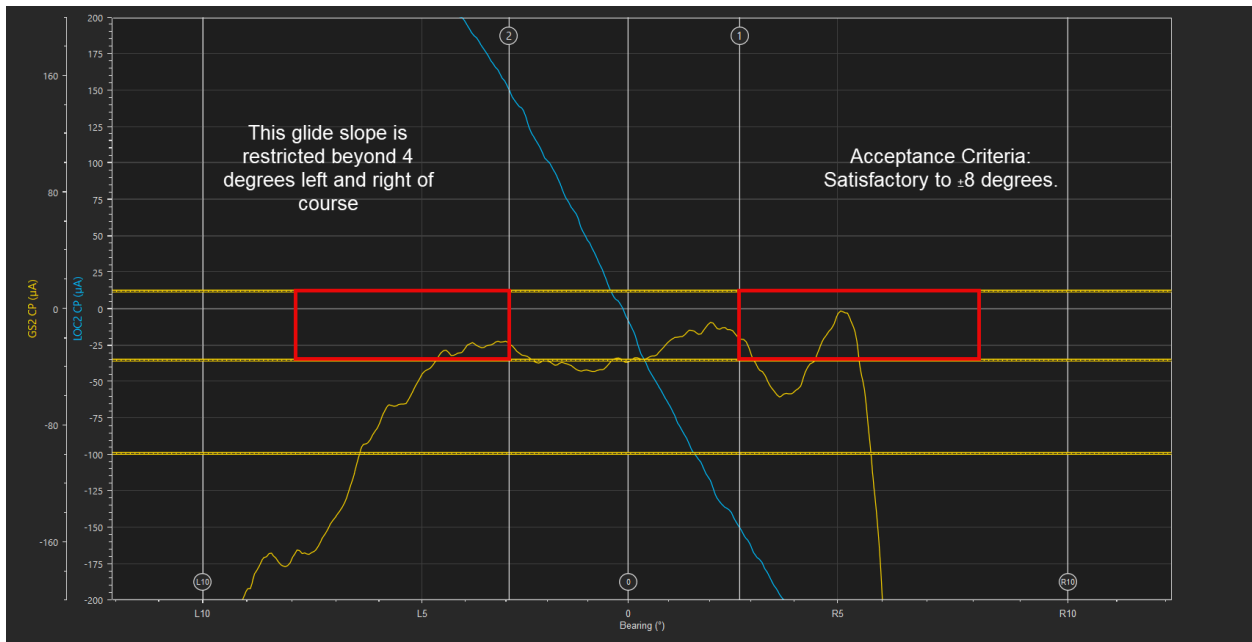


Figure 10. Example Flight Recording Illustrating the Outside Localizer Boundaries of the Assessment Zone

REFERENCES:

- [1] Watts Antenna Company, "Instrument Landing System End-Fire Glide Slope Antenna System Model 106," Instruction Book, Figure 1-2, Page 1-4, April 2004.