# INSTRUMENT LANDING SYSTEM PERFORMANCE PREDICTION

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## Abstract

An electromagnetic scattering model has been developed for predicting Instrument Landing System (ILS) localizer and glide slope performance. The model is used to predict course structure degradation resulting from a change in the airport environment. Such changes include the addition of new hangars, terminal buildings and control towers as well as terrain modifications. In addition, the model is used to predict comparitive ILS antenna array performance in order to help determine which ILS system is required for new runway instrumentation and for the upgrading of existing instrumented runways to a higher FAA category.

## Introduction

The Instrument Landing System or ILS is used to provide signals for the safe navigation of landing aircraft during periods of low cloud cover and other conditions of restricted visual range. Separate systems are used to generate vertical and horizontal guidance signals. The vertical system is called the Glide Slope and the horizontal system, the Localizer.

The ILS operates by the transmission of an RF carrier, amplitude modulated by two audio frequencies of 90 and 150 HZ. These are so phased that when an aircraft is headed along the runway centerline, the 90 HZ and 150 HZ modulations are equal in magnitude, resulting in no movement of the pilot's Localizer cross pointer indicator. On the other hand, if the aircraft is not on course, the modulations are unbalanced resulting in a movement of the pointer revealing the off course situation. Similarly, the Glide Slope modulations are equal in magnitude when the aircraft is on the prescribed glide path and unequal in magnitude when it is either below or above the glide path.

In a typical airport environment with hangars and other structures situated near the runway, the ILS radiation illuminates not only the aircraft receiver, but the surrounding structures as well. Thus the aircraft even when on a correct approach will receive indications of an off course approach due to the interference of direct and scattered signals. With the Glide Slope system, the main problem results from radiation scattered from non flat terrain. This is because the Glide Slope system is an image system requiring the combination of direct and ground reflected energy for the formation of the radiated vertical antenna pattern used for vertical guidance.

## Model Predictions

The effects of such non flat terrain and structures on ILS performance can, however, be predicted. The prediction has been accomplished through the development of a physical optics electromagnetic scattering model whose equations have been coded for use on a high speed computer.[1-4] The model predicts the ILS performance that would result from a proposed addition at an airport of hangars, terminal buildings or control towers. In addition, the model is used to predict comparative ILS antenna array performance. This prediction is useful in determining which ILS is required for specific terrain configurations, for new runway instrumentation or for the upgrading of existing instrumented runways to a higher category.

The present Localizer model is capable of predicting Localizer performance in an airport environment where the scatterers can be represented as large rectangular or cylindrical perfectly conducting reflectors of arbitrary orientation and tilt. These generally are not important limitations as most important derogators are typically the large nearly perfectly conducting metallic or metal reinforced concrete hangars and terminal buildings. For structures which are not perfectly reflecting, the model gives a worst case result.

The Localizer model, to date, has been used to predict the expected degradation of course structure at several airports. It was used to predict for the FAA the Localizer course structure for the four instrumented runways at the Dallas Fort Worth airport, Figure 1. In this case the performance of the V-Ring, 8-Loop and Alford antenna arrays were compared and recommendations were given. An example of the output is shown in Figure 2. The Localizer model was also used to predict the degradation to the front and back courses which would result at Peterson Field, Colorado Springs, Colorado if a proposed large water tower were constucted. The model was also used to predict and compare the performance of several different candidate antenna arrays for a proposed instrumented runway at the San Francisco airport. The problem in this case was the proximity to the runway of a large 747 hangar. The model was also used for predictive studies of the New Orleans and Tulsa airports, as well as for a model validation study at the Syracuse-Hancock airport. In this latter study the theoretical predictions were compared with flight test data. The agreement was good, Figure 3. It should be noted that the running time of this model is not excessive. For the Syracuse-Hancock study, there were 53 scatterers, the running time on a PDP-10 computer was 48 minutes. The total computer cost including plotting was $300 dollars.

The present Glide Slope model predicts the performance of image type Glide Slope arrays in the presence of certain types of terrain irregularities. These terrain irregularities are assumed to be large compared to a wavelength (3 feet) and which do not vary in the direction perpendicular to the centerline of the runway. (Work is presently underway to remove this restriction of variation only in a direction parallel to the runway centerline.) Like the Localizer model, the computer running time is moderate.

The Glide Slope model has been used to predict and compare the performance of the three basic image type Glide Slope antennas, the Null Reference, the Sideband Reference and the Capture Effect antennas, for non flat terrains. These include terrains which sloped upwards, which sloped downwards and which contained dropoffs as well as combinations of these. It was found that acceptable course structure often could only be found with one of these Glide Slope antennas without performing a major terrain regrading. An example of the output is shown in Figure 4.

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## Theory

The development of the theory may be found in references 1, 2, and 3. Here we simply outline this development.

Maxwell's equations are first formally integrated using the vector Green's theorem applied to the general problem of electromagnetic scattering. Under the assumption that the perturbations in the current and charge distributions of the primary source due to the presence of the scatterer can be neglected, the electromagnetic fields are represented as sums of the incident fields produced by the primary source and the scattered fields produced by the induced currents and charges in the scatterer. The scattered electric and magnetic fields at the observation point can be represented as surface integrals of the scattered fields over the surface of the scatterer.

To obtain approximate solutions to these surface integral equations for the scattered fields, an iterative approach is adopted. Specifically, from a knowledge of the boundary conditions which must be satisfied at the surface of the scatterer, approximate functional relationships among the scattered fields and the known incident fields are developed and then substituted into the surface integral equations. The functional relationships among the scattered and incident fields at the surface of the scatterer are extremely complicated in the case of certain structures, for example, for hollow dielectric buildings with various internal structure, but very simple in the case of perfect conductors or buildings with metal walls (or, to a good approximation, metal rod reinforced concrete walls.) In the theory, it is assumed that the scattering objects may be represented as perfect conductors.

Application of the boundary conditions for perfect conductors yields a relationship between the scattered magnetic field at the observation point and the surface integral over the scatterer of the tangential component of the total (incident plus scattered) magnetic field. To approximate the total magnetic field on the surface of the conducting scatterer, we first employ the principles of ray optics. Specifically, we assume as a first approximation that the total magnetic field is zero on the side of the scatterer not directly illuminated by the primary source. This is a good approximation when diffraction effects may be considered as second order effects. Diffraction effects may safely be considered second order when the wavelength of the incident radiation is small compared with the dimensions of the scatterer. This is the case for scattering from hangers; however, it is not the case for scattering from aircraft where the localizer wavelength and fuselage radius are comparable. To treat this case, special care would have to be taken to check that diffraction remains small.

It is next necessary to specify the tangential component of the magnetic field on the illuminated side of the scatterer. This is done by assuming plane wave reflection. For distances generally encountered in the ILS problem, this approximation is valid.

Since we are interested in the values of the scattered fields in the far field of the scatterer (the approaching aircraft being between the outer marker and the far end of the runway), the integral equations for the fields may be expanded asymptotically for large values of the distance between scatterer and observer; a similar far field approximation is made for the antenna-to-scatterer distance. Both the Fraunhofer and Fresnel versions of this approximation are used.

The application of the above approximations in the outlined analysis leads to the final expressions for the scattered electromagnetic field, which may be found in References 1, 2, and 3.

Finally, to effectively treat any existing or future ILS system, a predictive model must incorporate a signal detection model which adequately accounts for systems utilizing one or two carrier frequencies, for arbitrary relative phasing between different signal components, receiving antenna gain patterns and effects of aircraft speed. To incorporate the desired features, the TSC receiver model derives the simulated CDI from estimates of a number of parameters characterizing the received ILS radiation field, including the resultant amplitudes, phases and phase change rates of the separate transmitted signal components for both the course and clearance carrier frequencies. Such quantities are used to estimate the amplitudes of 90 and 150 HZ signals in the output of an ILS receiver considered to function as an ideal envelope detector.

## References


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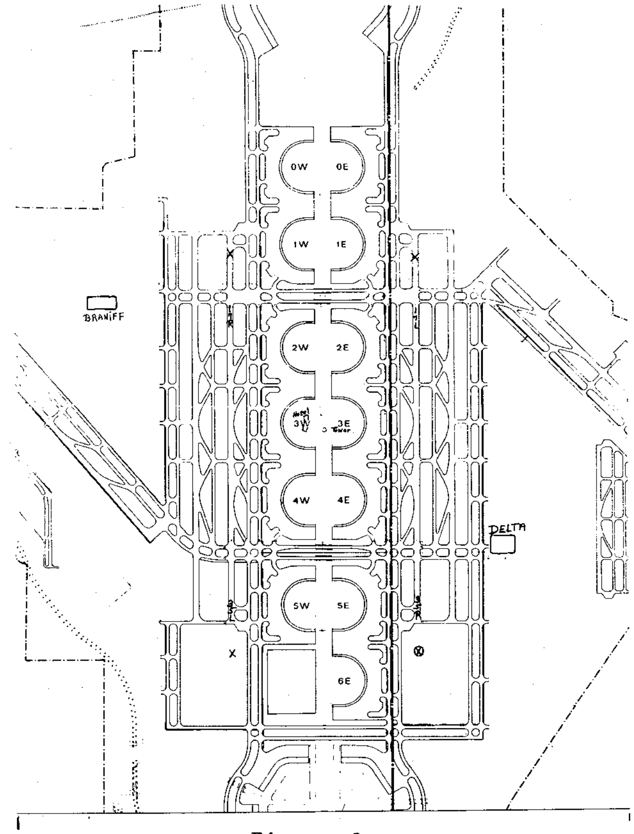



**Figure 1**

Proposed Dallas/Fort Worth Airport Layout Plan

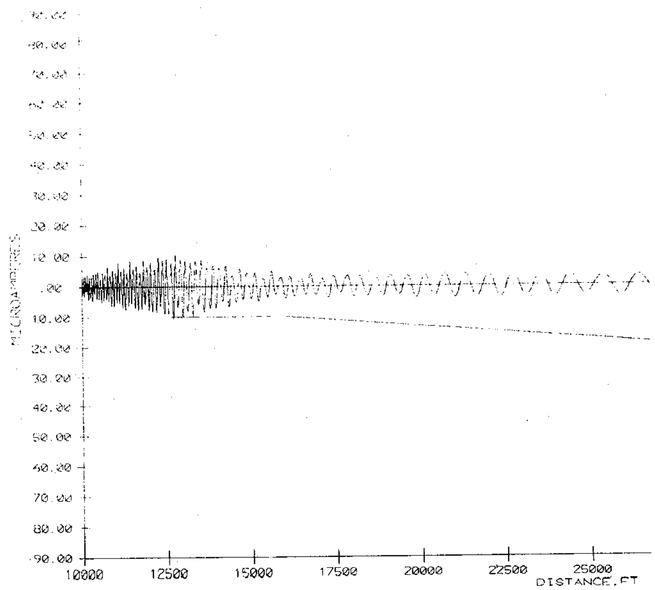



**Figure 2**

Predicted Course Structure in Presence of Terminals, Hotel and Tower Using a V-Ring Array for Runway 35L, Dallas/Fort Worth Airport

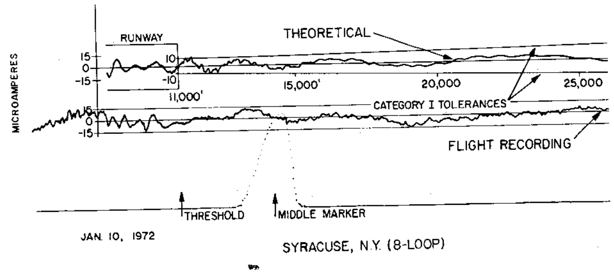
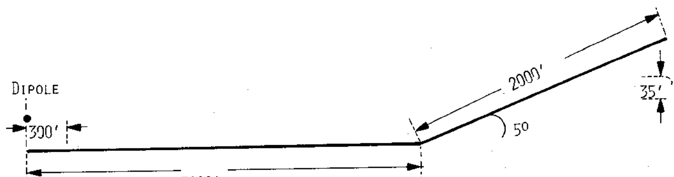
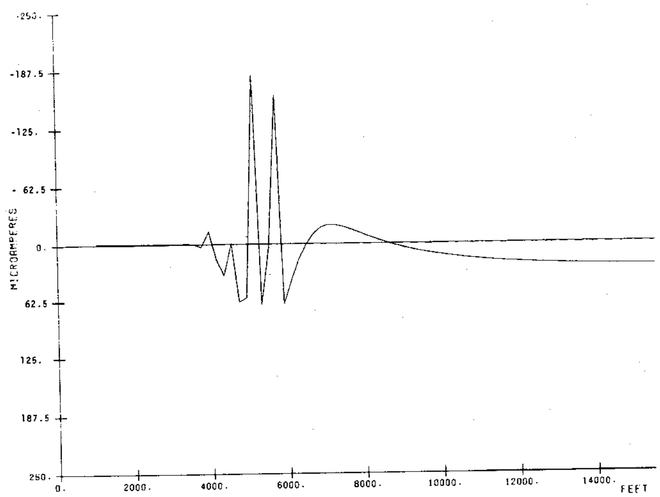



**Figure 3**

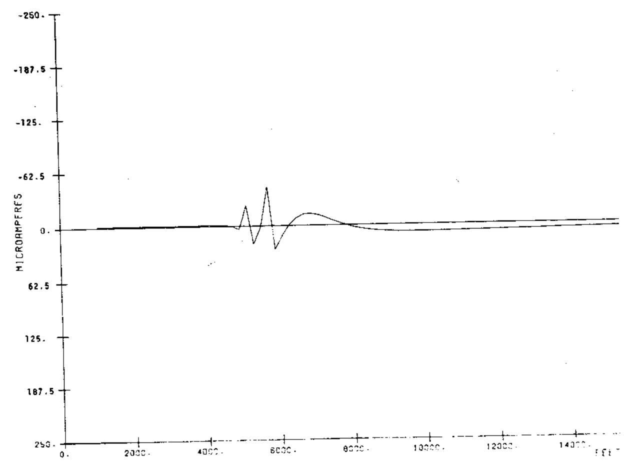
Comparison Between Flight Recording and Theory




4a




4b




4c

**Figure 4a,4b,4c**

4a: Schematic of terrain
4b: Flyability Run, Null Reference Antenna
4c: Flyability Run, Capture Effect Antenna