# Reduction of ILS Errors Caused by Building Reflections

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**An analysis of a concept for reducing beam distortion effects of an Instrument Landing System caused by reflections from buildings and other structures and a scale-model experimental verification of the concept on the localizer part of ILS are discussed. The concept, however, is not restricted to the ILS localizer error correction only and can be extended to correct glide-slope error with a similar but additional correction arrangement. A high degree of correlation between the predicted and measured data on the nature of reduction of derogation effects of structures has been achieved. Practical means to obtain corrections for beam distortions which do not require any modification of the landing system transmitter or receiver and which do not introduce any additional beam distortion problems are discussed in this paper. The scale-model experimental results indicate promises but suggest additional full-scale tests to assess the practical potentiality and constraints of the investigated approach in typical airports.**

## Introduction

THE Instrument Landing System (ILS) may be regarded as the primary airport approach and landing aid in use throughout the world. Reflections[1] or scattering from the ILS radiated signals from structures near the runway reduces the effectiveness of the ILS system. Recent construction of large hangars and large multistory buildings has accentuated the severity of the ILS beam bending problem. Since there is an ever-increasing demand of error-free instrument landing systems with increasing air traffic, it is desirable to seek a remedy of this beam distortion problem. One conceivable way to reduce errors caused by structures in the vicinity of an ILS localizer beam is to synthesize a cancelling signal that has the same amplitude and spectral characteristics as the building-reflected signal, but is opposite in rf phase such that the resultant cancelling and building-reflected signals approach zero. The problem of synthesizing such a signal for an almost arbitrary building-scattered signal, however, is very involved. Also, closed loop servo arrangements and often continuous monitoring operations are necessary so that the cancelling signal can be adjusted frequently.

The greatest difficulty in implementing this approach is to design and locate the radiating antenna system for the cancelling signal. This is because the building-scattered and cancelling signals must be phase congruent to effect a cancellation of such signals at any desired region. The phase congruence, on the other hand, requires the location of the cancelling signal antenna at the equivalent phase center of the building-scattered signal. Since, for arbitrary building or like scatterers, the phase center for the scattered signal may even be inside the structure itself, the implementation of this approach may not be possible even theoretically, particularly when the correction signal is to be applied over a large region of interest.

An alternate approach[2] is to generate a signal that would have its major effect at the output of the ILS receiver instead of cancelling the rf signal input at the receiver resulting from scattering from the building. If this is possible, phase congruence of the building-scattered and cancelling signals will no longer be required. Such an approach for the cancellation of the building-reflected signal has recently been investigated. In principle, the approach consists of reradiating a signal from or near the structure causing the ILS beam bending such that this reradiated signal, along with the building-scattered signal, yields a "zero" output at the ILS receiver, even when the instantaneous rf signal input to the ILS receiver is never zero.

The problem of appropriate synthesis of the signal required to be reradiated for this purpose and the design criteria for the implementation of an error-correcting system for the ILS beam distortion are further discussed in this paper. Experimental data on the distortion of ILS beam and its correction by the previously mentioned approach are obtained from a physical scale model. A comparison of the measured and predicted data indicating the degree of error correction establishes a strong correlation and indicates potential usefulness of such an approach to minimize ILS errors in many airports throughout the world. Results of appropriate analysis for the ILS beam correction and practical realization of this approach to minimize errors are discussed in the following sections of this paper.

## Formulation of the Problem

The problem of ILS error due to a building-scattered signal may be illustrated by Fig. 1. Let the effect of the localizer be considered first. In the absence of the building, the difference of the two modulating signal ampli-

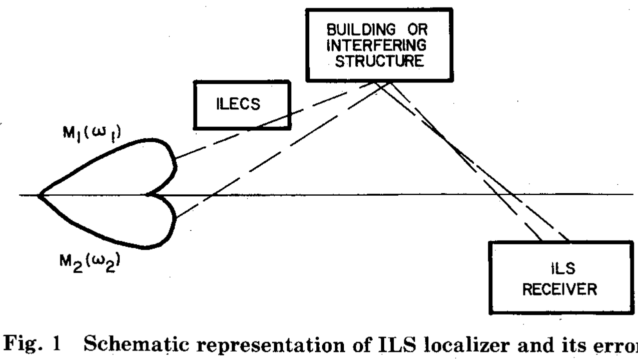


**Fig. 1 Schematic representation of ILS localizer and its error correcting concept.**

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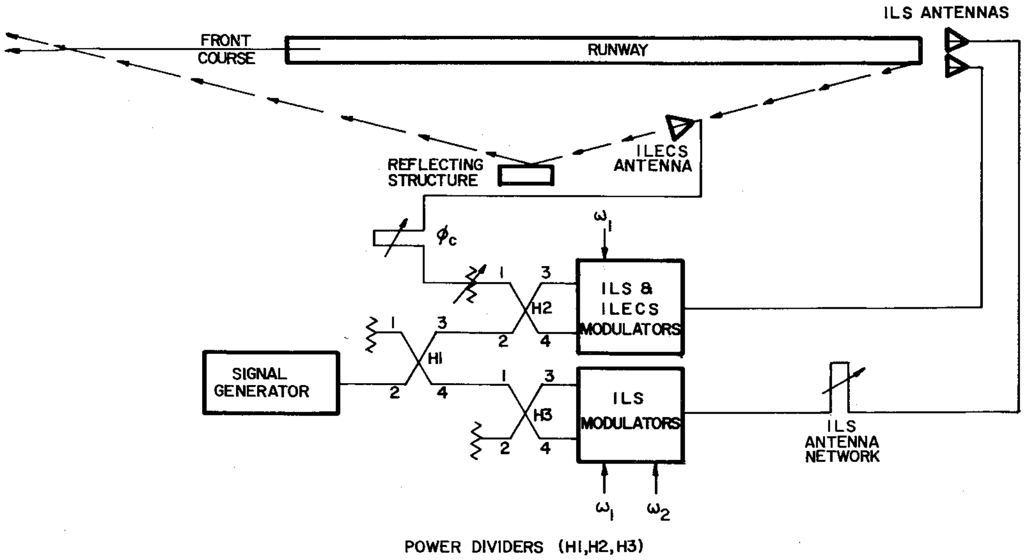


**Fig. 2 Arrangement for scale-model experiments to verify error correction concept.**

tudes, corresponding to 90-Hz and 150-Hz frequencies, is used to determine the position of the aircraft in the azimuthal plane, a zero difference being representative of the aircraft location at the center of the runway. In the presence of a building, the building-reflected localizer signal is added with the main-beam-signal, in phase or out of phase, depending on the receiver location. This causes the amplitude of the total detected signal at the ILS localizer receiver to be different from what it would have been in the absence of the building and hence a localizer error. If $M_1$ and $M_2$ denote, respectively, the amplitudes of the modulating signals of frequencies $\omega_1$ and $\omega_2$, corresponding to 90 Hz and 150 Hz, the input signal at the ILS receiver in an aircraft located at an arbitrary position, $p$, in the azimuthal plane and in the absence of the building can be expressed as

$$S_1(p) = A_1(1 + M_1 \sin\omega_1 t) \cos(\omega t + \varphi_1) \tag{1}$$

$$S_2(p) = A_2(1 + M_2 \sin\omega_2 t) \cos(\omega t + \varphi_2) \tag{2}$$

where $A_1$ and $A_2$ are, respectively, the carrier amplitudes for the signals corresponding to angular modulation frequencies $\omega_1$ and $\omega_2$. $M_1$ and $M_2$ are the modulation-carrier ratios for signals corresponding to $\omega_1$ and $\omega_2$, $\omega$ is the carrier frequency, and $\varphi_1$ and $\varphi_2$ are, respectively, the spatial phases of the signals corresponding to $\omega_1$ and $\omega_2$ and are functions of $p$. In general, $\varphi_1$ is equal to $\varphi_2$ by design.

When the signals $S_1$ and $S_2$ are reflected by an arbitrary structure, as shown in Fig. 1, the corresponding reflected signals will be modified, both in amplitude and in phase. Thus, the reflected signals at the same point $p$ may be expressed as

$$S_{1R}(p) = K_1 A_1(1 + M_1 \sin\omega_1 t) \cos(\omega t + \theta_1) \tag{3}$$

$$S_{2R}(p) = K_2 A_2(1 + M_2 \sin\omega_2 t) \cos(\omega t + \theta_2) \tag{4}$$

$\theta_1$ and $\theta_2$ being rf phases of the reflected signals at the point $p$ corresponding to the modulation frequencies $\omega_1$ and $\omega_2$. The combined signals arriving from direct and reflected paths can be written as

$$\bar{S}_1 = S_1 + S_{1R} = \bar{K}_1 A_1(1 + M_1 \sin\omega_1 t) \cos(\omega t + \psi_1) \tag{5}$$

$$\bar{S}_2 = S_2 + S_{2R} = \bar{K}_2 A_2(1 + M_2 \sin\omega_2 t) \cos(\omega t + \psi_2) \tag{6}$$

where

$$\bar{K}_1^2 = K_1^2 + 1 + 2K_1 \cos(\varphi_1 - \theta_1) \tag{7}$$

$$\bar{K}_2^2 = K_2^2 + 1 + 2K_2 \cos(\varphi_2 - \theta_2) \tag{8}$$

$$\tan\psi_1 = (\sin\varphi_1 + K_1 \sin\theta_1)/(\cos\varphi_1 + K_1 \cos\theta_1) \tag{9}$$

$$\tan\psi_2 = (\sin\varphi_2 + K_2 \sin\theta_2)/(\cos\varphi_2 + K_2 \cos\theta_2) \tag{10}$$

Since $\bar{K}_1$ and $\bar{K}_2$ are functions of the spatial position, $p$, of the aircraft, it is seen from Eqs. (5) and (6) that ILS localizer error will not be uniform at all points. Also, any arrangement to eliminate or reduce the localizer error due to building-reflected signals must be such that the effect of such signals at the output of the ILS localizer receiver approaches zero. This requirement, however, does not necessitate that the r.f. signal corresponding to $S_{1R}$ and $S_{2R}$ should be zero. For example, if one considers two signals similar to the one used for the ILS localizer

$$x(p) = C(1 + m \sin\omega_1 t) \cos[\omega t + W_1(p)] \tag{11}$$

$$y(p) = C(1 - m \sin\omega_1 t) \cos[\omega t + W_2(p)] \tag{12}$$

where $W_1 \neq W_2$, the rf signal corresponding to $(x + y)$ will not be zero at any arbitrary point $p$. But when this signal, $(x + y)$, is detected in an ILS receiver, the output involving the modulating signal becomes zero, regardless of the values of $W_1$ and $W_2$. Furthermore, this condition remains unchanged for any position $p$, for which Eqs. (11) and (12) are valid.

This concept of eliminating the modulating signal at the output of the receiver may be utilized for the cancellation or, at least, reduction of the building reflected signal for the ILS localizer since the phase congruence of the cancelling signal source and the scattering center of the building is not required. Also, once the correction is made at one point, its effect is maintained over an extended region corresponding to distances of the order of a quarter wavelength for the angular modulating frequency $\omega_1$.

Let it now be assumed that a correcting signal $S_3$ is projected toward the reflecting structure which causes the ILS beam distortion as shown in Fig. 1. Since for most cases the building reflected signal is dominated by either $S_{1R}$ or $S_{2R}$, and seldom both, it is evident that the correcting signal must correspond to the dominating signal, particularly insofar as its spectral characteristics are concerned. If, with no loss of generality, one assumes that the building reflected signal is predominantly a signal corresponding to the modulation frequency $\omega_1$, that is $S_{1R}$, the

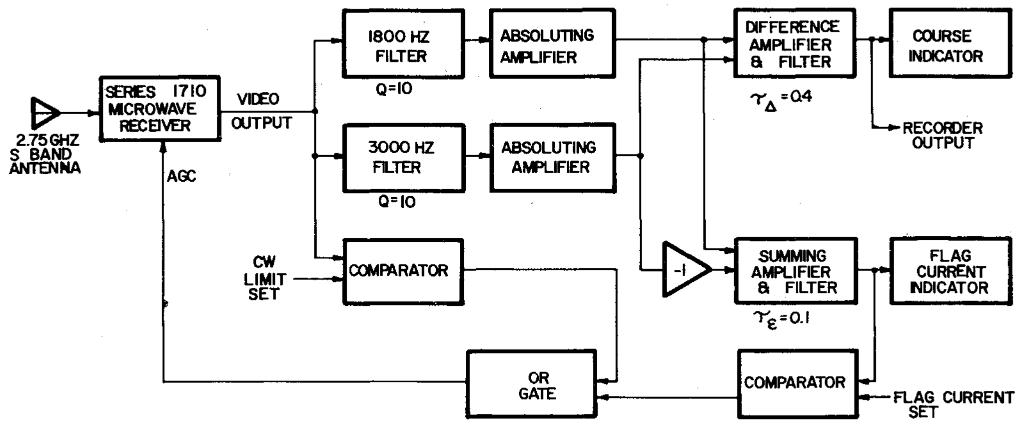


**Fig. 3 Scale-model ILS receiver and processor.**

correcting signal reflected from the building, as shown in Fig. 1, should be in accordance with Eqs. (11) and (12), of the form

$$\bar{S}_c = K_c S_3 = K_c A_c (1 - M_c \sin\omega_1 t)\cos(\omega t + \varphi_c) \quad (13)$$

where $K_c$ and $\varphi_c$ are, respectively, the reflection coefficient for the building corresponding to the correcting signal and the correcting signal phase at the point $p$, and $A_c$ and $M_c$ are the carrier and modulating signal amplitudes of the correcting signal.

Let it be assumed that the ILS localizer receiver is a linear detector. Following the detection of the combined signals, $\bar{S}_1$, $\bar{S}_2$, and $\bar{S}_c$, and the filtering the output for the passbands centered around $\omega_1$ and $\omega_2$, as occurs in an ILS receiver, one obtains

$$S_D = \sin\omega_1 t[K_1^2 A_1^2 M_1 - K_c^2 A_c^2 M_c + \bar{K}_1\bar{K}_2 A_2 M_1 A_1 \cos(\psi_1 - \psi_2) - \bar{K}_1 K_c A_1 A_c M_c \cos(\psi_1 - \varphi_c) + \bar{K}_1 K_c A_c A_1 M_1 \cos(\psi_1 - \varphi_c) - \bar{K}_2 K_c A_2 A_c M_c \cos(\psi_2 - \varphi_c)] \quad (14)$$

and

$$\sin\omega_2 t[\bar{K}_2^2 A_2^2 M_2 + \bar{K}_1\bar{K}_2 A_1 A_2 M_2 \cos(\psi_1 - \psi_2) + \bar{K}_2 K_c A_c A_2 M_2 \cos(\psi_2 - \varphi_c)] \quad (15)$$

Since the difference of the detected outputs corresponding to the modulation frequencies $\omega_1$ and $\omega_2$ constitutes the ILS-receiver-processed output, one can write this processed signal as

$$S_p = (A_1^2 M_1 - A_2^2 M_2) + (K_1^2 A_1^2 M_1 - K_2^2 A_2^2 M_2 - K_c^2 A_c^2 M_c) + 2K_1 \cos(\varphi_1 - \theta_1) A_1^2 M_1 - 2K_2 \cos(\varphi_2 - \theta_2) A_2^2 M_2 + [K_1^2 + 1 + 2K_2 \cos(\varphi_1 - \theta_1)]^{1/2} \times \quad (16)$$

$$K_c \cos(\psi_1 - \varphi_c)(A_1 A_c M_1 - A_1 A_c M_c) + \bar{K}_1\bar{K}_2 \cos(\psi_1 - \psi_2)(A_2 A_1 M_1 - A_1 A_2 M_2) - \bar{K}_2 K_c \cos(\psi_2 - \varphi_c)(A_2 A_c M_c + A_c A_2 M_2)$$

Some of the parameters indicated in Eq. (16), however, are restricted by the ILS design. For example, in all cases

$$M_1 = M_2 \quad (17)$$

Also, as mentioned earlier,

$$\varphi_1 = \varphi_2 = \varphi \quad (18)$$

When the contribution† of the building reflected signal corresponding to the nondominant modulation frequency, say $\omega_2$, is negligible, as assumed earlier, one may set $K_2 = 0$. Since, from Eq. (10), one may write

$$\cos(\psi_2 - \varphi_c) = (1/\bar{K}_2)(\cos\alpha + K_2 \cos\beta) \quad (19)$$

where $\alpha = \varphi - \varphi_c$ and $\beta = \varphi_c - \theta_2$, Eq. (16) can be expressed as

$$S_p = M\{(A_1^2 - A_2^2) + (K_1^2 A_1^2 - K_c^2 A_c^2) + 2K_1 A_1^2 \cos(\varphi - \theta_1) - 2K_c A_c A_2 \cos\alpha_2\} \quad (20)$$

when

$$M = M_2 = M_c = M$$

The first term within the bracket of Eq. (20) denotes the appropriate value of $S_p$ in the absence of any building reflection and the correction signal. An effort to minimize the error due to the building, then, will be to reduce or eliminate the remaining terms within the bracket. To achieve this, one has the flexibility of controlling the parameters $K_c A_c$ and $\alpha$ since they relate to the correction signal. An examination of Eq. (20) indicates that the resultant error due to the correcting and building-reflected signals has two parts. One part, as represented by the second term within the bracket of Eq. (20), is independent of the position, whereas the remaining terms are position dependent. When the reflection coefficient for the building, or $K_1$, is a very small fraction of unity, the position-dependent error, being proportional to the first power of $K_1$, becomes dominant. In most cases of practical interest, then, it is necessary to reduce the terms involving $\cos(\varphi - \theta_1)$ and $\cos\alpha$.

If it is assumed that the location of the aircraft, $p$, is sufficiently far from the scatterer such that the effect of the building-reflected signal is representable by a point source radiating the reflected signal with a complex radiation pattern depending on the building structure, it is possible to arrange the location of the correcting signal source and adjust its phase $\varphi_c$ such that a condition, $\theta_1 = \varphi_c$, becomes physically realizable. In general, to achieve this, the look-angle for the ILS transmitter and the correcting signal source, from the equivalent point source representing the building reflection, should be the same. One may conclude, therefore, that in order to minimize the effect of the building-reflected signal by a correction approach as

†The operation of the error correction arrangement is not strictly constrained by this assumption since, when $K_2 \neq 0$, one may require another correcting signal similar to the one shown in Eq. (13) but corresponding to $\omega_2$.

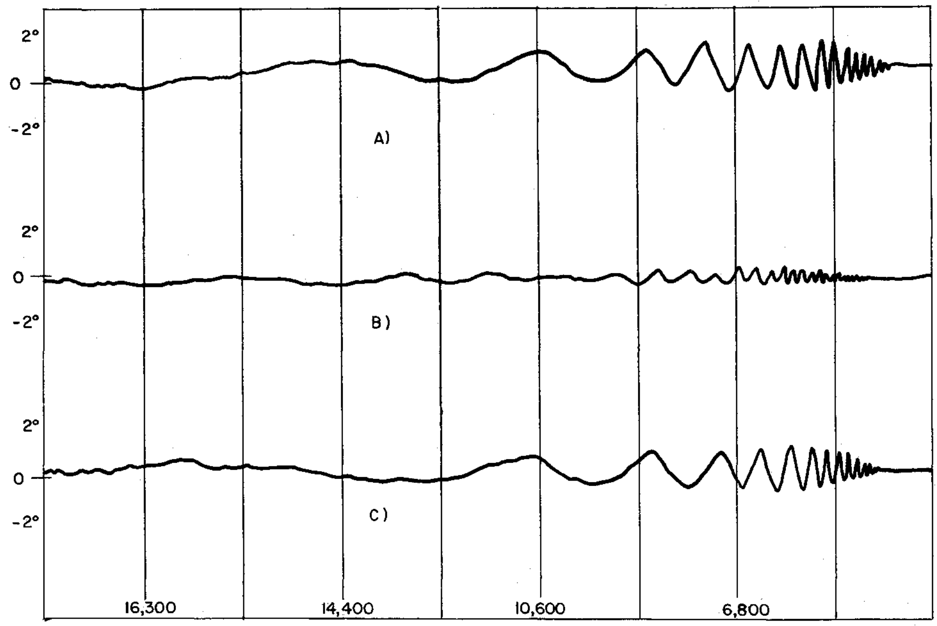


**Fig. 4 ILS localizer error due to various locations of a 100 ft high, 100 ft wide building: A) $x$ = 2500 ft, $y$ = 750 ft; B) $x$ = 2500 ft, $y$ = 1000 ft; C) $x$ = 2500 ft, $y$ = 625 ft; $x$ is along the runway, $y$ is at the right angle to $x$.**

described above, one needs to control the values of $A_c$ and $\varphi_c$ in addition to setting $M_c = M_1 = M_2$.

To investigate the practical effectiveness of this error reduction approach for the ILS localizer, experiments with a physical scale model of the ILS localizer and a reflecting structure were conducted. A review of these experiments and experimental results indicating the degree of error correction possible through this approach are discussed in the following section.

### Experimental Verification of the ILS Error Correcting Approach

To examine the feasibility of the approach discussed in the previous sections, a physical scale model of the localizer of an ILS, including a simulated runway and a reflecting structure, was built and tested. Only one large building capable of significantly distorting the ILS beam was used for the simulation. The scale factor used was 25:1. This physically reduced a 10,000-ft runway to 400 ft. The aircraft altitude of 50 ft became 2 ft in the scale model, permitting the receiving antenna for the ILS localizer receiver to be mounted on an automobile used in place of an airplane during simulation experiments.

The schematic arrangement of the experimental setup is shown in Fig. 2. Two horn antennas, each with a gain of 20 db, were used for the simulation of the ILS transmission. A 4 ft by 4 ft aluminum sheet on a wooden frame simulated 100 ft wide and 100 ft high reflecting structure. The error correcting system for the ILS, referred to as ILECS in Fig. 2, used a Horn antenna with a gain of approximately 15 db. This antenna radiating the correcting signal was located approximately along the geometric line of sight connecting the ILS transmitter and the building. Although in actual practice the correcting signal is likely to be synthesized from the ILS signal as received at or near the correcting signal source to insure exact values of the carrier angular frequency, $\omega$, and $\omega_1$ and $\omega_2$ required for the error reduction, a sample of the carrier frequency for the ILS signal was used directly during the simulation experiments. Thus, as shown in Fig. 2, the signal at 2.75 GHz from a signal generator was used for the two ILS signals corresponding to $\omega_1$ and $\omega_2$ and for the synthesis of the correcting signal through a power divider. Arrange-

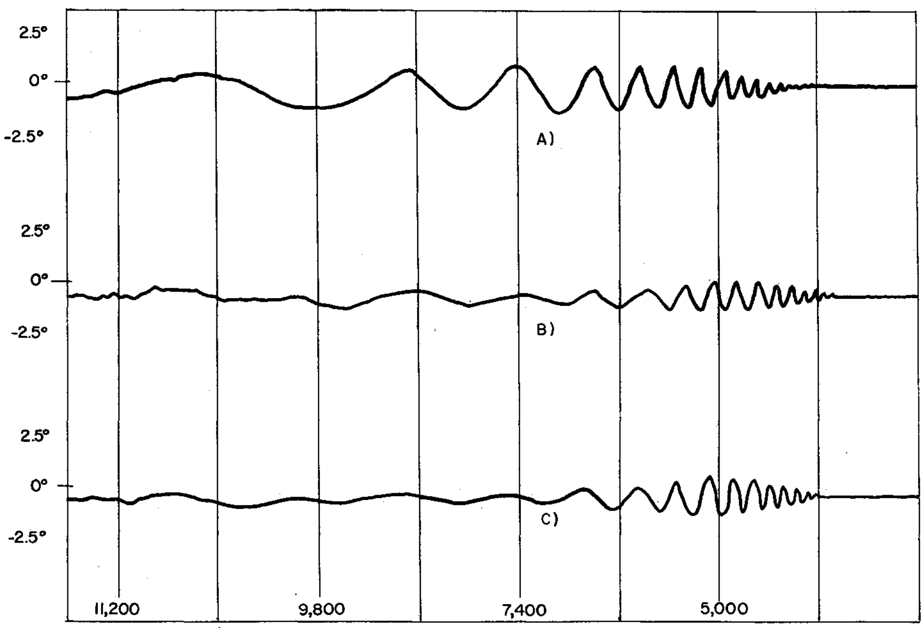


**Fig. 5 ILS error correction for different phases of correcting signal: building 100 ft high, 100 ft wide; $x$ = 2500 ft, $y$ = 625 ft; A) error without correction; B) error with correction, $\varphi_c$ = −33°; C) error with correction, $\varphi_c$ = 0°.**

ments were provided in the experimental setup to adjust the phase, $\varphi_c$, and to control the amplitude of the correction signal, $A_c$. No automatic controls by any servo arrangement were used during the simulation experiments. The commonly used modulation frequencies, $\omega_1$ and $\omega_2$ in ILS localizers, were scaled in accordance with the same scale factor during the simulation experiments.

The ILS receiver-processor arrangement used during the simulation experiment is shown in Fig. 3. To determine the effectiveness of the solution in simulation tests, it was necessary to simulate also the beam bending problem. Figure 4 shows the ILS signal derogation effect due to a building in the absence of any correcting signal for various building locations. The effect of different values of $\varphi_c$ on the reduction of beam distortion is shown in Fig. 5. It is seen from Fig. 5 that a significant improvement toward the reduction of beam distortion in the critical region of the runway is achievable with the approach as discussed. Thus, for example, the maximum total error, as measured from the positive error peak to the negative error peak, is reduced from 2.0° from the uncorrected situation, as shown in Fig. 4A, to 0.9° in Fig. 4B for distances greater than 7,000 ft on the runway. With an improved control of $\varphi_c$ this error is further reduced to 0.6° as shown in Fig. 4C. The corresponding reductions for distances less than 7,000 ft was 1.6° (Fig. 4B) and 2° (Fig. 4C) from the uncorrected value of 2.5°. The localizer error corrections observed during the scale-model experiments by the approach under consideration are indicative of the nature of corrections achievable in real life and certainly not the maximum extent of possible corrections. Indeed, the degree of error correction can be improved by the provision of automatic phase control for $\varphi_c$ and more precise control of $A_c$ than was possible during the scale-model tests.

## Conclusion

From the theoretical analysis and experimental verification of the error correcting approach for an ILS, as discussed in the preceeding sections, the following conclusions may be derived. a) The effect of building-reflected signal which distorts the ILS beam can be minimized by a correcting signal radiated at the same carrier frequency as that of the ILS and with the same modulation as that of the dominant ILS signal incident on the building or reflecting structure, except for a polarity reversal of the modulating signal. b) To achieve optimum correction, which is defined as the minimization of the ILS beam distortion, not only at the runway but also in all significant regions of interest, one must provide flexibilities to control the modulation ratio $M_c$ and the correction signal amplitude $K_c A_c$ and the relative phase $(\varphi_c - \theta_1)$ between the correcting and building-reflected signals. c) The optimized correction referred to in (b) is such that once the correction is achieved in one region, the effectiveness of ILS is not deteriorated in other regions. d) To achieve appropriate correction and to accommodate dynamic characteristics of the reflecting structure, such as opened or closed doors on a hangar, for example, it is desirable to illuminate the building or the reflecting structure with the correcting signal from an antenna that is located between the ILS transmitting antenna system and the reflecting structure as shown in Fig. 1. It may be remarked that the reduction of the beam distortion for the ILS is achievable with the approach as described here without necessitating any modification of the ILS transmitter and receivers. Furthermore, the correction arrangement can be localized at or near the offending structure.

During the simulation, it was observed experimentally that the addition of the correction signal did not introduce any additional observable errors in other regions. Such a result is possible when the equivalent radiation patterns of the reflecting structure, for the ILS transmitted signal and for the correction signal, are very nearly the same. This occurs when the phase centers for the correcting-signal source and the ILS transmitter are far from the equivalent phase center of the scattering structure or the building and these phase centers are practically colinear. Physical realization of such an arrangement does not seem to pose any serious problem for most ILS systems of concern.

## References

[1]Sauter, W. A. and Ghose, R. N., "Instrument Landing Error Correction System," Rept. FAA-RD-72-78, Feb. 1972, American Nucleonics Corp., Woodland Hills, Calif.

[2]"Multipath and Diffraction Effects of Structures on Localizer Systems," Rept. FAA-RD-70-28, Aug. 1970, IBM, Gaithersburg, Md.