Comments on "Effect of Wet Snow on the Null-Reference ILS System"

The subject paper has raised some issues regarding the probability of the Instrument Landing System (ILS) radiating out-of-tolerance vertical guidance signals. An independent study has substantiated the findings of that paper and adds further concern regarding some FAA ILS snow procedures. The principal conclusions of this paper are: 1) an analysis, based on Walton's discovery of rare snow conditions that cause the null-reference ILS antenna image to disappear, indicates that these conditions can cause out-of-tolerance guidance signals, 2) operation without a monitor of the image radiation can result in signal-in-space guidance signal errors that are significantly beyond the intended limit values, and 3) the integrity of image glide path equipment in snow environments does not satisfy the ILS integrity requirements.

I. INTRODUCTION

Walton's paper [1] describes a situation for the Instrument Landing System (ILS), glide path antenna that occurs during a period of time when a deep blanket of snow transitions from freshly fallen to the melted condition. During this time period the air, snow, and Earth reflection interaction may cause the ground reflection component of the guidance signal (image) to nearly vanish. This reduction in image strength has the potential to cause the glide path angle to change and to cause a decrease in the displacement sensitivity (indicated guidance error versus aircraft glide-path offset) of the vertical guidance signal. Current FAA Category I, II, and III operating procedures [4] allow snow cover that does not exceed 18 in for null-reference and capture-effect antennas without downgrading of service or category. These procedures also allow the glide path guidance signal to be radiated without integrity monitoring of the image component of the radiation.

For an image-type glide path antenna the image radiation is fundamental in generating the glide path guidance signal. The image has equal weight with the direct signal. Consequently, it is reasonable to expect that a degraded image will result in a degraded guidance signal.

Presented here are the results of an independent verification of Walton's key result, which relates the snow-Earth dielectric properties, snow depth and image strength. It addresses the following issues:

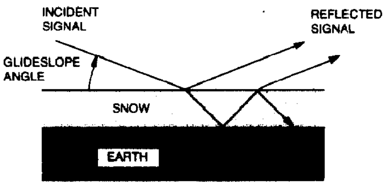

Fig. 1. Geometry of signal reflection from snow layer over Earth.

1) the implications of Walton's discovery that under certain rare snow conditions the glide path antenna image disappears;
2) operation without a monitor of the image component of the radiated signal-in-space;
3) the quantification of integrity for glide path equipment.

II. COMPUTATION OF REFLECTION COEFFICIENT

The problem is to determine the reflection coefficient at the air-snow interface. The geometry for this problem is presented in Fig. 1 (reproduced from Walton's Fig. 1). In [1] the Richmond method [3] was used to solve the problem. We used a modal transmission line approach. This method is outlined below.

1) Each angle of incidence is considered a mode.
2) For each mode
a) the phase velocities at the air-snow and snow-Earth interfaces are made equal,
b) the mode impedances are determined for the three regions,
c) the propagation constant is determined for the snow layer,
d) the Earth modal impedance is transformed to an impedance at the air-snow interface,
e) the reflection coefficient at the air-snow interface is computed.

Results which can be compared directly to the work presented in [1] are shown in Fig. 2. The plots presented show the variation of reflection magnitude at the snow-air interface versus the relative dielectric constant of snow for an Earth relative dielectric constant of 10 and for several snow depths. The curve for the 16 in snow depth was compared with Walton's result and found to be in good agreement. (It is noted that Walton's results are for power reflection and not voltage reflection as indicated in his Fig. 2.)

III. IMPLICATIONS OF WALTON'S RESULTS

The voltage reflection versus the relative dielectric constant of snow shown in Fig. 2 is useful in describing possible situations. As an example, we assume that a null-reference antenna is being used and that freshly fallen snow has a relative dielectric constant of 1.16

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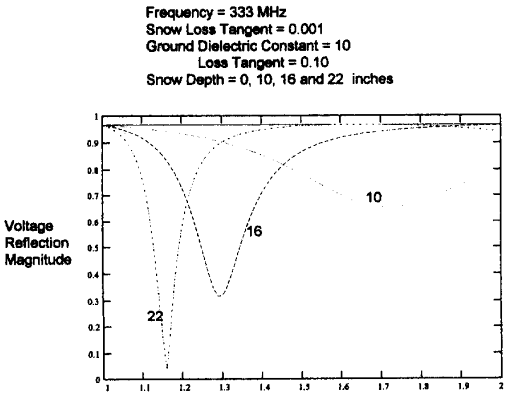

Fig. 2. Magnitude of reflection coefficient versus relative dielectric constant of snow for 3 deg grazing angle.

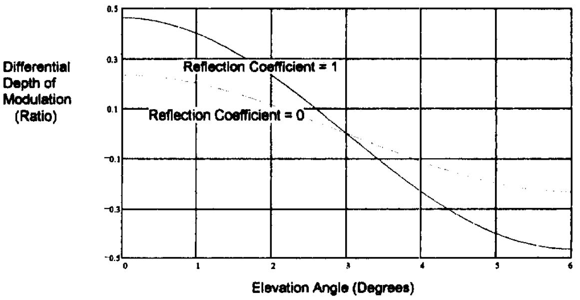

Fig. 3. Differential depth of modulation versus elevation angle.

and the Earth has a relative dielectric constant of 10. When it first starts snowing the image strength is 0.97 (close to unity). At 10 in of snow the image strength is about 0.94. When the snow reaches 16 in the image strength is about 0.85. If it continues to snow to a level of 22 in the reflection factor is less than 0.1; at this point the image is nearly extinguished. This situation does not result in the radiation of an out-of-tolerance guidance signal because current FAA procedures [4] require snow removal if the snow depth exceeds 18 in. However, if the snow depth does not exceed 18 in, snow removal is not required and full service and category are restored. The latter situations may result in the radiation of an out-of-tolerance guidance signal.

It is certain that at some time in the transition from freshly fallen to completely melted snow that the snow depth and wetness will cause a minimum in the strength of the image component. (The dielectric constant coordinate of the plot shown in Fig. 2 can be viewed as a time coordinate.) If, for example, the snow depth happens to be 16 in and the wetness corresponds to a relative dielectric constant of 1.3, an out-of-tolerance situation could exist. The image strength is about 1/3 the normal value. This reduced image strength may cause a significant degradation of the guidance signal.

IV. ESTIMATING POSSIBLE GUIDANCE SIGNAL DEGRADATION

The reflection coefficient computation described above, along with simple four-element array equations for computing far-field antenna patterns, such as given in [1], can be used to compute the differential depth of modulation (DDM), versus elevation angle. The aircraft glide path indicator readout is proportional to DDM. The DDM versus angle, for two simple cases, reflection coefficients of −1 and 0, are shown in Fig. 3 for the case of the null-reference antenna. It is interesting to note that for the case of no image (reflection coefficient = 0) the glide path angle (DDM = 0) remains at 3°. For this case the significant degradation is in the displacement sensitivity [5] (rate of change of the DDM with angle) which is less than 1/2 of the normal value. Significant decrease in the displacement sensitivity will result in an out-of-tolerance situation. Zero displacement sensitivity is equivalent to no guidance.

The results of a computation of reflection coefficient and DDM versus elevation angle for a set of air-snow-Earth parameters is shown in Fig. 4. For this case the glide path angle is shifted to 2.77° and the displacement sensitivity is 0.177 DDM/deg. There is even a region of negative slope from 3.5 to 4.5 deg. To determine trends with snow wetness, several computations of DDM versus elevation angle were used to determine the variation of the glide path angle and the displacement sensitivity versus the dielectric constant of snow. The results for two sets of parameters are presented in Fig. 5. Included in the plots for glide path angle versus the relative dielectric constant of snow are the FAA Category I, II, and III monitor limits [4]. For the two cases shown, wet snow causes shifts in the glide path angle that are outside of the monitor limits.

Fig. 5 also shows the variation of the displacement sensitivity (displacement sensitivity (DDM/deg = 0.175/path width) versus the relative dielectric constant of snow. Shown in the figure is the FAA Category I, II, and III monitor lower limit. Snow wetness can cause significant reduction in the displacement sensitivity such that it is less than the lower limit allowed for Category I, II, and III operations.

The results presented in Fig. 5 are for two representative cases which do not necessarily correspond to a worst case condition. The deviation from the nominal 3° glide path and the 0.25 DDM/deg displacement sensitivity is attributed to the snow, i.e., there are no other error components included. The integral monitor would indicate zero glide path angle error and zero displacement sensitivity error.

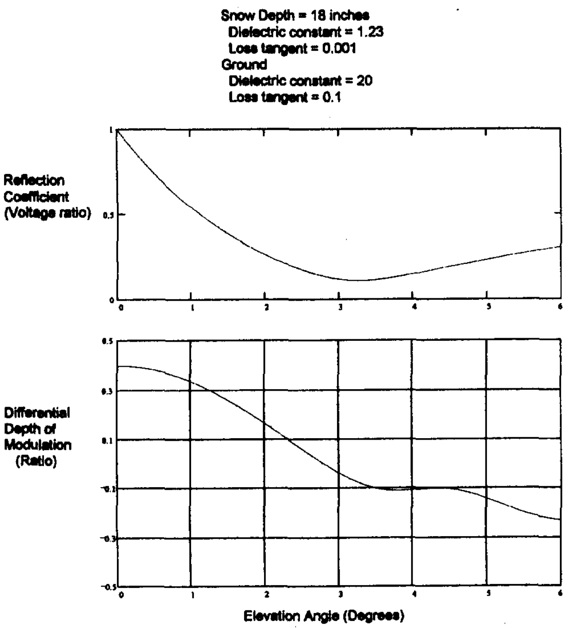

Fig. 4. *Note*: Glide path angle (DDM = 0) is at 2.77 deg. Displacement sensitivity on glide path is 0.171 DDM/deg. Example of computation of differential depth of modulation versus elevation angle.

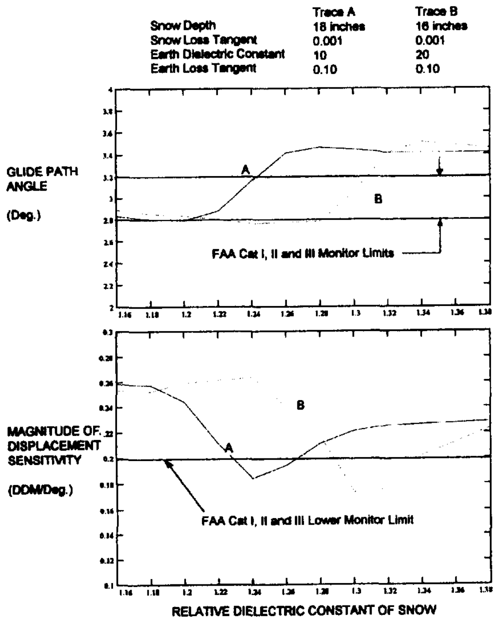

Fig. 5. Glide path angle and displacement sensitivity versus relative dielectric constant of snow.

V. OPERATION WITHOUT A MONITOR OF THE IMAGE RADIATION

According to FAA Order 6750.49 [4], field monitors for the image glide path antennas are no longer required. Although the integral monitor is beneficial in the integrity monitoring of the glide path guidance equipment it only monitors the internal electronics. It does not monitor that portion of the far-field radiated signal-in-space that is provided by the image or is affected by the environment. This point is well illustrated in Fig. 7 which shows substantial variation of the far-field glide path angle and path width while the integral monitor indicates perfect performance. The integral monitor also does not monitor mechanical motion. The mechanical motion can be monitored by means of a level sensor. The radiated signal-in-space, however, is difficult to monitor.

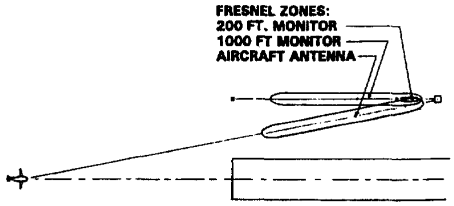

Fig. 6. Comparison of Fresnel zones for field monitors and aircraft antenna.

The image radiation can be viewed as radiation emanating from the Fresnel zone on the ground surface. The Fresnel zone can be considered as a window through which the image is viewed. Degradation of the window surface results in the degradation of the image radiation. Fig. 6 shows a plan view for an aircraft on final approach and the Fresnel zone associated with the ground image. To monitor the image radiation very accurately would require locating a field monitor antenna at the location of the aircraft antenna. This, obviously, is impossible. Shown in the figure is the Fresnel zone for a typical field monitor antenna at a distance of 200 ft from the transmitter. It is noted that the size and location of the Fresnel zones for the typical field monitor and aircraft antennas are very different. The reflection angle of incidence is also very different. This field monitor thus lacks integrity. The surface characteristics in the small localized Fresnel zone could cause an effect at the field monitor which has no relationship to the received guidance signal at the aircraft. It is easy to understand why this type of integrity field monitor was abandoned [4].

Fig. 6 shows a field monitor antenna located near the runway threshold with a corresponding Fresnel zone that has a size and location that is much more representative of the actual Fresnel zone. This location for the field monitor antenna could provide some beneficial level of integrity monitoring of the direct and image radiation. It is recognized that there are difficulties in implementing such a field monitor.

The problem with operating without a monitor of the image component of the signal-in-space is that the equipment could be radiating a signal-in-space that is at the limit of the integral monitor and, snow effects could cause an image error component that results in a signal-in-space that is outside of the intended limit. For example, the equipment may be radiating a signal with the glide path at 3.19° which is just within the upper monitor limit of 3.20°. An 18 in snow blanket typically raises the reflected surface by an equivalent amount and causes an upward shift of the glide path by 0.15°. The resulting glide path is at 3.34°, which is out-of-tolerance.

For the anomalous snow conditions, discovered by Walton, significant out-of-tolerance conditions can exist with the integral monitors near the limit values. For the two cases shown in Fig. 5 the glide path angle can be as low as 2.6° and as high as 3.7°; the displacement sensitivity can be as low as 0.14. These out-of-tolerance conditions are significantly beyond the specified limit values.

VI. INTEGRITY CONSIDERATIONS

Integrity has been defined as that quality which relates to the trust which can be placed in the correctness of the information supplied by the facility. The level of integrity is expressed in terms of the probability of not radiating out-of-tolerance, potentially hazardous guidance signals. The ability to achieve high integrity is dependent on a monitoring system that receives the radiated signal, compares the detected guidance information to preset thresholds and extinguishes the out-of-tolerance transmissions whenever the thresholds are exceeded.

An equation for quantifying ILS integrity is given in [5, attachment C to part I]. The integrity depends on 1) the hazardous failure rate of the transmitter, 2) the hazardous failure rate of the monitoring and the associated control system, and 3) the square of the period of time between checks on the monitoring and associated control system. The monitor is the single most important element in the measure of integrity.

If the integral monitor produced an accurate sample of the radiated signal-in-space then its hazardous failure rate and time between monitor checks would quantify the integrity. For the image glide path equipment in snow conditions the integral monitor does not provide any measure of the image radiation which is varying and comprises 1/2 of the radiated signal-in-space. For snow conditions one would conclude that the glide path integrity is very low.

The desired level of integrity for Category III operation for a glide path equipment is one hazardous out-of-tolerance radiated signal in two billion landings. If one million landings per year were made on ILS equipped runways it would take 2000 years to verify that the integrity level was achieved. The point is that 50 years of ILS experience provides no real measure of the integrity of the image-type glide path equipment.

VII. EXPERIMENTAL RESULTS

There has been a substantial effort, dating back to the late 1960s [6, 7], to obtain experimental information on the effects of snow on image glide path equipment. According to [7] the only data available prior to the work reported in [7] involved undisturbed snow layers less than 12 in in thickness or occasional layers up to 24 in which were quickly plowed. In [7] the testing over a period of 4 months, starting in January of 1976, involved snow layers having a maximum depth of 36 in. Subsequent work on snow layers exceeding 12 in has not been reported. The work reported in [7] does not include continuous measurements of the glide path angle and path width with time. Temperature and Earth parameters were not available. The potential for creating an out-of-tolerance situation depends on the relative dielectric constant of the Earth and snow. A measure of this parameter is required to assess the potential for an out-of-tolerance situation. The relative dielectric constant of the Earth varies from about 7 for a low conductivity Earth to about 30 for a high conductivity Earth [8].

One set of data was reported in [6] which shows an increase in path width (decrease in displacement sensitivity) versus time for a case of a snow layer that was only 3.5 in and the temperature was near freezing. This data is reproduced in Fig. 7. The path width is seen to increase to a value which is 1/2 the width tolerance (monitor limit).

The experimental data available is considered to be inadequate to establish, with a high level of confidence, that unrestricted Category I, II, and III operations with snow layers up to 18 in will be assured of radiated guidance signals that are within the specified tolerances.

VIII. CONCLUSION

The issues raised in this paper are difficult to resolve. Walton's discovery, that under certain unique snow conditions the image of an image-type glide path antenna disappears, has resulted in a theoretical analysis that shows that out-of-tolerance operation may occur under these conditions. The fundamental element of the problem is the lack of a monitor for the signal-in-space component radiated by the image. The combination of the variation of the signal-in-space allowed by the integral monitor and the unmonitored variation caused by snow effects can result in guidance signals that are substantially beyond the intended limits for the signal-in-space. It is recognized that a high

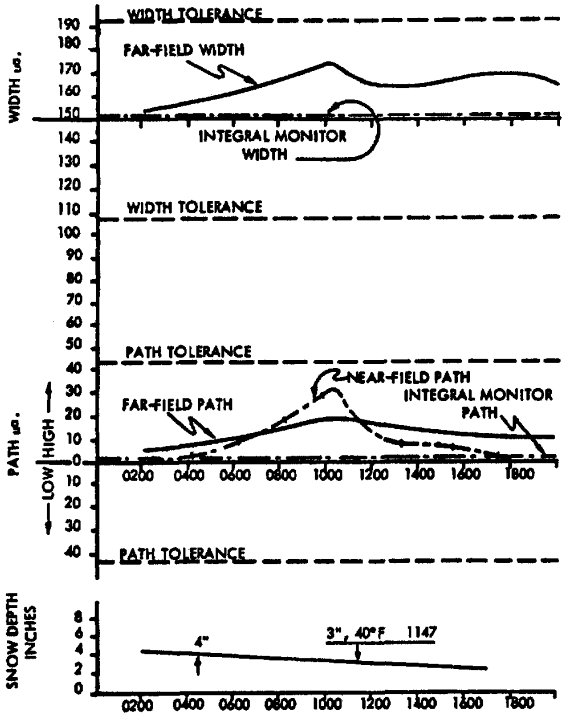

Fig. 7. Reproduced from [6]. "Fig. 9. Capture effect far-field/near-field/integral monitor versus snow depth on 18 Jan. 72."

integrity monitor for the image radiation is difficult to implement but the fact remains that operation without this type of monitor will not possess the integrity levels required for Category I, II, and III operations.

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A Method for Improving Extended Kalman Filter Performance for Angle-Only Passive Ranging

A relatively simple method is presented which eliminates previously reported [1] erratic estimation performance associated with Cartesian formulations of the extended Kalman filter (EKF) for the 2D angle-only emitter location problem. The technique is based on an initialization procedure which combines *a priori* probability density function (pdf) information with single measurement *a posteriori* pdf information in a manner which is more efficient than the EKF. Simulation results are presented which demonstrates the utility of the technique as compared with a previously offered modified gain EKF [1].

I. INTRODUCTION

Angle-only position estimation arises in many situations where only direction-of-arrival (DOA) information is available to an observer about some target of interest, but where it is desired to also know the range of the target (and/or higher order derivatives if the target is assumed to be moving). Apart from the inherent nonlinearity of the problem, an additional fundamental problem arises in practical applications, viz., a significant lack of *a priori* target position information which is required by both iterative or recursive estimation procedures.

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