Suppressed-Image ILS Glide Slope Antenna

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BIOGRAPHY

Mr. Lopez received the BEE from Manhattan College, Riverdale N.Y. in 1958 and the MSEE from Polytechnic University, Brooklyn, N.Y. in 1963. He is a Life Fellow of the IEEE and a member of ION. He has been associated with Hazeltine's Wheeler Laboratories since 1958. He started ARL Associates Inc. in 1990, a consulting service specializing in antennas, propagation and radiating systems.

As a member of the Hazeltine staff Mr. Lopez spent over 20 years working on the definition, development, implementation, installation, testing, and certification of the Microwave Landing System. He has maintained an interest in aircraft approach and landing systems.

Mr. Lopez has been awarded 20 U.S. Patents and has published extensively in the IEEE Transactions. He was the recipient of the IEEE AP Society's Harold A. Wheeler Award in 1988, the IEEE Region 1 Award in 1990, and the IEEE Long Island Section Harold A. Wheeler Award in 1993.

ABSTRACT

The Instrument Landing System, ILS, was to be replaced by the Microwave Landing System, MLS, in the 90's. This is not the current plan. The FAA has canceled it's MLS production contract and is moving rapidly toward implementing precision and Cat I approach and landing procedures using the Differential Global Positioning System, DGPS. The future role for MLS in the international community is not clear. It is envisioned that a Global Navigation Satellite System, GNSS, will ultimately provide approach and landing capability internationally. There are questions of when Cat II and Cat III service will be available and on the viability of Cat IIIC (autoland) using the GNSS. What is clear is that ILS will have a substantially extended life span. Therefore, improved ILS equipment should be of interest to the navigation community.

The current FAA inventory of ILS glide slope antennas include image types (null-reference, capture effect, sideband-reference) and the non-image end fire antenna. All of these antennas are difficult to monitor and are sensitive to snow. The image-type antennas require large reflecting ground surfaces and can not be installed at some difficult sites. The end-fire antenna solves some of the difficult site problems but it has snow and icing problems.

This paper describes a suppressed-image glide slope antenna that overcomes the existing problems with current glide slope antennas. It utilizes components in the current FAA inventory. This antenna is designed to suppress radiation in the direction of the ground image. It is based on a spatial-angle filter concept that is analogous to a stop-band frequency filter. A key requirement for this spatial-angle filter is that it have at least a second-order null in the direction of the ground image. The significant features of this antenna are:

- Not affected by snow
- Critical zone in front of antenna greatly reduced
- Low cost alternative for difficult sites
- Operates with standard glide slope transmitters
- Uses corner reflector antennas in FAA inventory
- Uses standard glide slope tower
- Aperture is reduced - a far field monitor is practical

GLIDE SLOPE ANTENNAS

The Current FAA inventory of glide slope antennas includes two basic types, the image and the end-fire types [1]. The most common of all glide slope antennas is the null-reference antenna. This antenna type is shown at the top of Figure 1. The signals created by the images combine with the direct signals to form the guidance signal. The stability of the glide path angle depends on the stability of the earth reflecting surface. Under most conditions the earth reflection coefficient is very stable with the exception of snow. For this case it well known that the glide path angle can change as much as 0.1° per foot of snow [2]. The initial field monitors for this antenna type lacked integrity (truthfulness). The FAA has subsequently eliminated the requirement for a field monitor. Consequently, the glide path signal-in-space is not being monitored.

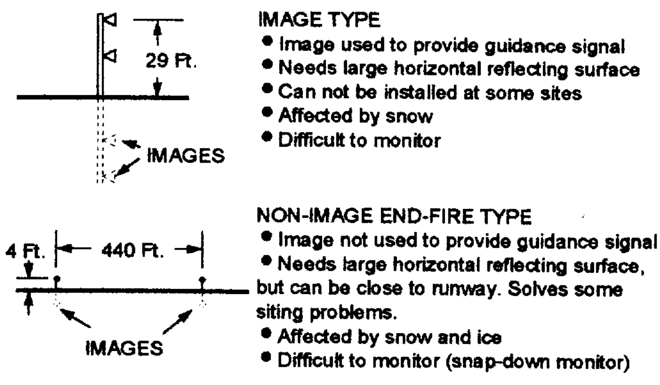


IMAGE TYPE
- Image used to provide guidance signal
- Needs large horizontal reflecting surface
- Can not be installed at some sites
- Affected by snow
- Difficult to monitor

NON-IMAGE END-FIRE TYPE
- Image not used to provide guidance signal
- Needs large horizontal reflecting surface, but can be close to runway. Solves some siting problems.
- Affected by snow and ice
- Difficult to monitor (snap-down monitor)

Figure 1. Current ILS glide slope antennas.

The non-image end-fire antenna solves some siting problems since, because of its low height, it can be located very close to the runway surface. This antenna actually does have images, but the images do not play a role in developing the guidance signal. It is the images, however, that makes this antenna type sensitive to snow. Monitoring of this antenna is difficult because of its close proximity to the runway surface. A "snap down" electronic-scan technique is used to monitor the glide path guidance signal.

This antenna uses two traveling-wave 120 feet long radiating elements that, with the field monitor included, requires an installation area that is about 1000 ft. long and 150 ft. wide. It requires 1800 ft. of trenching for 2300 ft. of cabling. 1120 ft. of air-pressurized coaxial cable is used for glide path angle stability. The cost of this antenna is substantially more than that of the image antennas.

SUPPRESSED-IMAGE GLIDE SLOPE ANTENNA

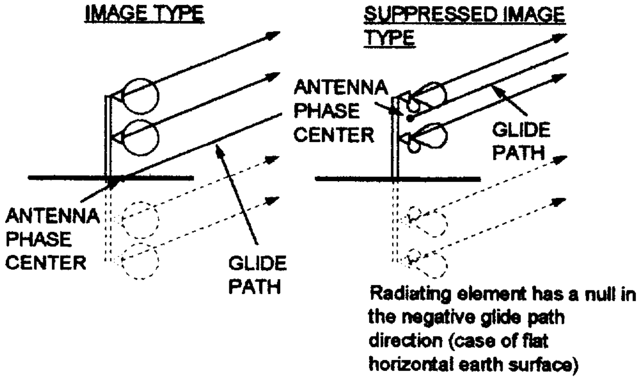


Figure 2. Concept for suppresses-image antenna.

The basic concept of the suppressed-image glide slope antenna is depicted in Figure. 2. For comparison purposes the null-reference is shown in the figure. For this case the radiating elements (corner reflectors) have a radiation pattern with a peak on the horizon and radiate equally above and below the horizon. For the suppressed-image antenna a radiating element is used that does not have a peak on the horizon but does have a null in the direction of

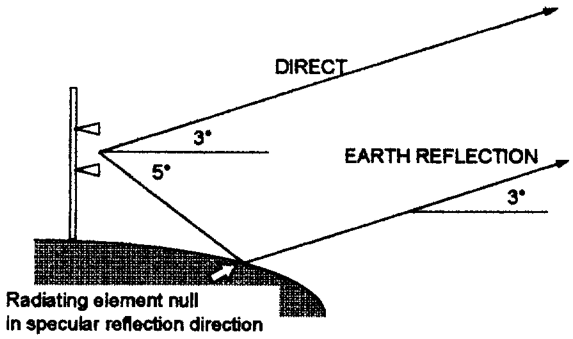


Figure 3. Concept for difficult site

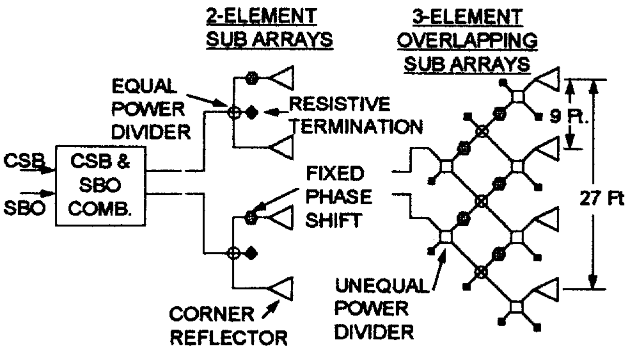
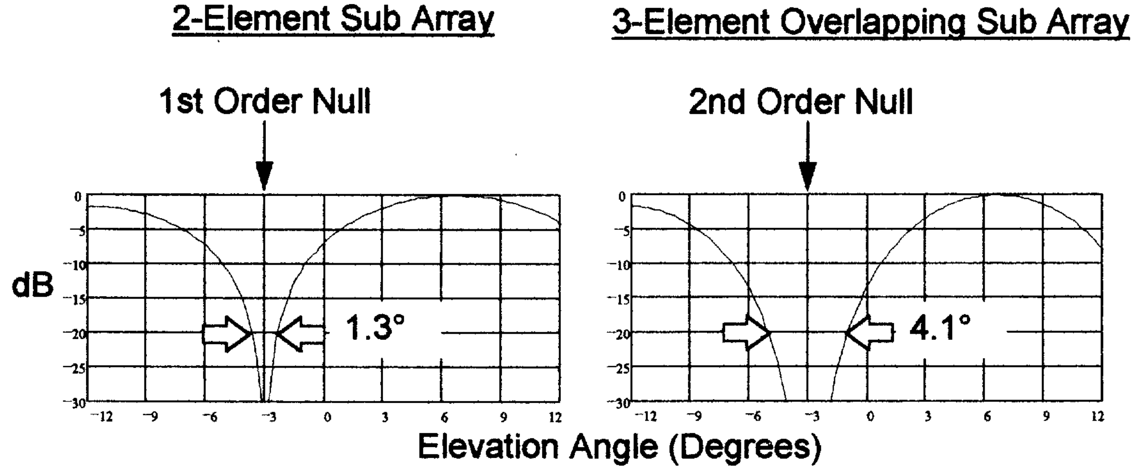


Figure 4 Suppressed-image antenna types.

the earth images. The principle is to suppress the earth reflection (snow included) such that the glide path is a line passing through the center of the antenna.

The suppressed-image concept for a difficult site (sloping ground) is shown in Figure 3. The radiation pattern for the two array elements has a null in the direction of the specular reflection point. The angle of the null in the direction of the ground reflection point is not necessarily equal to the glide path angle.

Two approaches for suppressed-image antennas are shown in Figure 4. The first one is a 2-element array of sub arrays, where each sub array is a 2-element array. The second one is also a 2-element array but, in this case, the sub arrays are 3-element arrays which overlap [3][4]. The radiation patterns for the two cases are presented in Figure 5. The details of the first nulls below the horizon are presented in the figure. The null for the simple 2-element sub array is not broad in width (1.3° wide at the -20 dB points). Computer simulations have shown that the desired independence of the ground reflection can not be achieved with such a narrow null. What is required is at least a second order null as shown for the overlapping sub array. This is discussed in more detail in the Performance section below.



Key Concept: Need at least a second order null in image direction

Figure 5. Sub array radiation patterns

The sub-array feed network can be viewed as a spatial-angle filter in a manner analogous to a frequency filter. This spatial-angle filter is inserted between the transmitter and the corner reflector antennas and operates as a notched angle (frequency) filter which suppresses radiation (transmission) over an angle (frequency) band.

The details of the overlapping sub-array feed network are shown in Figure 6. The network is designed such that a 1 volt input to the upper port of the network excites the three upper corner reflectors as shown in the figure. A 1 volt input to the lower port will excite the three lower corner reflectors in an identical manner. The excitations generate a second-order null in the direction of the ground reflection point. The fixed phase shifters provide the required phase gradient and the combination of equal and unequal power dividers provide the required relative amplitudes.

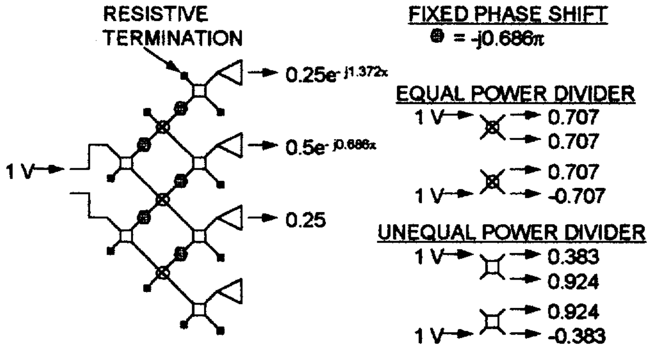


Figure 6. Principle of overlapping feed network

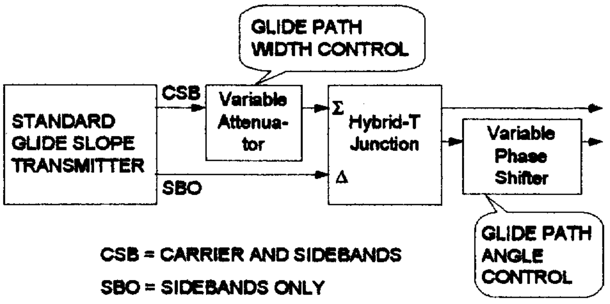


Figure 7. Glide path signal formation and control

The outputs from a standard glide slope transmitter are combined as shown in Figure 7 to form the guidance signal. An input to the sum (Σ) port to the Hybrid-T junction produces equal-magnitude and equal-phase signals at the two outputs. An input to the difference (Δ) port produces equal-magnitude and out-of-phase signals at the two outputs. The amplitude balance between the carrier-and-sidebands and the sidebands-only, which controls the glide path width (displacement sensitivity), is not critical. The phase control of the outputs of the Hybrid-T junction, which controls the glide path angle, is critical. The two paths from the outputs of the Hybrid-T junction to the radiating elements must be phase stable to within ± 2°. This is practical with current off-the-shelf components operating at 300 MHz. (The end-fire antenna requires about the same level of phase stability.) The formulas which relate the required amplitude and phase tolerances to the system requirements are presented in Figure 8.

$\Psi = 2\pi(D/\lambda)\theta$ $\quad$ $A = (\lambda/2\pi D)(57.3/\Omega)(0.175DDM)$

$\Delta\Psi = 2\pi(D/\lambda)\Delta\theta$ $\quad$ $\Delta A = -A(\Delta\Omega/\Omega)$

Ψ = 2-Element Array Relative Phase (Degrees)
A = Sideband Only / Carrier (Voltage Ratio)
D = 2-Element Array Element Spacing (9 Feet)
λ = RF Wavelength (3 Feet)
θ = Glide Path Angle (3 Degrees)
Ω = Glide Path Width (0.7 Degrees)
DDM = Difference in the Depth of Modulation

Stability Requirements (1/2 Monitor Limits)	Tolerance Requirements
$\Delta\theta = \pm 0.10°$	$\Delta\Psi = \pm 2°$
$\Delta\Omega = \pm 0.10°$	$\Delta A = \pm 0.1$ (± 0.8 dB)

Figure 8. Tolerance formulas

PERFORMANCE

The performance of the suppressed-image glide slope antenna was simulated on a computer. The simulation included the effects of the earth's reflection. The dielectric constant and loss tangent of the earth was set equal to 20 and 0.1 respectively. The earth's surface was assumed to be flat and horizontal. The system parameters were set for a glide path angle of 3°.

The ILS vertical guidance is provided by modulation of the carrier at 90 and 150 Hz in a spatial pattern that allows the 90 Hz to be detected above the glide and the 150 Hz to be detected below the glide path [5]. The difference in the depth of the 90 and 150 Hz

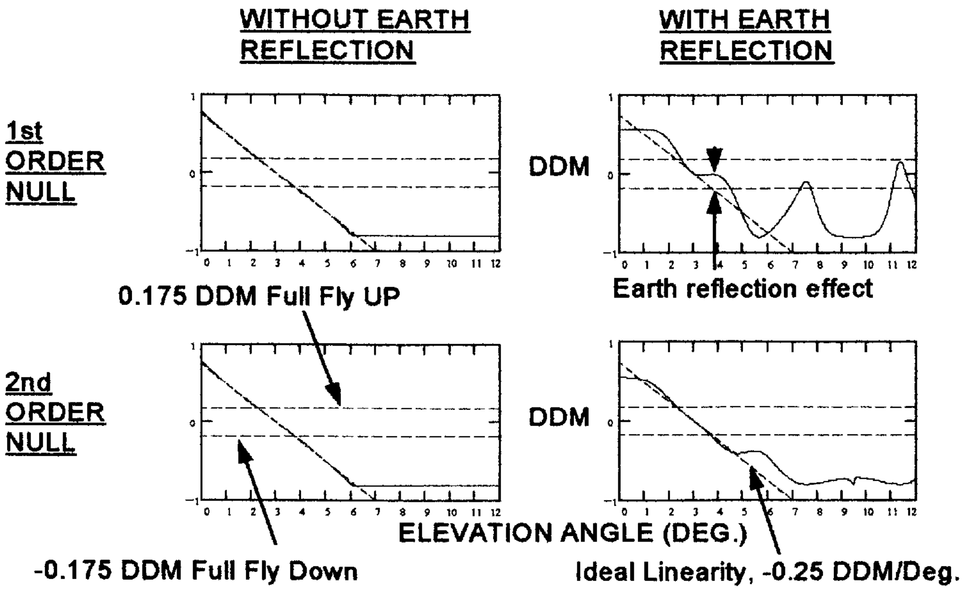


Figure 9. Differential depth of modulation versus elevation angle

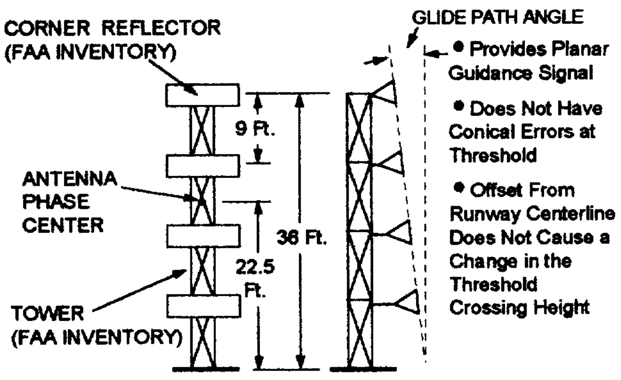


Figure 10. Antenna configuration

modulations causes a current to drive the up-down cross-pointer.

The computed differential depth of modulation versus elevation angle for the suppressed-image antenna is shown at the bottom right in Figure 9. The linearity of the guidance signal extends beyond the required path width of ± 0.7°. The figure also presents the performance of a 1st order null system with and without the earth reflection present. The undesired dependence on the earth reflection is seen in the upper right of the figure. The desired independence is achieved with the 2nd order null system.

SUPPRESSED-IMAGE ANTENNA CONFIGURATION

There are several alternative configurations for the suppressed-image antenna. One practical configuration is shown in Figure 10. It consists of four corner reflector antennas (FAA inventory) mounted on a standard tower (FAA inventory). The two key parameters are the spacing (9 ft.) between the corner reflectors and the antenna height (36 ft.). The 9 ft. spacing provides a sub-array pattern with a peak at 6° and a null at -3°; the gain at 3° is 3 dB down from the peak. The height, of course, is constrained by the runway obstacle clearance surface and is critical to the siting of the glide slope station. A height of 36 ft. is moderate and should not cause any special siting problems. The phase center is at a height of 22.5 ft. which provides a benefit with respect to reduced critical and sensitive zones. This aspect is discussed below.

The corner reflector antennas are squinted up above

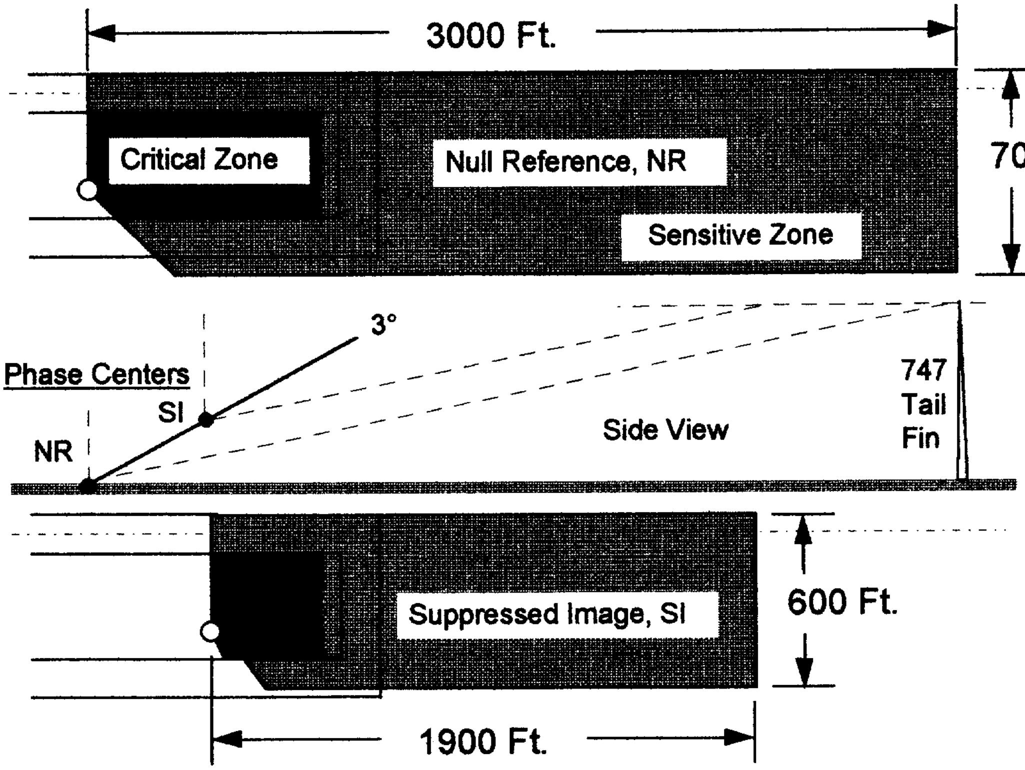


Figure 11. Reduced critical and sensitive zones

the horizon. This provides additional suppression of the earth's reflection without significant gain degradation.

The corner reflector antennas are shown in Figure 9 positioned along a line that is perpendicular to the glide path angle. This provides what is called a planar guidance signal, i.e. the zero DDM surface is a plane containing the glide path line and a horizontal line passing through the phase center of the glide slope antenna. This type of guidance signal allows offsetting the glide slope station from the runway centerline without affecting the runway threshold crossing height. This is a desirable feature in many siting situations.

CRITICAL AND SENSITIVE ZONES

Critical and sensitive zones are defined in [6].

" a) The ILS critical area is an area of defined dimensions about the localizer and glide path antennas where vehicles, including aircraft, are excluded during all ILS operations. The critical area is protected because the presence of vehicles and/or air craft inside its boundaries will cause unacceptable disturbance to the ILS signal-in-space.

b) The ILS sensitive area is an area extending beyond the critical area where the parking and/or movement of vehicles, including aircraft, is controlled to prevent the possibility of unacceptable interference to the ILS signal during ILS operations. The sensitive area is protected against interference caused by large moving objects outside the critical area but still normally within the airfield boundary."

Typical critical and sensitive zones for a glide slope antenna are shown at the top of Figure 11. At the center of the figure is a side view depicting the relative positions of the phase centers for the null-reference and suppressed-image antennas. The dashed lines represent the bottom edge of the corresponding sensitive zones for the case of a B-747 aircraft type. The higher position of the suppressed-image antenna phase center allows the reduction in the size of the combined critical and sensitive zone from an area of 3000 ft. by 700 ft. to an area of 1900 ft. by 600 ft. as shown in the figure.

PRACTICAL FIELD MONITOR

Executive monitoring of the signal-in-space is a fundamental element in the ILS integrity equation. Reference [6] states:

"2.8.2.13 In general, monitoring equipment design is based on the principle of continuously monitoring the radiated signals-in-space at specific points within the coverage volume to ensure their compliance with the

Antenna Component	Vertical Aperture,D (Ft.)	Far-Field Distance, $2 D^2 / \lambda$ (Ft.)	Field Monitor Height (Ft.)
Null-Reference (Ref. case) (Guidance Signal)	50	1700	89
Suppressed-Image			
• 2-Element Array (Guidance Signal)	18	216	34
• Radiating Element (3-Element Sub Array, Image Suppression)	27	486	48

λ = Carrier Wavelength

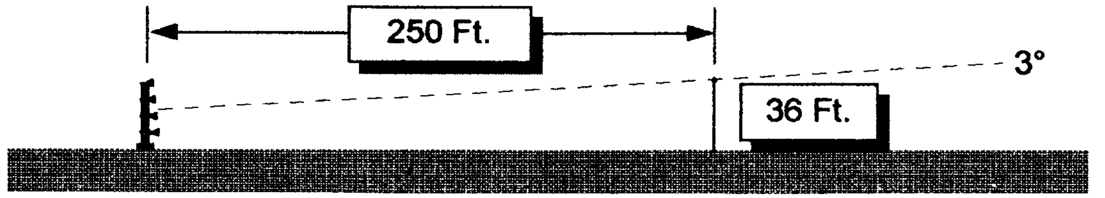


Figure 12. Field monitor

Standards specified ...."

The suppressed-image antenna, because of its small active vertical aperture size, can accommodate a practical field monitor. The relevant aperture sizes are presented in Figure 12. The case of the null-reference antenna is presented as a means for comparison. The value of D = 50 Ft. is an effective vertical aperture size which corresponds to a path difference of 1/16 wavelength between the lower and upper antennas. A field monitor distance of 1700 Ft. and a height of 89 Ft. precludes the use of a far-field monitor for the null-reference antenna.

A field monitor in the far-field of the antenna has high integrity. However, if the far-field distance is large, other factors, such as taxiing aircraft affect the integrity. Based on initial analysis, a configuration for a high-integrity practical field monitor has been defined. The key dimensions for this field monitor are shown in the figure. The relatively short field monitor distance of 250 ft. and a height of 36 ft. makes this monitor practical.

LOW COST APPROACH FOR DIFFICULT SITES

The suppressed-image and the image type antennas are comparable in cost. This is because they utilize the same basic components; corner reflectors, towers and transmitters. A difficult site is defined as a site where an adequate earth reflecting surface does not exist for the standard image type antennas. In some cases, a viable alternative for the difficult site has been the end-fire antenna. This antenna, however, is substantially more expensive than the image-type antennas. It uses two 120 ft. traveling-wave antennas to provide the required guidance signal, it requires 1800 ft. of trenching for cabling, it requires 1200 ft of pressurized coaxial cables, and it requires a 1000 x 150 ft. flat surface for installation and operation. The ground images of the traveling-wave antenna elements are affected by snow which makes maintenance difficult. Another reported problem is ice on the traveling-wave elements. The acquisition and maintenance cost of the end-fire antenna is estimated to be about four times that of the image types or the suppressed-image antennas.

The suppressed-image antenna does not require a large flat reflecting surface for its operation. Thus, it can be installed at difficult sites.

CONCLUSION

A concept for a suppressed-image ILS glide slope antenna has been presented (patent applied for). This new low-cost antenna type provides benefits with respect to practical field monitoring, reduced critical and sensitive zones, alternative for difficult sites, and reduced sensitivity to snow effects.

This idea was first conceived in the early 1980's while working on the development of MLS. It was not pursued at that time because, obviously, ILS was soon to be replaced by MLS. Well now in 1995 it is clear that ILS will have a substantially extended life. The Global Navigation Satellite System will ultimately be the primary approach and landing aid. It is envisioned that ILS, and specifically the glide slope element, will have a substantially extended life expectancy beyond the year 2020.

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