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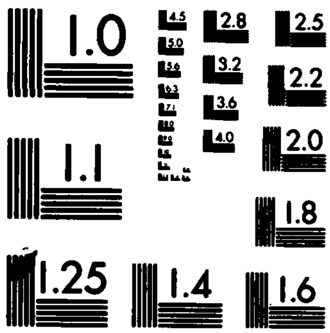

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EVALUATION OF
INSTRUMENT LANDING SYSTEM
DDM CALIBRATION ACCURACIES

THESIS

AFIT/GE/EE/83D-43

Dennis M. McCollum
Capt USAF

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirement for the Degree of
Master of Science

by
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Dennis M. McCollum

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ABSTRACT

Instrument landing system (ILS) accuracy is highly dependent upon the accuracy of the test instrumentation used in maintaining it. In an effort to upgrade calibration support to Air Force instrument landing systems, the Air Force Measurement Standards Laboratory requested an independent study be done on modulation factor and DDM accuracies. In this thesis report, ILS accuracy requirements are analyzed along with the accuracy specifications of test instrumentation. The report provides a short tutorial on ILS concepts in chapter II. In chapter III, modulation factor and DDM accuracy specifications have been compiled from various source documents. The evaluation, in chapter IV, looks at the adequacy of ILS test instruments and the ILS modulation factor and DDM calibration hierarchies. Based on the decision criteria used, it shows that existing instrumentation cannot adequately support all Categories of ILS. The significant results of the evaluation are summarized in chapter V along with the author's recommendations.

I. INTRODUCTION

Flight safety has long been, and continues to be, a major topic of interest to both civil and military aviation. In the short history of flying, a number of aids to navigation have been developed in order to promote flight safety. One such aid is the instrument landing system, or simply ILS (A short, but excellent, overview of the history of the ILS is presented in reference 7). Over the years, ILS's have proven to be reliable and dependable, and with improvements in electronic devices, they have evolved into very accurate systems. The quest to further improve ILS accuracy has not stopped. The USAF is currently working to upgrade calibration support to Air Force instrument landing systems. The purpose of this report is to present the results of a study conducted by the author to assess ILS DDM and modulation factor calibration accuracies.

Background

The Air Force Measurement Standards Laboratory, located at the Aerospace Guidance and Metrology Center (AGMD), Newark Air Force Station, Ohio, is the Air Force's primary calibration laboratory. It is responsible to assure that Air Force systems are calibration traceable to national standards.

The AGMC is in the process of upgrading calibration support of all Air Force instrument landing systems, and in this regard, requested an independent evaluation be done of ILS DDM and modulation factor calibration accuracies.

Problem

In upgrading the support to Air Force instrument landing systems, AGMC must know system performance requirements in order to develop a calibration strategy that will assure that these requirements are achieved. A systems approach to analyzing the DDM and modulation factor accuracies of system components and test instrumentation was needed.

Scope

This investigation was limited to the evaluation of DDM and modulation factor accuracies in instrument landing systems. No specific system was considered.

System specifications used in this evaluation were derived from four primary sources:

1) The International Civil Aviation Organization, Annex 10 publication entitled "International Standards and Recommended Practices Relevant to ILS".

2) The United States Flight Inspection Manual, Air Force manual 55-8.

3) Aeronautical Radio, Incorporated's document, ARINC Characteristic 578-3: Airborne ILS Receiver.

4) Radio Technical Commission for Aeronautics' documents, RTCA DO-131A: Minimum Performance Standards. Airborne ILS Localizer Receiving Equipment, and DO-132A: Minimum Performance Standards, Airborne ILS Glide Slope Receiving Equipment.

Approach

The effort began with research to determine ILS DDM and modulation factor accuracy requirements of the system ground and airborne components, i.e. the localizer and glide slope and airborne receivers. Additional research was conducted to determine the specific items of test instrumentation used in maintaining ILS's and the accuracy specifications of each test device. Once the research was complete, then the evaluation was conducted.

The evaluation consisted of first comparing system accuracy requirements with the accuracy specifications of maintenance test instruments in order to determine if these test instruments were adequate for maintaining system DDM and modulation factors to the required levels of accuracy. Finally, the DDM and modulation factor calibration hierarchies were identified and analyzed. Each calibration instrument was evaluated in terms of it's ability to provide the levels of accuracy needed to support instrument landing systems. Results from the evaluation were discussed and proposals to improve system accuracies were given.

Organization

This thesis report is comprised of five chapters. the information in Chapter II is tutorial in content and is presented to acquaint the reader with instrument landing systems concepts. Chapter III provides a summary of system and test instrument DDM and modulation factor performance requirements and specifications. The evaluation of ILS modulation factor and DDM accuracies is contained in Chapter IV. Chapter V presents a summary with detailed conclusions and recommendations.

II. ILS CONCEPTS

This chapter is included as an aid to the reader who is not familiar with instrument landing system concepts. The chapter is tutorial in content, presenting those concepts necessary to the understanding of this thesis report. For the reader who wishes a more detailed treatment of the subject, the references listed in the bibliography are highly recommended.

GENERAL CONCEPTS

System Description. An ILS is an electronic system designed to help aircraft pilots land their aircraft safely during periods of poor visibility. The ILS accomplishes this task by providng guidance information to the pilot via cockpit instruments.

A typical ILS is composed of the following subsystems:

(1) Localizer

(2) Glide Slope

(3) Marker Beacon

(4) Monitor & Control

(5) Airborne Receiver.

Figure II-1 illustrates how each of these subsystems, with the exception of the airborne receiver, might be configured at an airport.

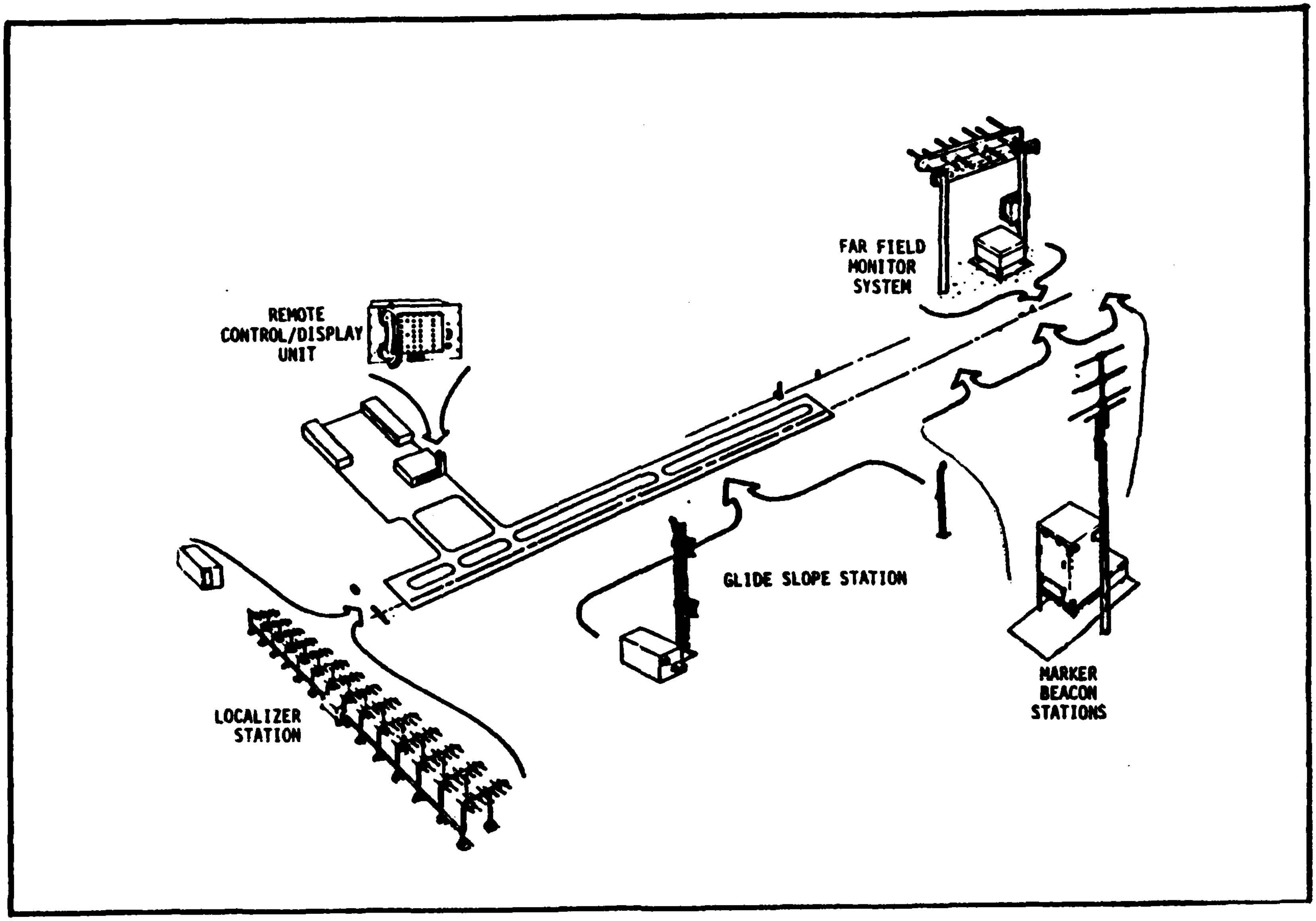


Fig. II-1. Typical ILS Configuration.

Guidance to the runway is provided by highly directional ratio signals. The localizer produces the signals necessary for laterial guidance while vertical guidance signals are provided by the glide slope subsystem.

Distance to runway indications are provided by marker beacon equipment. The marker beacon subsystem may have up to three marker beacon stations placed at specific locations along the approach path. These are called the outer marker, middle marker, and inner marker. Their distance from the runway threshold determines which type they are. Normally, the outer marker will be located where the aircraft intercepts the glide-path. This is approximately 4 to 7 miles from the runway threshold. The middle marker is generally located about 3500 feet from threshold, or where the aircraft is "on glide-path" at an altitude of 200 feet above ground level. The inner marker designates the "decision point" between the middle marker and the threshold. This point is where the pilot must decide whether or not to continue the approach. Most ILS configurations do not use all three markers.

The monitor & control circuits keep continuous watch over critical system parameters and provide warning indications to airport control tower personnel should out-of-tolerance conditions exist.

The airborne receiver converts the signals generated from the localizer and glide slope subsystems into horizontal and vertical guidance indications. These indications are displayed on an ILS indicator which is located on the cockpit instrument panel. An example of the kinds of indications that a pilot might see are shown in Fig. II-6 on a crosspointer indicator.

Localizer. The localizer generates the signals that provide lateral landing guidance to aircraft. It does this by establishing an RF pattern in space whose signal is proportional to lateral displacement from the vertical plane through the runway centerline (Ref 8:529).

The localizer subsystem consists of transmitter equipment housed in one building and an array of antennas. The localizer equipment is located at the end of the runway opposite the approach end (refer to Fig. II-1).

Two localizer transmitters, one called the course transmitter and the other called the clearance transmitter, operate in the 108MHz to 112MHz (VHF) frequency range. Each transmitter develops two AM RF signals; a carrier-plus-sidebands (CSB) signal and a sidebands-only (SBO) signal. The signals are so named because of their energy make up. The CSB signal is a double-sideband (DSB) signal containing sideband energy at 90Hz and 150Hz above and below the assigned carrier frequency. The SBO signal is also double-sideband; however the carrier has been suppressed. This DSB-SC (double-sideband suppressed-carrier) signal has sideband energy located at 90Hz and 150Hz above and below the assigned carrier frequency. Details describing how these signals are developed are presented in a subsequent section. The RF output of the course transmitter is 4.75KHz above the assigned localizer frequency and the output power of the CSB signal and the SBO signal is 15 watts and 0.6 watt, respectively. The clearance transmitter RF output is 4.75KHz below the assigned localizer frequency and the output powers of the CSB and SBO signals are 10 dB below those of the course transmitter. The 9.5KHz separation between the course and clearance RF signals is to prevent mutual interference from occurring between these signals.

The composite localizer radiation pattern is made up of two signal patterns: (1) A course pattern; and, (2) a clearance pattern. The course pattern provides aircraft with lateral landing guidance while the clearance pattern prevents aircraft from making approaches on false courses. In some localizer designs, two antenna arrays are used to develop the composite localizer pattern. In other designs, one array is shared by the course and clearance transmitters. Regardless of the design, all produce the same signal pattern in space. The course array elements radiate the pattern that forms the normal approach course, or front course. This array uses a large number of antenna elements in order to achieve a high degree of directivity toward the approach area. Most of the energy is concentrated in a 25 degree sector symmetrically aligned around the approach radial (Ref 4:3-56). The course and clearance radiation patterns are depicted in Fig. II-2. The clearance radiation pattern is much broader than that of the course. This is because it uses fewer antenna elements than does the course array. The course pattern contains side-lobes that, without the clearance pattern, could cause an aircraft to select a wrong (sidelobe) course. Within the region of the true course (i.e., $\pm$ 10 degrees about the designed procedural course), the signal strength due to the course array is greater than that from the clearance array. In the regions where the sidelobes exist, the clearance signal predominates. Airborne ILS receivers are designed to respond to the greater of the two signals. The course and clearance patterns are tailored in such a way that in the region where the clearance pattern predominates, an aircraft indicator will produce full fly-left or full fly-right indications, depending on whether the aircraft is to the right or left of the course centerline.

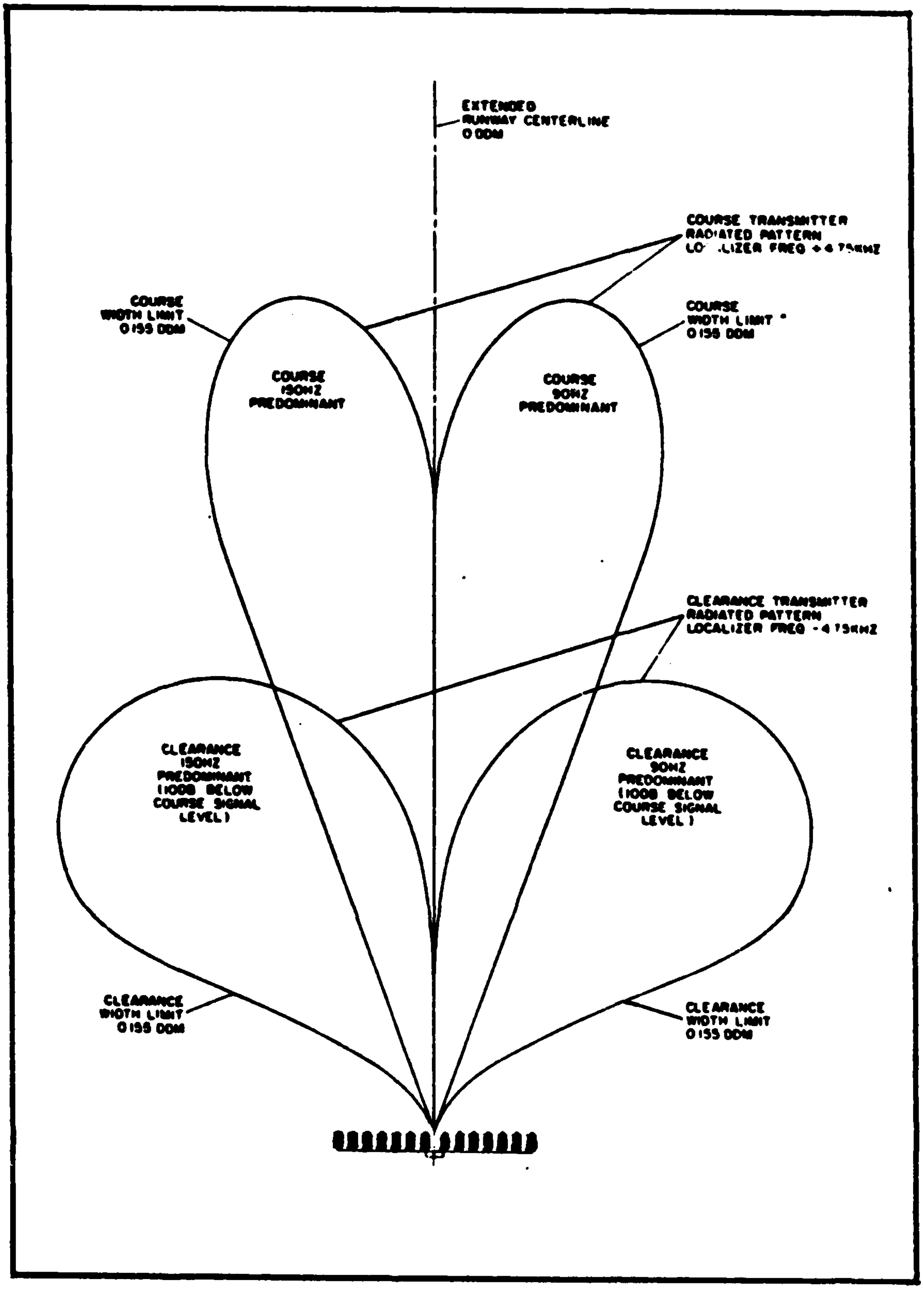


Fig. II-1. Localizer Radiation Patterns.

Glide Slope. The glide slope is the vertical guidance portion of the ILS. It generates a radiation pattern in space from which a signal is derived proportional to the vertical displacement from the glide-path.

The glide slope subsystem consists of transmitter equipment housed in a shelter and two antennas mounted on a 40 foot tower. These components are located as shown in Fig. II-1.

The transmitter operates in the 328 to 336MHz (UHF) frequency range and produces two RF signals similar to those produced by the localizer; a carrier-plus-sidebands (CSB) signal and a sidebands-only (SBO) signal.

Two antennas are used by the glide slope subsystem to develop the spatial glide-path pattern. Figure II-3 illustrates the pattern produced by the glide slope. The relative position of each antenna with respect to the ground and each other determines the spatial properties of the RF pattern. The top antenna is called the sidebands antenna because it is fed the SBO (sidebands-only) signal. The lower antenna is called the carrier antenna because it receives the CSB (carrier-plus-sidebands signal. The height of the carrier antenna determines the glide-path angle. The height of the sidebands antenna is set precisely to twice that of the carrier antenna.

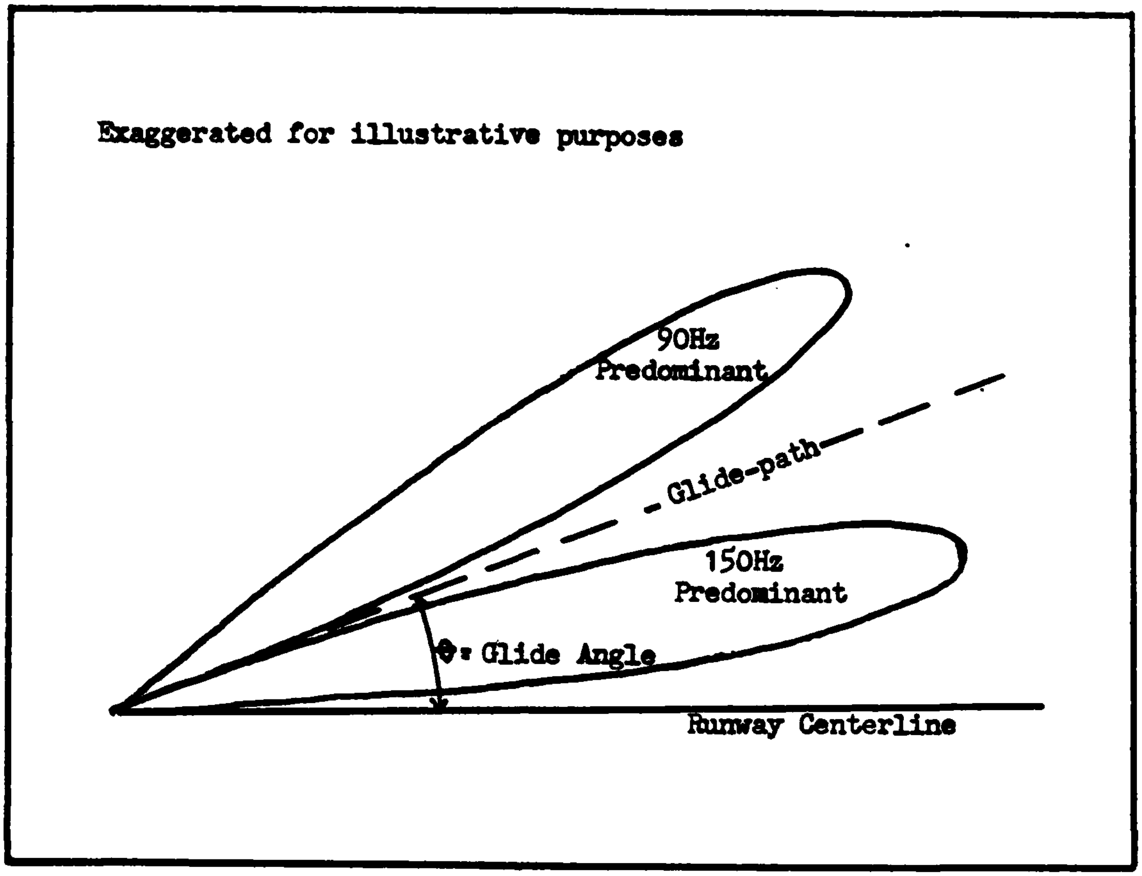


Fig. II-3. Glide Slope RF Pattern.

The glide slope generates a basic glide-path by producing a combination of radiation patterns, which results in two signal areas. One signal is predominant below the desired glide-path and is amplitude modulated with a 150Hz tone. The other signal is predominant above the desired glide-path and is amplitude modulated with a 90Hz tone. These signals. act on receiving equipment within the aircraft in such a way that an indicator pointer is horizontal when the aircraft is on the correct path, and is deflected if the aircraft deviates from the path. (see Fig. II-6).

LANDING CONCEPTS

Visibility Limitations. Visual landings are permitted as long as visibility in the airport approach area exceeds three miles in range and the ceiling (the height of the clouds) is greater than 1000 ft. When visibility is below these minimums (as judged by airport control tower personnel) instrument landings are required.

The International Civil Aviation Organization (ICAO), an agency of the United Nations which promotes worldwide standardization of navigation, communication, and air traffic control, has established minimum (visibility) condition categories; Categories I, II, and III. These categories specify minimum runway visual range and decision altitude. Runway visual range is a measure of terminal-area visibility. The minimum runway visual range can vary from 2600 feet for Category I to zero feet for Category III (Ref 8:522). The decision altitude is the height at which the pilot must decide whether conditions are adequate for a safe landing or not. when an aircraft making an instrument approach reaches the minimum decision altitude, the law requires that the crew establish visual contact with the runway or abort the landing. The decision point for each ILS category is shown in Fig. II-4.

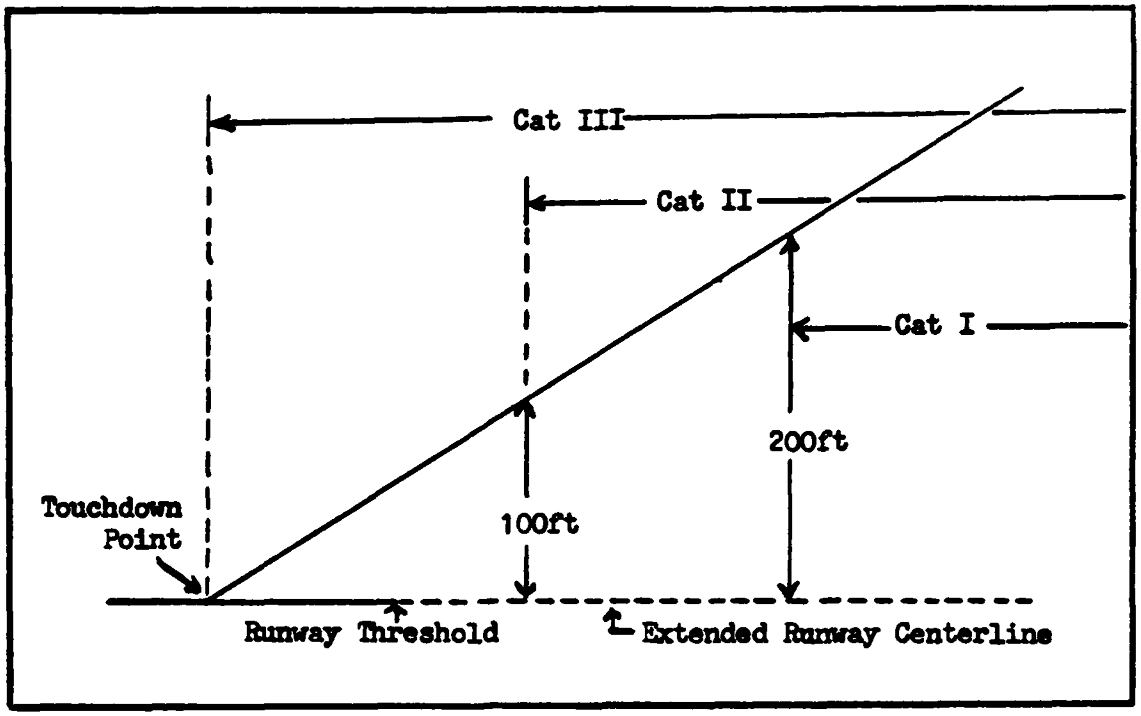


Fig. II-4. ILS Decision Points.

When used with an ILS, these categories also define specific levels of facility performance. For example, an ILS facility designed for Category I airport operations will provide acceptable guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide-path at a height of 200 ft above the plane containing the runway threshold. Similarly, a Category II facility will provide acceptable guidance from the ILS coverage limit to the 50 foot point.

It can be seen from the above explanation that a system designed for Category III operations requires greater accuracy than one designed for either Category I or Category II.

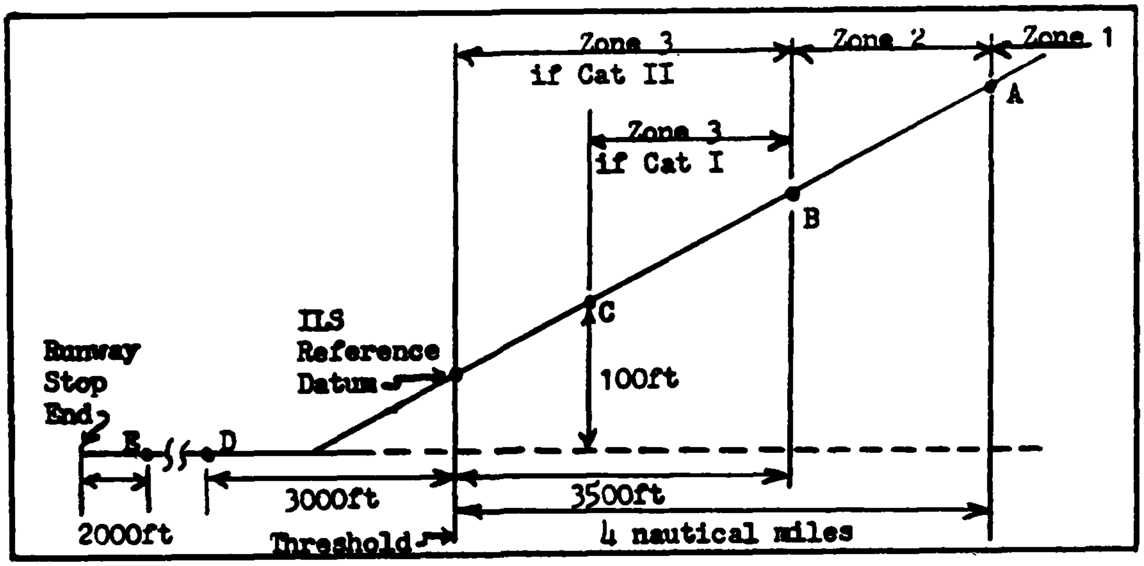


Fig. II-5. ILS Points and Zones.

The Approach Area. The ILS approach area is divided into zones 1, 2, and 3. The limits of these zones are established by "points". These points are called A, B, C, D, E, and the ILS Reference Datum point. These points are illustrated in Fig. II-5, and each is defined in Appendix A (e.g. see ILS-Point "A").

The Approach. An aircraft making an instrument approach does so in two stages; an initial approach and a final approach. The initial approach to the ILS is generally made from an enroute navigational facility on a predetermined heading to the localizer front course. The front course is the course which is situated on the same side of the localizer as the runway. A straight-in approach is used whenever possible.

The final approach is the course of action where the aircraft proceeds inbound to intercept the glide-path before descending to the final approach altitude. The final approach altitude is the height where the aircraft intercepts the glide slope on-path signal at the time of passing over the outer marker beacon station (see Fig. II-6).

If the aircraft is exactly on-course and on-path, the cockpit crosspointer indicator will be centered as in (A) of Fig. II-6. As the aircraft passes over the outer marker beacon station, the marker beacon signal activates a blue light on the cockpit instrument panel. When the aircraft is over the middle marker beacon, an amber light comes on. When the aircraft passes over the inner marker beacon, a white light is lit.

The pilot's charts show the distance of the marker beacon stations from the approach end of the runway as well as the height (with respect to the runway) of an on-course aircraft. The vertical angle of the glide-path with respect to the airport ground plane is usually set to between 2.25 and 3.0 degrees. the middle marker is usually located at a point along the extended runway centerline where the vertical distance from the ground to the glide-path is 200 ft (Ref 6:1.4.1-2).

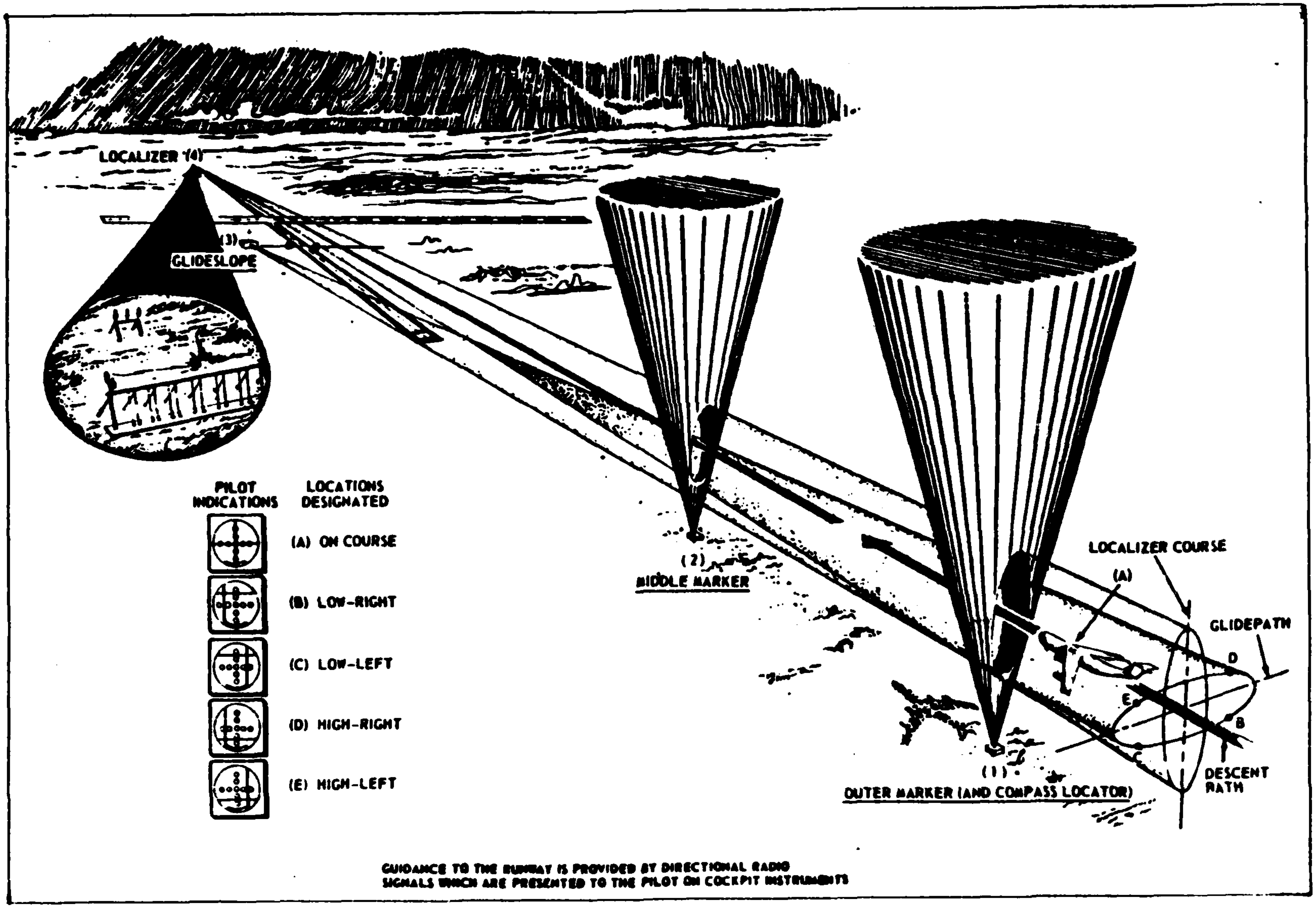


Fig. II-6. Instrument Approach

SYSTEM CONCEPTS

There are many different types of instrument landing system throughout the world but all perform the same basic task; that of providing landing guidance to pilots.

For an ILS to provide guidance information, it must create a signal pattern in space that has this guidance information imbedded in it. In all ILS designs, this information is contained in the difference in depth of modulation (DDM) between two sinusoidally modulated AM RF carriers; one modulated with 90Hz and the other modulated with 150Hz. The circuits used to transmit and receive these signals are discussed in more detail in subsequent sections.

ILS Signal Generation. ILS signals are unusual when compared to most AM signals and the method used to create them is considered unique. The complete modulation process is a two-part process, the first part is called "transmitter modulation" and the second part is termed "space modulation". The localizer and glide slope subsystems produce transmitter modulation in essentially the same manner; however, space modulation is effected in different ways. the development of transmitter modulation and space modulation is considered next.

Transmitter Modulation. The method of generating transmitter modulated RF signals for the localizer and glide slope subsystems is essentially the same. the primary differences between these signals are the band of frequencies that each is assigned (i.e. the localizer operates at VHF while the glide slope operates at UHF), and the amount of power allotted for each signal. Figure II-7 is a block diagram of the circuits used to generate these signals.

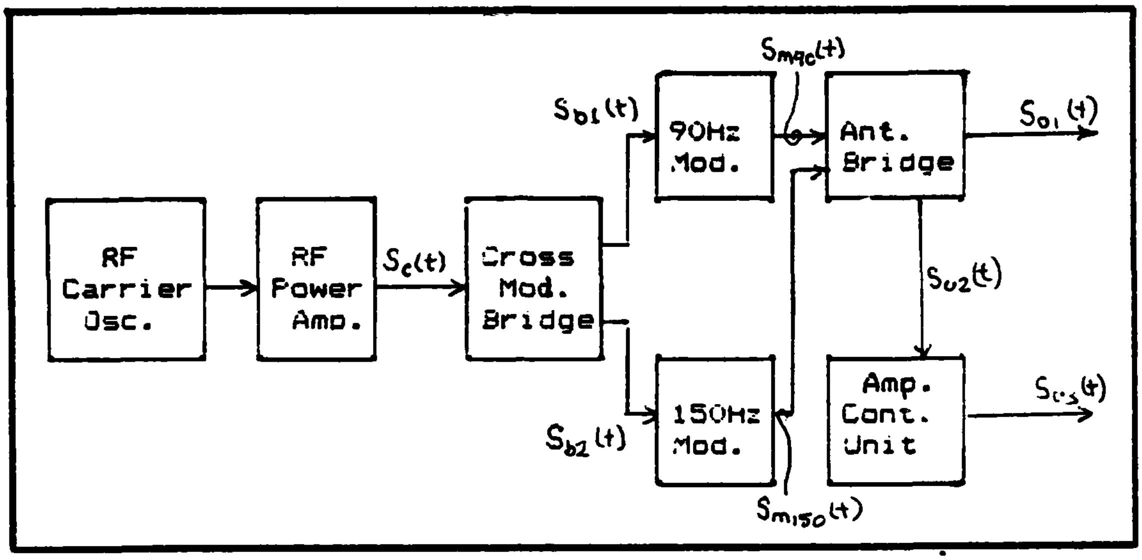


Fig. II-7. Transmitter Block Diagram

The carrier transmitter generates a continuous wave signal at the carrier frequency. This signal has the form

$$S_c(t) = A_c \operatorname{Cos}(W_c t) \tag{1}$$

where A_c is the carrier signal amplitude and W_c is the carrier radian frequency.

The carrier signal is input to the radio modulator where it enters the Cross-Modulation Bridge. In the Cross-Modulation Bridge, the signal is split into two equal parts; each part containing one-half the power of the original signal, i.e.

$$S_{b1}(t) = S_{b2}(t) = 0.707\ A_c \operatorname{Cos}(W_c t) \tag{2}$$

These carriers are then sent to the 90Hz and 150Hz tone modulators where each is amplitude modulated to a specific depth of modulation. For localizer and glide slope signals, the depth of modulation of each carrier signal is set at 20% and 40%, respectively. The output of either tone modulator is

$$S_m(t) = [K_1 \operatorname{Cos}(W_m t) + K_2]\operatorname{Cos}(W_c t) \qquad (3)$$

where K_1 and K_2 are lumped system constants and W_m is the radian frequency of the modulating tone.

The output of each tone modulator is sent to the Antenna Bridge where the two signals are combined to yield

$$\begin{aligned} S_{o1}(t) &= S_{m90}(t) + S_{m150}(t) \\ &= K_3\{\operatorname{Cos}[(W_c + W_{90})t] \\ &+ \operatorname{Cos}[(W_c - W_{90})t] \\ &+ \operatorname{Cos}[(W_c + W_{150})t] \\ &+ \operatorname{Cos}[(W_c - W_{150})t]\} \\ &+ K_4 \operatorname{COS}(W_c t) \qquad (4) \end{aligned}$$

and

$$\begin{aligned} S_{o2}(t) &= S_{m90}(t) - S_{m150}(t) \\ &= K_3\{\operatorname{Cos}[(W_c + W_{90})t] \\ &\quad + \operatorname{Cos}[(W_c - W_{90})t] \\ &\quad - \operatorname{Cos}[(W_c + W_{150})t] \\ &\quad - \operatorname{Cos}[(W_c - W_{150})t]\} \qquad (5) \end{aligned}$$

A close examination of $S_{01}(t)$ and $S_{02}(t)$ reveals that although $S_{01}(t)$ and $S_{02}(t)$ are both double-sideband signals, $S_{01}(t)$ has a carrier component while $S_{02}(t)$ contains only sidebands. Figure II-8 shows the spectrum of each signal.

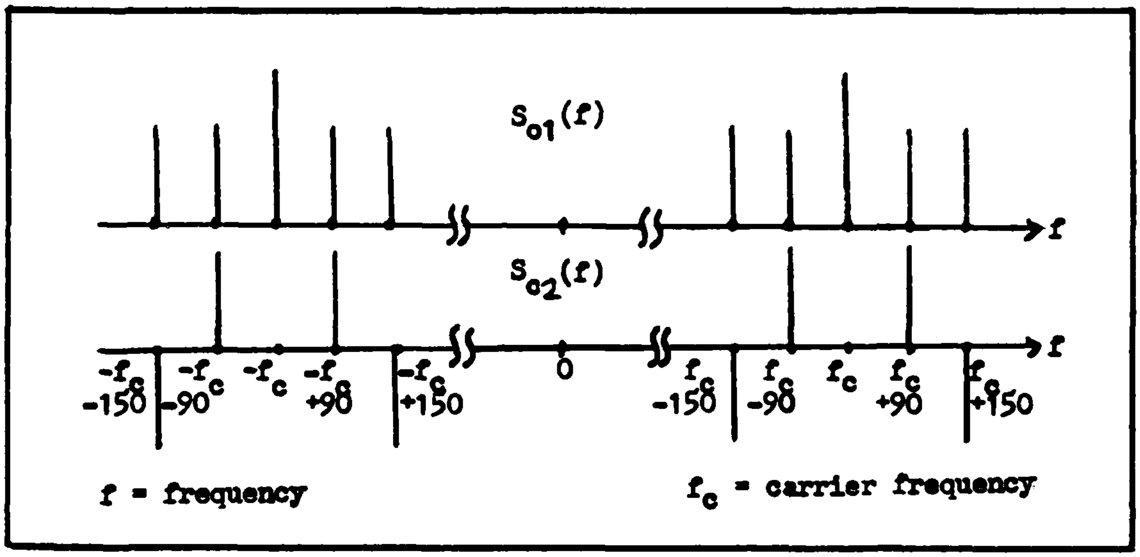


Fig. II-8. Transmitter Signal Spectra.

Signal $S_{02}(t)$, from the Antenna Bridge, is sent to the Amplitude Control Unit (ACU). This unit is used to control the amount of transmitted sideband signal power. The output of the ACU is a scaled version of $S_{02}(t)$, i.e.,

$$S_{03}(t) = K_5 \; S_{02}(t) \tag{6}$$

Signals $S_{01}(t)$ and $S_{03}(t)$, are the final products of transmitter modulation.

Space Modulation. In order to gain insight into how the localizer and glide slope subsystems are capable of providing landing guidance to aircraft, one must understand space modulation. Space modulation results when two or more signals, each radiated from a different antenna, combine in space. The methods used by the localizer and glide slope in accomplishing space modulation are different enough to warrant separate analyses.

Localizer Analysis. The localizer develops the course radiation pattern from summing the signals from its' many antenna elements. The analysis of space modulation from an actual localizer antenna array is not presented due to the complexity of such an analysis. Instead, an analysis is performed on a simple two antenna array. The two antenna analysis is sufficient to convey the concepts necessary to understand space modulation in the localizer.

The two antenna array to be analyzed is depicted in Fig. II-10. The circuits used to distribute signal energy to these antennas are shown in Fig. II-9.

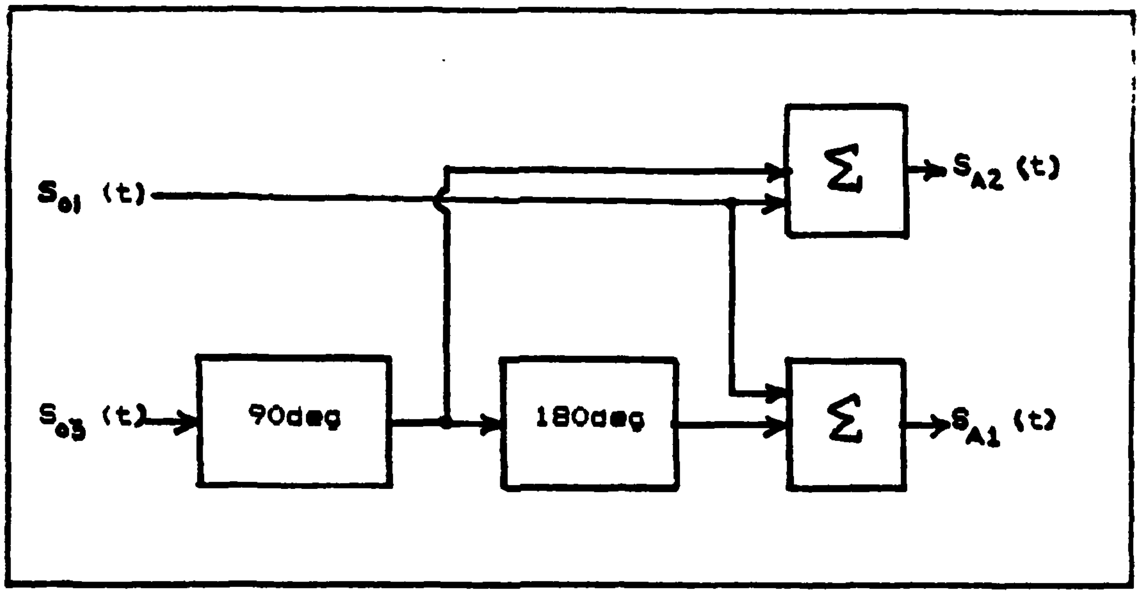


Fig. II-9. Two Antenna Signal Distribution.

Transmitter modulated signals, $S_{01}(t)$ and $S_{03}(t)$, which were discussed previously, are fed to antenna distribution circuits where $S_{03}(t)$ is adjusted in phase before being summed with $S_{01}(t)$. The outputs of the antenna distribution circuits are

$$S_{A1}(t) = S_{01}(t) \underline{/0deg} + S_{03}(t) \underline{/270deg} \qquad (7)$$

and

$$S_{A2}(t) = S_{01}(t) \underline{/0deg} + S_{03}(t) \underline{/90deg} \qquad (8)$$

Since $S_{03}(t) \underline{/270deg} = - S_{03}(t) \underline{/90deg}$, Eq(7) can also be written as

$$S_{A1}(t) = S_{01}(t) \underline{/0deg} - S_{03}(t) \underline{/90deg} \qquad (9)$$

Signals $S_{A1}(t)$ and $S_{A2}(t)$ are fed to antenna elements 1 and 2, respectively. The antenna elements are located at the stop end of the runway and are symmetrically positioned about the extended runway centerline as shown in Fig. II-10.

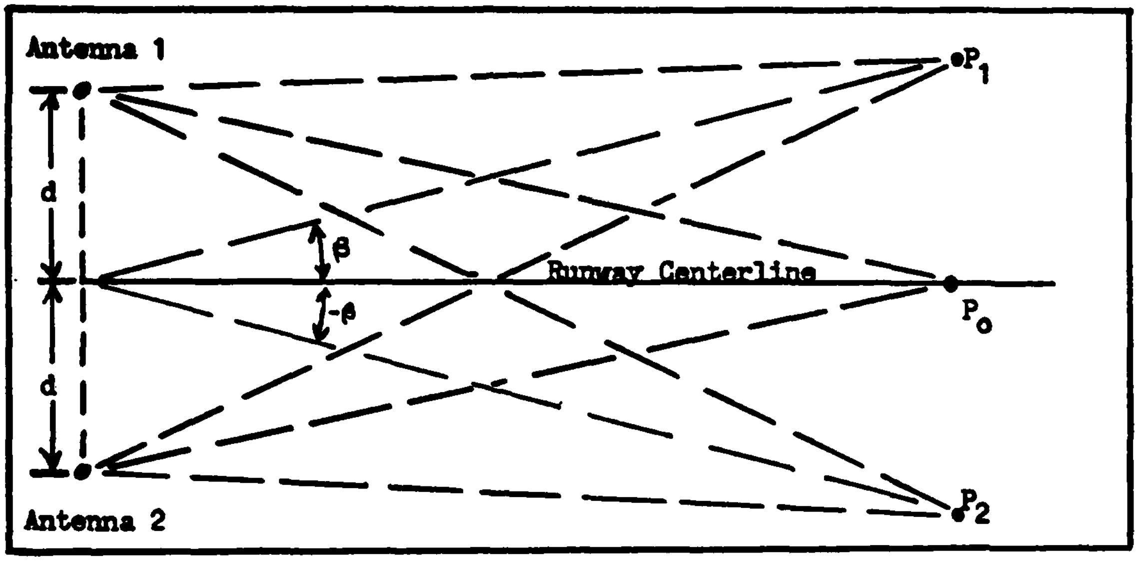


Fig. II-10. Two Antenna Array Analysis.

The signal at a point in space (ref to Fig. II-10) is the algebraic sum of the signals emitted by antenna elements 1 and 2. At point P_0, signals from antenna elements 1 and 2 arrive in the same relative phase relationship in which they were transmitted. This is because both signals travel exactly the same distance. The signal at P_0 can be described by:

$$S_{p0}(t) = K_1\, S_{A1}(t) + K_2\, S_{A2}(t) \tag{10}$$

where K_1 and K_2 are attenuation factors resulting from free-space propagation.

Since the distance from either antenna element to point P_0 is the same, K_1 and K_2 will also be the same. Substituting Eqs(8) and (9) into Eq(10) yields

$$S_{p0}(t) = 2K\ S_{01}(t) \tag{11}$$

Recalling the spectrum of $S_{01}(t)$ (ref to Fig. II-8), it is seen that this signal contains equal amounts of 90Hz and 150Hz modulation; therefore the DDM of this signal is zero. This situation will be true at all points on the extended runway centerline.

At point P_1, the signal from antenna element 1 travels a shorter distance than does the signal from antenna element 2. Assuming the distance to P_1 is much larger than the distance separating the antenna elements, it can be shown that the phase lead of the signal from antenna element 1 (with respect ot the center of the array) is approximately equal to the phase lag of the signal from antenna element 2 (with respect to the center of the array). Also under this assumption, K_1 is approximately equal to K_2. Thus, the signal at point P_1 becomes

$$S_{p1}(t,\beta) = K_1\ S_{A1}(t)\underline{/-\phi} = K_2\ S_{A2}(t)\underline{/+\phi} \tag{12}$$

where $\phi = 360d \text{ Sin } (\beta)/\lambda$ degrees, and λ = wavelength.

Substituting Eq(8) and Eq(9) into the above equation produces

$$\begin{aligned} S_{p1}(t,\beta) + K\ S_{01}(t)\ &\underline{/(0-\phi)\text{deg}} \\ + S_{01}(t)\ &\underline{/(0+\phi)\text{deg}} \\ + S_{03}(t)\ &\underline{/(90+\phi)\text{deg}} \\ + S_{03}(t)\ &\underline{/(270-\phi)\text{deg}} \end{aligned} \tag{13}$$

which can be reduced to

$$S_{p1}(t,\beta) = 2K[\mathrm{Cos}(\phi)S_{01}(t) - \mathrm{Sin}\,(\phi)\,S_{03}(t)] \qquad (14)$$

A similar analysis of signals at point P_2 yields

$$S_{p2}(t,-\beta) = 2K[\mathrm{Cos}(\phi)\,S_{01}(t) + \mathrm{Sin}\,(\phi)\,S_{03}(t)] \qquad (15)$$

Equations (14) and (15) reveal that at P_1, the 150Hz modulation component is greater than the 90Hz component while at P_2 the opposite is true. Note that when $\phi = 0$ degrees, Eqs (14) and (15) reduce to Eq (11); as they should. In general, the localizer course is tailored in such a manner that over the course sector, the DDM increases linearly with β. All ILS's are designed so that 150Hz modulation predominates to the right of the course centerline (as seen by an approaching aircraft) while 90Hz prevails to the left.

Glide Slope Analysis. Two antennas are used to produce the space modulated glide slope signal pattern. These antennas are mounted on a tower at heights selected to provide the required glide-path angle. Because of the signal distriubution to the antennas, the top-most antenna is called the sidebands antenna and the lower antenna is called the carrier antenna. The diagram in Fig. II-11 is used in the analysis of glide slope signals.

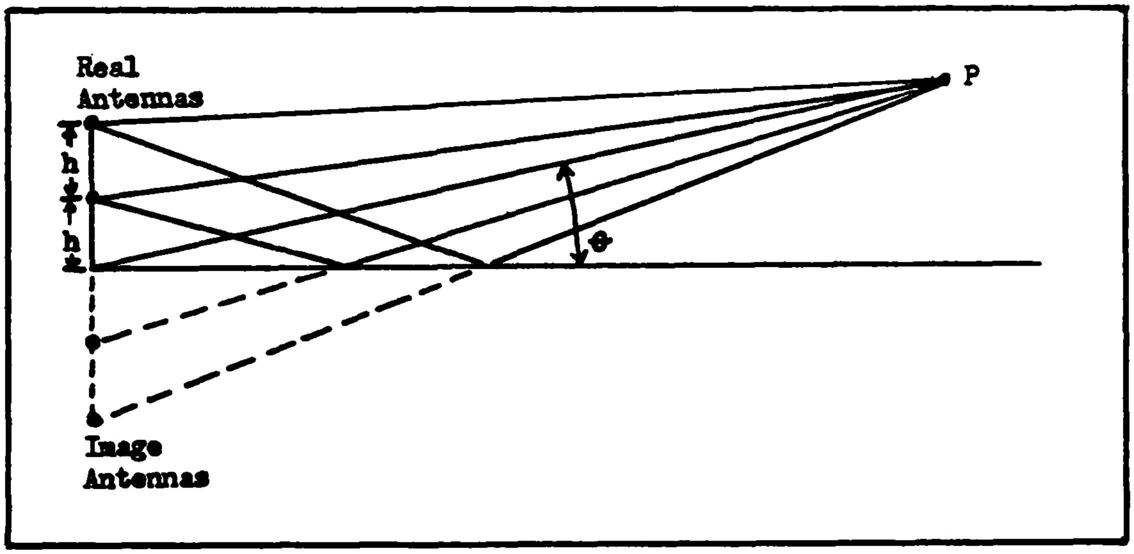


Fig. II-11. Glide Slope Signal Analysis.

The signal at point P is the sum of the signals received from each antenna via the direct path and the reflected path. The analysis is simplified somewhat if the signals from the reflected path are thought of as coming from a pair of image antennas in which the phase of the signals driving these image antennas is shifted 180 degrees from the phase of the signals driving the real antennas. This phase shift is necessary to satisfy the boundary condition of a perfectly reflecting surface. Using this image antenna idea, the analysis becomes identifical to that used with the two-antenna localizer analysis.

The sidebands real and image antennas are fed sidebands-only signals $S_{03}(t)\ \underline{/180deg}$ and $S_{03}(t)\ \underline{/0deg}$, respectively. The carrier real and image antennas are fed carrier-plus-sidebands signals $S_{01}(t)\ \underline{/0deg}$ and

$S_{01}(t)$ $\underline{/180 \text{ deg}}$, respectively. Assuming the distance to point P is very large compared to antenna spacing, the signal at point P can be described by

$$S_p(t,\theta) = K[S_{01}(t) \underline{/-\phi} - S_{01}(t) \underline{/+\phi}$$

$$+ S_{03}(t) \underline{/+2\phi} - S_{03}(t) \underline{/-2\phi}\,] \qquad (16)$$

where θ = angle shown in Fig. II-11, and ϕ = phase shift = $360h \operatorname{Sin}(\theta)/\lambda$ degrees.

and simplification yields

$$S_p(t,\theta) = 2K[\operatorname{Sin}(\phi)S_{01}(t) \underline{/-90\text{deg}}$$

$$- \operatorname{Sin}(2\phi)S_{03}(t) \underline{/-90\text{deg}}] \qquad (17)$$

A polar plot of each term in the right-hand side of Eq(17) is shown in Fig. II-12 for an antenna spacing-to-wavelength ratio $(h/\lambda) = 5.73$. This ratio produces a nominal glide-path angle of 2.5 degrees.

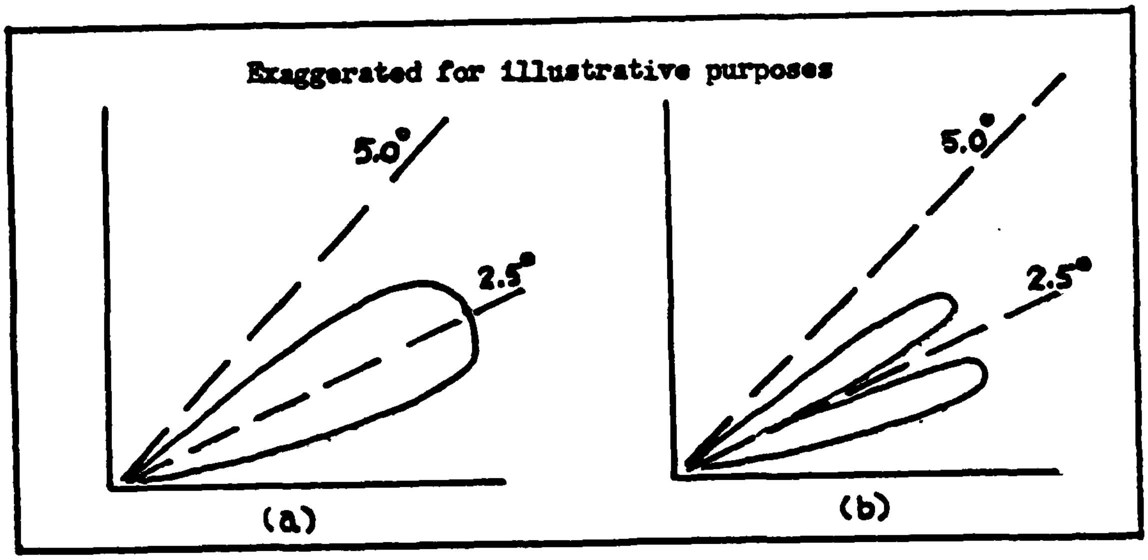


Fig. II-12. Glide Slope Signal Patterns.

The first term, plotted in (a) for 0 deg < θ < 5deg, contains both carrier and sidebands energy. This energy is distributed symmetrically about θ = 2.5 degrees.

The second term, plotted in (b) for 0deg < θ < 5deg, contains sidebands-only energy. The energy above θ = 2.5 degrees is 180 degrees out of phase with the energy below θ = 2.5 degrees.

When the two patterns combine, the sideband energies produce a composite pattern in which the depth of modulation of the 90Hz component of the signal predominates in the region above the glide-path while the 150Hz prevails below the glide-path.

Difference in Depth of Modulation (DDM). The primary mechanism which makes it possible for a pilot to obtain guidance to the runway is the aircraft receiver's ability to detect the difference in the depth of modulation (DDM) between the 90Hz modulation and the 150Hz modulation.

An analysis of the ILS receiver is helpful in gaining an understanding of DDM. Since the localizer and glide slope receivers operate basically in the same way, only one of these receiver channels is considered. This channel is depicted in Fig. II-13.

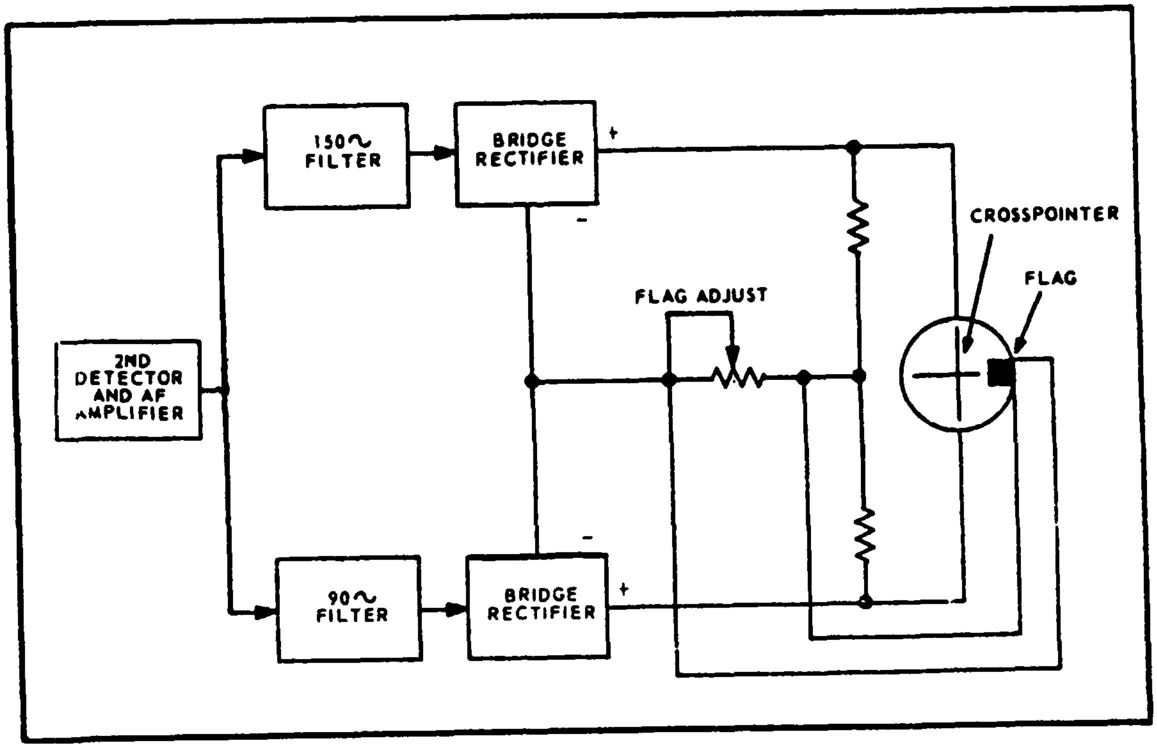


Fig. II-13. ILS Receiver Circuits.

Within the receiver, the ILS signals are selected and amplified by the receiver front-end circuits. The output of the front-end circuits is sent to a detector. The detected signals are amplified, filtered by 90Hz and 150 Hz narrowband filters, and converted to DC voltages by the bridge rectifier circuits. The magnitudes of the DC voltages produced from the 90Hz and 150Hz detected audio signals are directly proportional to the depth of modulation of the 90Hz and 150Hz components. The positive DC voltage output of each rectifier is fed to a crosspointer indicator and a resistive voltage divider network which in turn feeds a flag indicator. The crosspointer indicator displays the difference in rectifier output voltages, or equivalently the difference in depth of modulation (DDM) between the 90Hz and 150Hz signal components. The flag indicator tells the pilot whether or not the RF signal is of sufficient strength to be relied upon.

An aircraft that is on-course and on-path will present to the receiver an input signal containing equal 90Hz and 150Hz depths of modulation. An input of this type produces equal voltages out of the bridge rectifiers. These equal voltages cause no deflection of the crosspointer meter movement; they do, however, produce a current through the flag adjust resistor that is proportional to the sum of the two voltages. A meter movement, connected across the flag adjust resistor, responds to changes in the current flow. The movement activates a flag indicator, located within the ILS indicator which remains in view until the current reaches a predetermined level. When the pilot can see the flag, he/she knows that the RF field strength is not sufficient to provide valid guidance readings. A schematic diagram of an aircraft ILS indicator is shown in Fig. II-14.

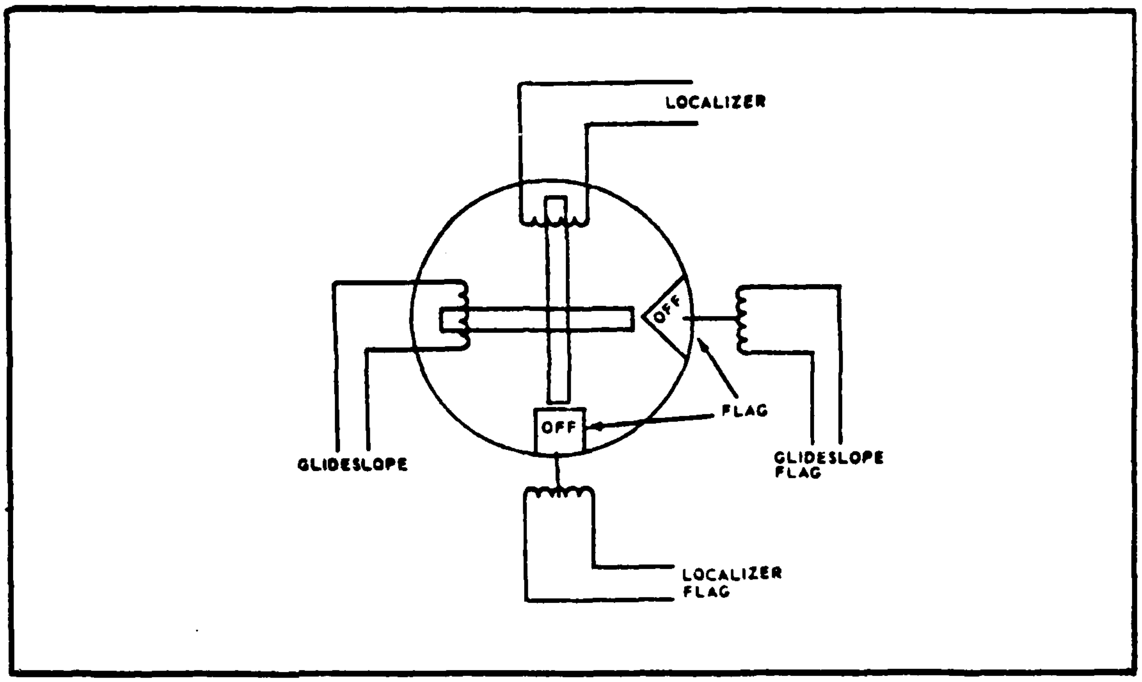


Fig. II-14. ILS Indicator Schematic Diagram.

An aircraft that is not on-course and/or on-path will be presented with RF signals in which the difference in depth of modulation is not zero. In such a case, the positive DC voltage from the 90Hz rectifier is different than the DC voltage from the 150Hz rectifier. The difference will produce a deflection of the DDM meter.

ILS Relationships. The ILS is a worldwide system, and as such, it must conform to certain standards. In the following paragraphs, design standard relationships are presented.

General Relationships. The composite ILS localizer and glide slope signals are similar in form. Each signal results from the summing of carrier-plus-sidebands (CSB) energy and sidebands-only (SBO) energy in space. The general form of a localizer or glide slope signal in space is

$$S(t) = (E_{cs90} + E_{ss90})\{\operatorname{Cos}[(W_c + W_{90})t] + \operatorname{Cos}[(W_c - W_{90})t]\} + (E_{cs150} - E_{ss150})\{\operatorname{Cos}[(W_c + W_{150})t] + \operatorname{Cos}[(W_c - W_{150})t]\} + E_c[\operatorname{Cos} W_c t] \tag{18}$$

where: E_{cs90} = amplitude of the CSB, 90Hz AM component
E_{cs150} = amplitude of the CSB, 150Hz AM component
E_{ss90} = amplitude of the SBO, 90Hz AM component
E_{ss150} = amplitude of the SBO, 150Hz AM component
E_c = amplitude of the carrier component

At a point in space to the left of the runway centerline (as observed from an approaching aircraft) or above the glide-path, the amplitudes of the 90Hz and 150Hz AM components of the composite signal are

$$E_{90} = E_{cs90} + E_{ss90} \tag{19}$$

$$E_{150} = E_{cs150} - E_{ss150} \tag{20}$$

while to the right of the runway centerline, or below the glide-path, these amplitudes are

$$E_{90} = E_{cs90} - E_{ss90} \tag{21}$$

$$E_{150} = E_{cs150} + E_{ss150} \tag{22}$$

From the above relationships, the 90Hz and 150Hz AM modulation factors on the left side of the runway centerline are

$$M_{90} = E_{90}/E_c = E_{cs90}/E_c + E_{ss90}/E_c \tag{23}$$

$$M_{150} = E_{150}/E_c = E_{cs150}/E_c - E_{ss150}/E_c \tag{24}$$

While to the right of the runway centerline they are

$$M_{90} = E_{90}/E_c = E_{cs90}/E_c - E_{ss90}/E_c \tag{25}$$

$$M_{150} = E_{150}/E_c = E_{cs150}/E_c + E_{ss150}/E_c \tag{26}$$

Total modulation factor is defined as

$$M = M_{90} + M_{150} \tag{27}$$

and difference in depth of modulation (DDM) is

$$DDM = M_{90} - M_{150} \tag{28}$$

In both glide slope and localizer, $E_{cs90}/E_c = E_{cs150}/E_c$ and $E_{ss90}/E_c = E_{ss150}/E_c$, thus, Eqs(27) and (28) can be simplified to

$$M = 2E_{cs}/E_c \tag{29}$$

$$DDM = 2E_{ss}/E_c \tag{30}$$

Also from Eqs(27) and (28), another set of useful expressions is derived

$$M_{90} = 0.5(M + DDM) \quad (31)$$

$$M_{150} = 0.5(M - DDM) \quad (32)$$

One additional relationship which relates the ratio of M_{90} and M_{150} to total modulation and DDM is

$$R = M_{90}/M_{150} = (E_{90}/E_c) / (E_{150}/E_c)$$

$$= E_{90}/E_{150} = (M + DDM) / (M - DDM) \quad (33)$$

Localizer Relationships:

Depth of Modulation. The depth of modulation of the individual 90Hz and 150Hz AM signal components is set at 0.2 for all localizer stations; therefore, M = 0.4, and Eqs(31) and (32) become

$$M_{90} = 0.2 + 0.5\ DDM \quad (34)$$

$$M_{150} = 0.2 - 0.5\ DDM \quad (35)$$

Course Sensitivity. A DDM value of 0.155 will produce full scale deflection on the pilots localizer course deviation indicator; thus, indicator sensitivity is linearly related to DDM through

$$0.155\ DDM = 150\ ua \quad (36)$$

Course Width. The localizer course sector is tailored to a width of 700 feet at the ILS Reference Datum point (for a definition of the ILS reference Datum point, see Appendix A). This fact allows expressing the course sensitivity in terms of distance from the runway centerline at the ILS Reference Datum; i.e.,

$$0.155 \text{ DDM} = 350 \text{ feet} \tag{37}$$

Glide Slope Relationships.

Depth of Modulation. The individual 90Hz and 150Hz AM RF signal components are modulated to a depth of 40% which produces a total modulation factor of M = 0.8. The total 90Hz and 150Hz modulation factors may be computed from Eq(31) and (32) as

$$M_{90} = 0.4 + 0.5 \text{ DDM} \tag{38}$$

$$M_{150} = 0.4 - 0.5 \text{ DDM} \tag{39}$$

Course Sensitivity. A DDM value of 0.175 will produce full scale deflection of the pilots glide-path deviation indicator. The indicator reading is linearly related to DDM through

$$0.175 \text{ DDM} = 150 \text{ ua} \tag{40}$$

Path Width. Glide-path width is set at 0.7 degrees. Path width is the width between the 75ua (0.0875 DDM) points. This relationships gives a measure of vertical displacement sensitivity such that

$$0.35 \text{ degrees} = 0.0875 \text{ DDM} \tag{41}$$

III. ILS PERFORMANCE SPECIFIATIONS

This chapter presents a summary of modulation factor and DDM performance specifications pertinent to ILS localizer and glide slope ground components, airborne ILS receivers, and the test instrumentation used in ILS maintenance.

Performance specifications from several sources are presented. Requirements dealing with overall system performance were obtained from International Civil Aviation Organization (ICAO) (Ref 1:37-60) and United States Air Force specifications (Ref 15). Performance criteria concerning the airborne ILS receiver were obtained from Aeronautical Radio, Inc. (ARINC) (Ref 1) and Radio Technical Commission for Aeronautics (RTCA) (Refs 12 & 13) documents. Performance requirements for ILS test instrumentation were obtained from Air Force Technical Orders (TO's) and manufacturers specifications.

Localizer On-Course Accuracy Requirements.

ICAO Specifications:

Modulation Accuracy (Ref 1:40). The nominal depth of modulation of the RF carrier due to each of the 90Hz and 150Hz tones shall be 20% along the course line. For Cat I and II systems, the modulation due to each tone shall be maintained within 18 to 22%. For Cat III systems, the modulation due to each tone shall be maintained to within 19 to 21%.

Course Alignment Accuracy (Ref 1:41). The ICAO specifies localizer course alignment accuracy in terms of maximum displacement distance (in feet) from the runway centerline at the ILS reference datum. The specifications for categories I, II, and III are 0 ± 35 ft, 0 ± 25 ft, and 0 ± 10 ft, respectively. Since ILS's are normally tailored to a linear course sector width of 700 ft at the runway threshold see Eq(37) (Ref 15:217-21), these displacements are equivalent to 0.0155 DDM, 0.0111 DDM, and 0.0044 DDM, respectively.

Course Structure (Ref 1:40). Bends in the course strucuture, measured from the mean course line, should not exceed the values given in Table III-1.

Table III-1. ICAO Course Line Bend Limits

Category I.

Zone	Limit (DDM)
Outer limit of coverage to ILS point A.	± 0.031.
ILS point A to ILS point B.	± 0.031 at ILS point A decreasing at a linear rate to ± 0.015 at point B.
ILS point B to ILS point C.	± 0.015.

Category II and III.

Zone	Limit (DDM)
Outer limit of coverage to ILS point A.	± 0.031.
ILS point A to ILS point B.	± 0.031 at point A decreasing at a linear rate to ± 0.005 at ILS point B.
ILS point B to the ILS Reference Datum.	± 0.005.

Category III only.

Zone	Limit (DDM)
ILS Reference Datum to ILS point D.	± 0.005.

AFM 55-8 Specifications:

Course Structure (Ref 15:217-35). Deviations within the course structure must be within the following specifications:

Zone 1 - From the average course alignment:

CAT I, II, III: $\pm$ 30ua to point A.

Zone 2 - From the actual course alignment:

CAT I: $\pm$ 30 ua at point A; linear decrease

to $\pm$ 15 ua at point B.

CAT II, III: $\pm$ 30 ua at point A; linear decreases

to $\pm$ 5 ua at point B.

Zone 3 - From the actual course alignment:

CAT I: $\pm$ 15 ua at point B; $\pm$ 15 ua at point C

Zone 3 & 4 - From the actual course alignment:

CAT II, III: $\pm$ 5ua at point B; $\pm$ 5ua at point D

Zone 5 - From the actual course alignment:

CAT III: $\pm$ 5ua at point D; linear increase

to $\pm$ 10ua at point E

Modulation Level (Ref 15:217-35). Modulation factor for the 90Hz and 150Hz AM components is to be within the limits of 20% ± 2% for Cat I and II installations, and 20% ± 1% for Cat III facilities.

Course Alignment (Ref 15:217-35): The maximum azimuth deviation from the designed procedural azimuth for each category of facility performance is given in microamperes (ua). For Categories I, II, and III, the maximum deviations are 15ua, 11ua, and 5ua, respectively. Recalling Eq(36), which gives the relationship between DDM and current as 0.0155 DDM = 150ua, these maximum (current) deviations are equivalent to 0.0155 DDM, 0.0114 DDM, and 0.0052 DDM, respectively.

Localizer Off-Course Accuracy Requirements.

ICAO Specifications:

Displacement Sensitivity (Ref 1:41). The nominal lateral displacement sensitivity within the half course sector at the ILS Reference Datum shall be 0.00044 DDM/foot. This sensitivity shall be adjusted and maintained within the limits of plus or minus:

a) 17% of the nominal value for performance categories I and II.

b) 10% of the nominal value for performance category III.

AFM 55-8 Specifications:

Course Sector Width (Ref 15:217-21). Localizers which support Cat II or III operations shall be tailored to a linear course sector width of 700 ft at the runway threshold; however, course width shall not exceed 6 degrees. Cat I facilities should be tailored to Cat II requirements, or as close to Cat II requirements as practicable.

Glide Slope On-Path DDM Accuracy Requirements.

ICAO Specifications:

Modulation Level (Ref 1:44). The nominal depth of modulation of the RF carrier due to each of the 90Hz and 150Hz tones shall be 40% along the ILS glide-path. The depth of modulation shall not deviate outside the limits of 37.5% to 42.5%.

Glide-Path Angle Alignment (Ref 1:43). The nominal glide-path angle θ shall be adjusted and maintained within:

a) $\theta \pm 0.075$ for Cat I and II:

b) $\theta \pm 0.040$ for Cat III.

Glide-Path Structure (Ref 1:44). Glide-path structure should not have amplitudes which exceed the following:

i) Cat I - From the outer limit of coverage to ILS point C, on-path DDM should be 0 ± 0.035;

II) Cat II and III - From the outer limit of coverage to ILS point A, on-path DDM should be 0 ± 0.035. From ILS point A to ILS point B, DDM should decrease linearly from 0.035 DDM to 0.023 DDM. From ILS point B to the ILS reference datum, DDM should not be greater than 0.023.

AFM 55-8 Specifications:

Modulation Level (Ref 15:217-37). Periodic inspection of Glide slope modulation should find that modulation is within 80% $\pm$ 5%.

The maximum difference between modulation factors (modulation balance) shall be less than 5ua, or 0.0058 DDM.

<u>Glide-Path Structure (Ref 15:217-38)</u>. Glide-path structure deviations are limited according to zone and category of facility operations. The most stringent limits are as follows:

Zone	Category I
1	30ua from the graphical average path.
2	30 ua from the actual path angle.
3	30 ua from the graphical average path.

Zone	Category II & III
1	30ua from the graphical average path.
2	From the actual path angle 30 ua at point A, then a linear decrease to 20ua at point B.
3	20ua from the graphical average path.

<u>Glide-Path Angle Alignment (Ref 15:217-37)</u>. The mean glide-path angle is to be adjusted to within ± 0.05 degrees of the commissioned angle. Alignment is to be maintained within ± 37.5ua of the commissioned angle at point B; expanding linearly to ± 48.75ua about the commissioned angle at point C; expanding linearly to ± 75ua about the commissioned angle at the ILS Reference Datum point.

Glide Slope Off-Path DDM Accuracy Requirements.

ICAO Specifications:

Displacement Sensitivity (Ref 1:45). The nominal glide-path angular displacement sensitivity for Cat I ILS performance shall correspond to a DDM of 0.0875 at angular displacements above and below the glide-path between 0.07θ and 0.14θ. For Cat II ILS paths, the angular displacement sensitivity shall correspond to a DDM of 0.0875 at an angular displacement of:

a) 0.12θ below path with a tolerance of plus or minus 0.02θ;

b) 0.12θ above path with a tolerance of plus 0.02θ and minus 0.05θ.

For Cat III, the nominal angular displacement sensitivity shall correspond to 0.0875 at angular displacements above and below the glide-path of 0.12θ with a tolerance of plus or minus 0.02θ.

AFM 55-8 Specifications:

Path Sector Width (Ref 15:217:37): Path width is to be set to 0.70 ± 0.03 degrees. Path width is the width in degrees between the 75ua (0.0875 DDM) points.

Airborne Localizer Receiver Specifications.

Localizer Receiver On-Course DDM Requirements.

ARINC Characteristic No. 578-3 (Ref 1:11): the maximum on-course (centering) error for an ILS receiver designed to ARINC specifications is given as 40 millivolts (mv) for the high level output. The high level output is linearly related to DDM through the following relationship:

$$2.0 \text{ volts} = 0.155 \text{ DDM} \quad (42)$$

Thus, the maximum on-course error is 0.0031 DDM.

RTCA Document DO-131A (Ref 12:3): The maximum centering error for the localizer receiver output has been tabulated for several classes of receiver performance. These error limits are given in microamperes (ua) with respect to indicators whose full scale deflection is 150ua. Only the most stringent requirement is given here for both Cat I and Cat II systems; it is specified as 5% of standard deflection. Cat III requirements are not addressed by the RTCA document. Standard Deflection for the localizer is defined as 60% of full scale (Ref 12:A-4). Using this fact and using Eq (36), this ua limit is equivalent to 0.00465 DDM.

Localizer Receiver Off-Course DDM Requirements.

ARINC Characteristic No. 578-3 (Ref 1:11): From zero to 0.0465 DDM, the statistical 2 sigma deviation error from the high level output should not exceed $\pm\sqrt{(0.0031)^2 + (X/20)^2}$, where X is the ideal deviation in DDM. From $\pm$ 0.0465 DDM to $\pm$ 0.155 DDM the deviation should be within 10% of the ideal proportionality and from $\pm$ 0.155 DDM to $\pm$0.310 DDM, within 20%.

RTCA Document DO-131A (Ref 12:9): Over the course deviation range from zero to $\pm$ 0.155 DDM, the deviation current shall be within 10% of being proportional to the difference in depth of modulation of the 90 and 150Hz signals, or the deviation current shall be within 5% of standard deviation current of being proportional to the difference in depth of modulation, whichever is greater.

Airborne Glide Slope Receiver Specifications.

Glide Slope Receiver On-Path DDM Requirements.

ARINC Characteristic No. 578-3 (Ref 1:12): The maximum on-path (centering) error for an ILS receiver designed to ARINC specifications is given as 80 millivolts for the high level output. The high level output is linearly related to DDM through the following:

$$2.0 \text{ volts} = 0.175 \text{ DDM} \tag{43}$$

Thus, the maximum on-path error is 0.007 DDM.

RTCA Document DO-132A (Ref 13:3): The maximum centering error for the glide slope receiver output has been tabulated for several classes of receiver performance. These error limits are given in microamperes (ua) with respect to indicators whose full scale deflection is 150ua. Only the most stringent requirement is given here for Cat I and Cat II systems. Cat III requirements are not addressed in this document; however, reference 9:83 gives the tolerance as 10ua, which is the same as the Cat II specification. The maximum centering error for a Cat I receiver is specified as 17% of Standard Deflection. The maximum centering error for a Cat II (or Cat III) receiver is given as 13% of Standard Deflection. Standard Deflection is defined as 52% of full scale deflection. These errors, converted to DDM, are 0.0155 and 0.0118 for Cat I and Cat's II and III, respectiv‹ ıy.

Glide Slope Receiver Off-Path DDM Requirements.

ARINC Characteristic No. 578-3 (Ref 1:12): Over the course deviation range from zero to ± 0.0455 DDM, the statistical 2 sigma deviation error from the high level output should not exceed $\pm\sqrt{(0.007)^2 + (X/20)^2}$, where X is the ideal deviation in DDM. From ± 0.0455 DDM to ± 0.175 DDM, the deviation should be within 10% of the ideal proportionality.

RTCA Document DO-132A (Ref 13:9). Over the course deviation range from zero to ± 0.175 DDM, the deviation current shall be within 10% of being proportional to the difference in depth of modulation of the 90 and 150Hz signals, or the deviation current shall be within 5% of standard deviation current of being proportional to the difference in depth of modulation, whichever is greater. Since 5% of standard deviation current corresponds to 0.00455 DDM, the specification can be restated as: Over the course range from zero to 0.175 DDM, the glide slope signal DDM shall be within 10% of the ideal DDM or within ± 0.00455 DDM, whichever is greater.

Test Instrumentation Description & Accuracy Specifications.

There are five different test instruments used to maintain ILS modulation factor and DDM alignment. These are: (1) the AN/GRM-112, Radio Receiving Test Set; (2) the Collins 479A-6, VOR/ILS Signal Generator; (3) the Crescent Model 5301 ILS Modulation Meter; (4) the Crescent Model 5401 Modulation Meter; and, (5) The NBS Modulation Factor Standard. The following paragraphs present the DDM and modulation factor measurement capabilities and limitations of each:

AN/GRM-112, Radio Receiving Test Set (Ref 19): The AN/GRM-112 is a portable ILS receiver test set used by maintenance personnel to evaluate ILS ground system performance. The test set is capable of separately measuring the modulation factors of the 90Hz and 150Hz AM signals as well as being able to measure DDM and RF signal strength. Operation and maintenance instructions are provided in TO 33D7-36-42-1 and calibration instructions are contained in TO 33K3-4-1-12.

The AN/GRM-112 allows DDM (or modulation factor) measurement results to be obtained in two different ways. DDM readings can be taken directly from the test set DDM meter or by measuring the voltage from the DDM Out jack with an external DC voltmeter. The DDM Out jack voltage is directly equivalent to DDM.

The test set DDM meter displays measurement results on three DDM measurement scales: 0 to 0.05 DDM: 0 to 0.25 DDM: and, 0 to 0.5 DDM. Resolvability of meter readings is possible to within one-half of one minor division. One-half of one minor division corresponds to: 0.001 DDM for measurements taken on the 0 to 0.05 DDM scale; 0.005 DDM for measurements taken on the 0 to 0.25 DDM scale; and, 0.01 DDM for measurements taken on the 0 to 0.5 DDM scale.

The DDM Out jack provides an additional way of obtaining measurement readings of DDM (or modulation factor). Within the test set, DDM is converted directly into a DC voltage. At the DDM Output jack, this voltage is available for measurement by an external meter.

The localizer and glide slope signal 0 DDM measurement accuracy is specified as $\pm$ 0.002 VDC. Since DDM is converted to voltage within the test set such that DDM and voltage are equivalent, this accuracy can also be specified as $\pm$ 0.002 DDM (Ref 19:4-21).

The AN/GRM-112 calibration procedure (Ref 20:1171) evaluates the test instrument's DDM measurement accuracy for localizer and glide slope signals at several values of DDM. A summary of these values and the required measurement accuracy are given in Table III-2.

Table III-2. AN/GRM-112 Measurement Accuracy.

Measured Signal		Measurement Accuracy	
Type	DDM Value	DDM Meter	DC Voltmeter
Localizer	0.000	0.000 ± 0.002	0.000 ± 0.002
	0.155	* 0.155 ± 0.005	0.155 ± 0.002
	0.200	0.200 ± 0.005	0.200 ± 0.005
Glide Slope	0.000	0.000 ± 0.002	0.000 ± 0.002
	0.175	* 0.175 ± 0.005	0.175 ± 0.003
	0.400	0.400 ± 0.010	0.400 ± 0.010

* value does not match the calibration T.O. value. The T.O. value apparently did not take meter resolution uncertainty into account. This value accounts for the resolution uncertainty.

Collins Model 479S-6, ILS/VOR Signal Generator (Ref 18): The 479S-6 produces all required audio modulation and RF carrier signals to test and troubleshoot ILS localizer and glide slope receivers.

Performance specifications are given in T.O. 33A1-8-843-1 and T.O. 33K3-4-1-12. Table III-3 lists the performance specifications that pertain to DDM and modulation.

Table III-3. 479S-6 Performance Specifications

Characteristic	Specification
Amplitude Modulation	
Accuracy (per tone)	
Localizer & Glide Slope	2.5% of the modulation factor
DDM	
Audio Error	
On-Course	0.0001 DDM
Off-Course	0.0002 DDM
Modulation Error	
Localizer	
On-Course	0.00046 DDM
Off-Course	0.00046 DDM + 2.5% DDM
Glide Slope	
On-course	0.00092 DDM
Off-Course	0.00092 DDM + 2.5% DDM
Total System Error (audio + modulation)	
Localizer	
On-Course	0.00056 DDM
Off-Course	0.00056 DDM + 2.5% DDM
Glide Slope	
On-Course	0.00102 DDM
Off-Course	0.00102 DDM + 2.5% DDM

<u>Crescent Model 5301 ILS Modulation Meter (Ref 10) (Ref 17)</u>: The 5301 ILS Modulation Meter is a solid state, portable, AC powered modulation meter designed to measure the modulation levels of the ILS localizer and glide slope signals, and signal generators used in the alignment of airborne ILS receivers. The equipment readout is a three digit digital display with a fixed decimal indicator between the second and third digits; giving the indicator a resolution of 0.1%.

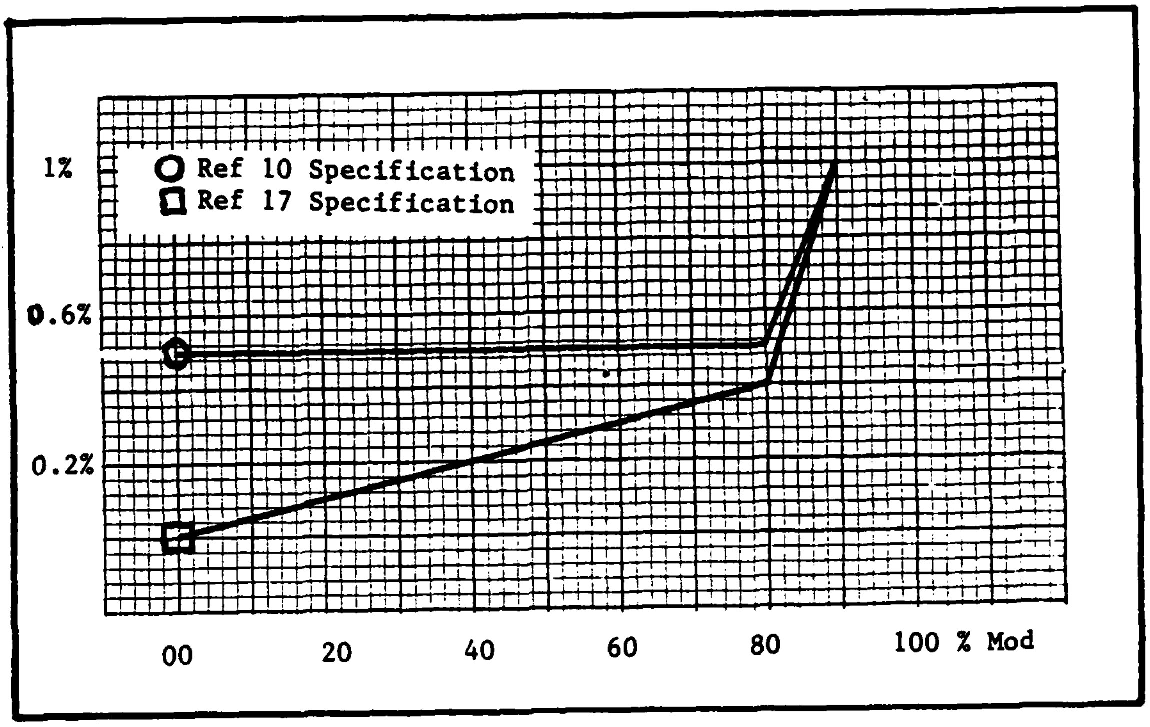


Fig. III-1. 5301 Accuracy Specifications.

The meter is capable of separately measuring the depth of modulation of the 90Hz and 150Hz AM components of localizer and glide slope signals, and according to reference 17, is capable of providing these measurements within ± 0.5 percent of the true value of the percentage of modulation for modulation measurements up to 80%. Additionally, the measurement accuracy at 90% modulation must be within ± 1% of the true value of the percentage of modulation. The accuracy between 80% and 90% shall increase from ±0.5% to ±1.0% in a linear fashion. Reference 10 on the other hand, states that for readings between 0% and 80%, the accuracy tolerance is ±0.5%, and for readings between 80% and 90%, the accuracy tolerance increases linearly from 0.5% to 1%. The distinction between these two sets of specifications is shown in figure III-1. The specifications given by reference 10 are used in the remainder of this report.

Model 5401, ILS Modulation Meter (Ref 3): The Model 5401 ILS Modulation Meter is a portable AC powered unit utilized in measuring the modulation levels of ILS localizer and glide slope facilities, and signal generators used in the alignment of airborne ILS receivers. Readings of modulation level are displayed on a four digit display with a fixed decimal point between the second and third digits. The indicator resolution is 0.01%.

The equipment is capable of separately measuring the amplitude modulation of the 90Hz and 150Hz components of localizer and glide slope signals. Accuracy of measurements are given in Table III-4. It is worth noting that this instrument provides readings that are accurate to three digits, yet it has a four digit display.

Accuracy verification is by means of Interim Modulation Standards traceable to the Electromagnetics Division of the National Bureau of Standards.

Table III-4. 5401 Measurement Accuracy.

Measurement Range (%)	Accuracy
1 to 10	Indication ± 0.20
10 to 50	Indication ± 0.10
50 to 60	Indication ± 0.15
60 to 70	Indication ± 0.20
70 to 80	Indication ± 0.25
80 to 90	Indication ± 0.30
90 to 99	Indication ± 0.40

NBS Modulation Factor Standard (Ref 2): The NBS Modulation Factor Standard was designed by the National Bureau of Standards (NBS) at the request of the Federal Aviation Administration (FAA). It is a laboratory instrument which serves two functions: (1) It produces a highly accurate amplitude-modulated RF signal of known modulation factor, and (2) it is capable of measuring modulation factor to a high degree of precision. The accuracy of the signal generator portion of the test instrument is unspecified because it derives its' accuracy from the modulation factor meter. The accuracy of the modulation factor measurement portion of this instrument is given in Table III-5.

Table III-5. Total Measurement Error (Ref 2:36)

Modulation Factor	Measurement Error, (±) 108-118MHz	328-336MHz
0.1000	0.00027	0.00028
*0.2000	0.00033	0.00036
0.3000	0.00041	0.00045
**0.4000	0.00050	0.00054
0.5000	0.00059	0.00064
0.6000	0.00069	0.00074
0.7000	0.00079	0.00085
0.8000	0.00089	0.00097
0.9000	0.00099	0.00109

* - indicates nominal modulation factor used by the localizer.

** - indicates nominal modulation factor used by the glide slope.

IV. EVALUATION.

The ILS is a highly accurate guidance system and as such, demands a high degree of measurement accuracy from the test instrumentation used in maintaining it. In this chapter, ILS test instrumentation DDM & modulation factor accuracies are evaluated.

The evaluation is performed in two parts, First, maintenance test instrumentation accuracy specifications are compared to system accuracy requirements in order to determine if these test instruments are adequate for maintaining the ILS. Finally, the ILS DDM & modulation factor calibration hierarchies are examined to determine if test instrument measurement accuracies are capable of being achieved.

Before beginning with the evaluation it is necessary to first discuss what criteria is used in deciding whether an instrument is adequate or not. All Air Force measurement test instruments are required to be calibration traceable to national standards. Traceability is necessary to assure that these instruments accurately reflect (within a reasonable uncertainty) the true value of the quantity being measured. In order to maintain controlled uncertainty throughout the traceable chain, each level in the calibration hierarchy must have less uncertainty than the level directly below. There was at one time a generally accepted rule that the calibration instrument had to be at least 10 times better than the calibrated instrument (Ref 14:88). The current rule calls for a 4:1 margin between levels (Ref 16:2-4). In the evaluation, the 4:1 rule is used to determine the adequacy of test instrumentation.

Assessment of Test Instrument Adequacy Based on a Comparison of System Accuracy Requirements with Test Instrument Accuracy Specifications:

Modulation Factor Accuracy Assessment:

The required modulation factor accuracies of the localizer and glide slope 90Hz and 150Hz AM signal components were given in chapter III as:

	CAT I & II	CAT III
Localizer	20 ± 2%	20% ± 1%
Glide Slope	40 ± 2.5%	40 ± 2.5%

Using the 4:1 rule, the maximum tolerable test instrument measurement uncertainties for measurements made on localizers operating within Cat's I & II, and Cat III specifications are ±0.005, and ±0.0025 modulation factor units, respectively. For Glide Slope subsystems, the maximum tolerable test instrument measurement uncertainty is ± 0.00625 modulation factor units. The Crescent Model 5301 Modulation Meter and the AN/GRM-112 Radio Receiver Test Set are used by maintenance personnel to check and adjust ILS modulation factors.

5301 Modulation Factor Measurement Accuracy: Measurement accuracy for the 5301 was given as ± 0.5% for modulation factor measurements up to 80%. This accuracy specification is 4 times better than the accuracy requirement of Cat I & Cat II localizers, 2 times better than the accuracy required of Cat III localizers, and 5 times better than the glide slope accuracy requirement. If calibrated to the specified level of accuracy, the 5301 is considered adequate for maintaining modulation factors in glide slope subsystems and Cat's I and II localizer subsystems. The 5301 is, however, inadequate for use in maintaining modulation factors in Cat III localizers.

AN/GRM-112 Modulation Factor Measurement Accuracy: The uncertainty in measurement accuracy of the AN/GRM-112 when measuring localizer and glide slope modulation factors is given in Table III-2 as ±0.005 DDM and ±0.01 DDM, respectively. The AN/GRM-112's accuracy is 4 times better than the Cat I & II localizer accuracy requirement, 2 times better than the accuracy requirement for Cat III localizers, and 2.5 times better than the accuracy requirement for glide slope subsystems. If calibrated to specifications, the AN/GRM-112 has sufficient accuracy to maintain modulation factors for Cat I & II localizers; however, it is inadequate with regard to maintaining Cat III localizer modulation factors and glide slope modulation factors.

DDM Accuracy Assessment.

Localizer Station On-Course (0 DDM) Accuracy. ICAO specifications state that the localizer course must be aligned within ±35 feet of the runway centerline at the ILS Reference Datum point to be within Cat I limits, ± 25 feet to be within Cat II limits, and ± 10 feet to be within Cat III limits. Lateral displacement sensitivity at the ILS Reference Datum was given in chapter III as 0.00044 DDM = 1 foot. In terms of DDM, the ± 35 ft, ± 25 ft, and ± 10 ft displacements are equivalent to ± 0.0155 DDM, ± 0.0111 DDM, and ±0.0044 DDM, respectively.

Measurement of DDM within the course radiation pattern is accomplished using the AN/GRM-112. The accuracy of the AN/GRM-112 for on-course (0 DDM) measurements was given in Table III-2 as ± 0.002 DDM. Compared to the Cat I, II, and III limits, the AN/GRM-112 accuracy is 7.75, 5.55, and 2.2 times better, respectively. From the foregoing results, it is considered that the AN/GRM-112 accuracy is adequate for maintaining Cat I and II on-course DDM alignment. Because the AN/GRM-112 measurement uncertainty does not meet the 4:1 rule, it is considered inadequate for use with Cat III systems.

Localizer Station Off-Course DDM Accuracy. The ICAO specifies that lateral displacement sensitivity is to be 0.00044 DDM/foot at the ILS Reference Datum point and that it shall be maintained with ± 17% of the nominal value for Cat I & II operations, and within ± 10% for Cat III.

Off-course measurements are made using the AN/GRM-112. Its accuracy specifications are given in Table III-2. A plot of the ICAO specification tolerance versus DDM accuracy of the AN/GRM-112 is shown in figure IV-1. The dashed lines represent the extrapolation of accuracy between specification points. From the figure, it is not readily apparent as to how the AN/GRM-112 accuracy compares with the localizer requirements. Figures IV-2,3, and 4 are included to clarify these relationships. From the figures, it is clear that the AN/GRM-112 accuracy is adequate for all DDM measurements on Cat I and II localizers as long as these measurements are taken from the DDM Out jack. For Cat III localizers, DDM Out jack measurement accuracy for DDM measurement values below 0.08 DDM (where the ratio of the AN/GRM-112 accuracy to localizer accuracy falls below 4:1) is inadequate.

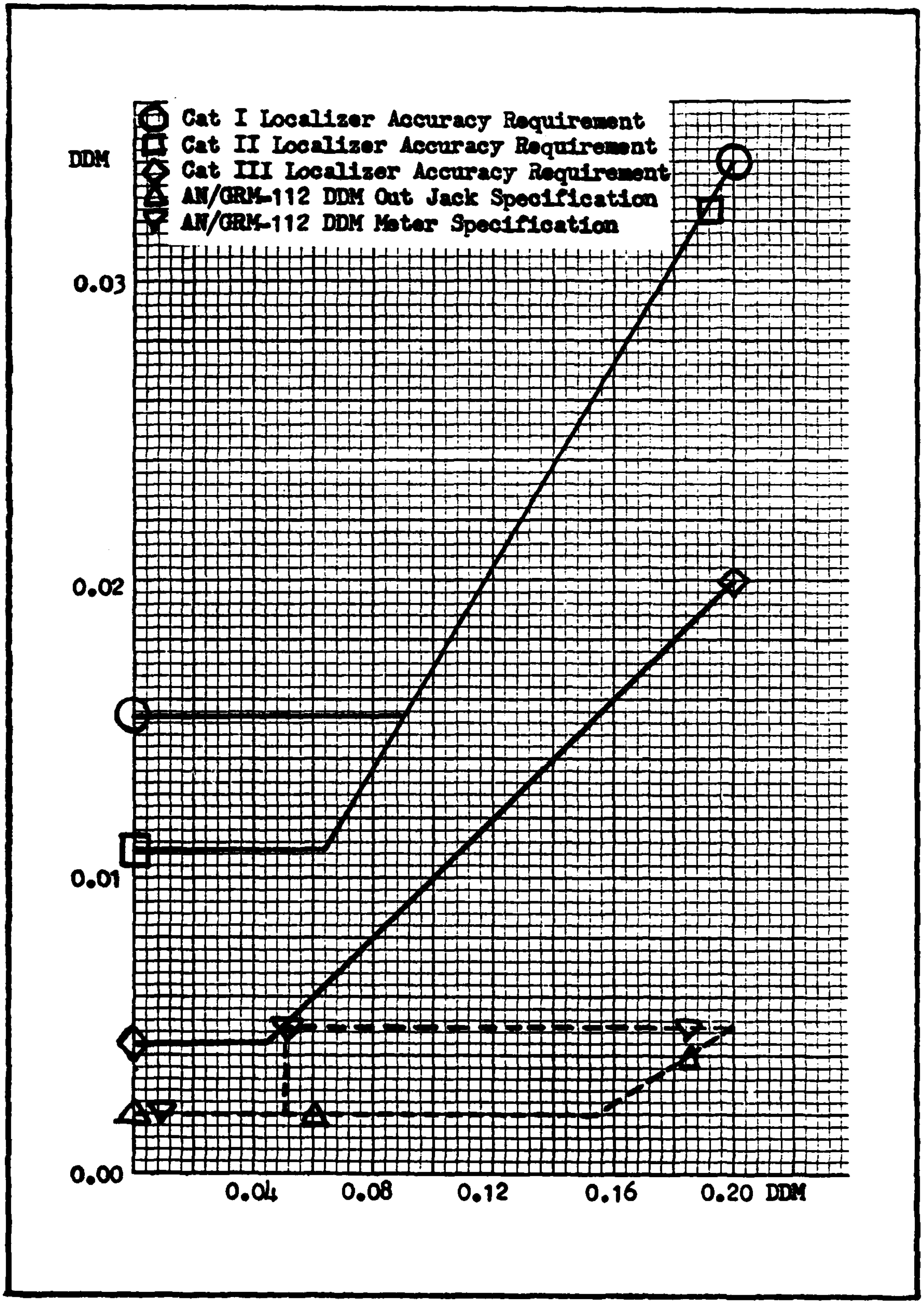


Fig. IV-1. Localizer & AN/GRM-112 Accuracies.

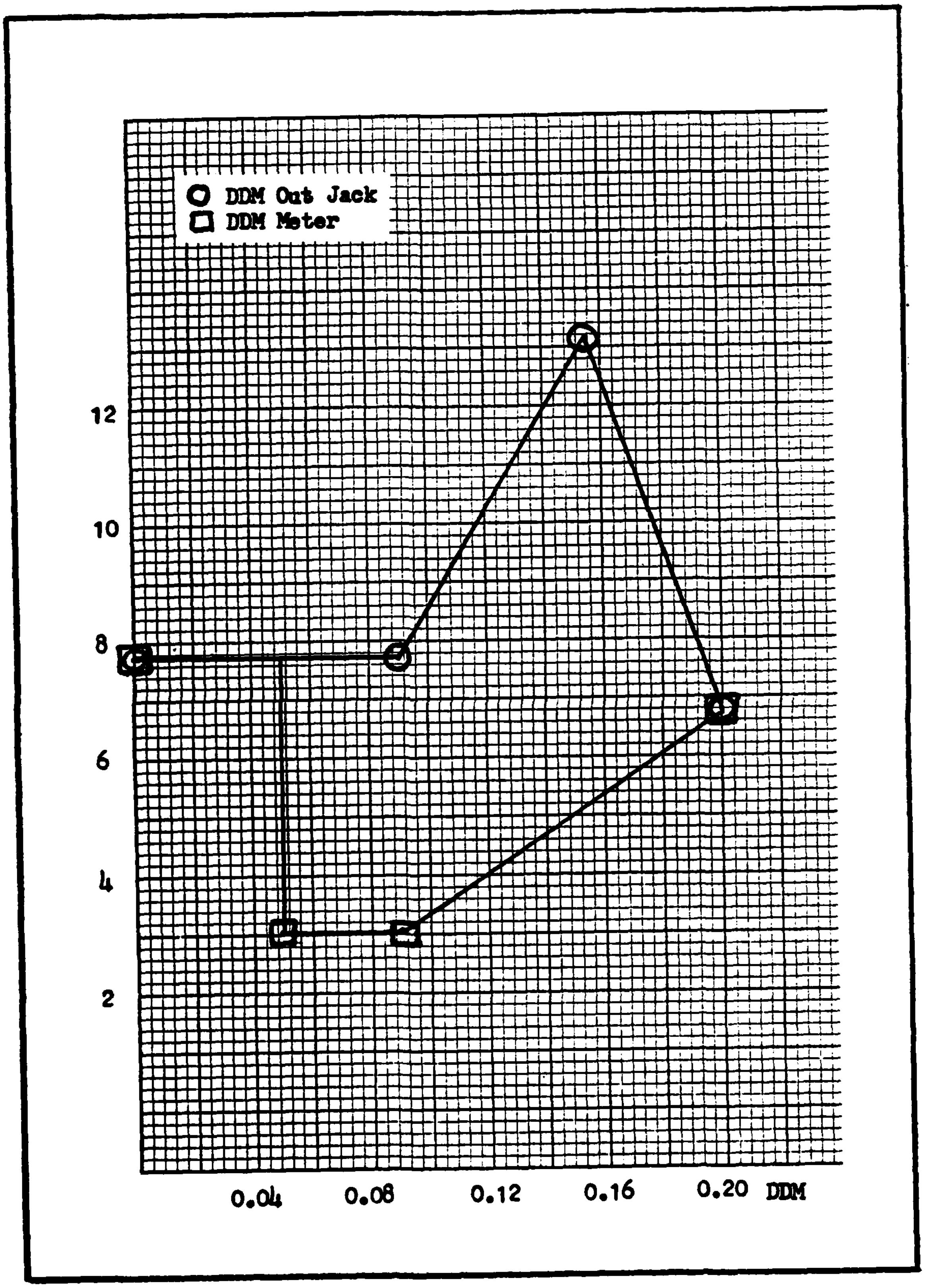


Fig. IV-2. Cat I Localizer/AN/GRM-112 Accuracies.

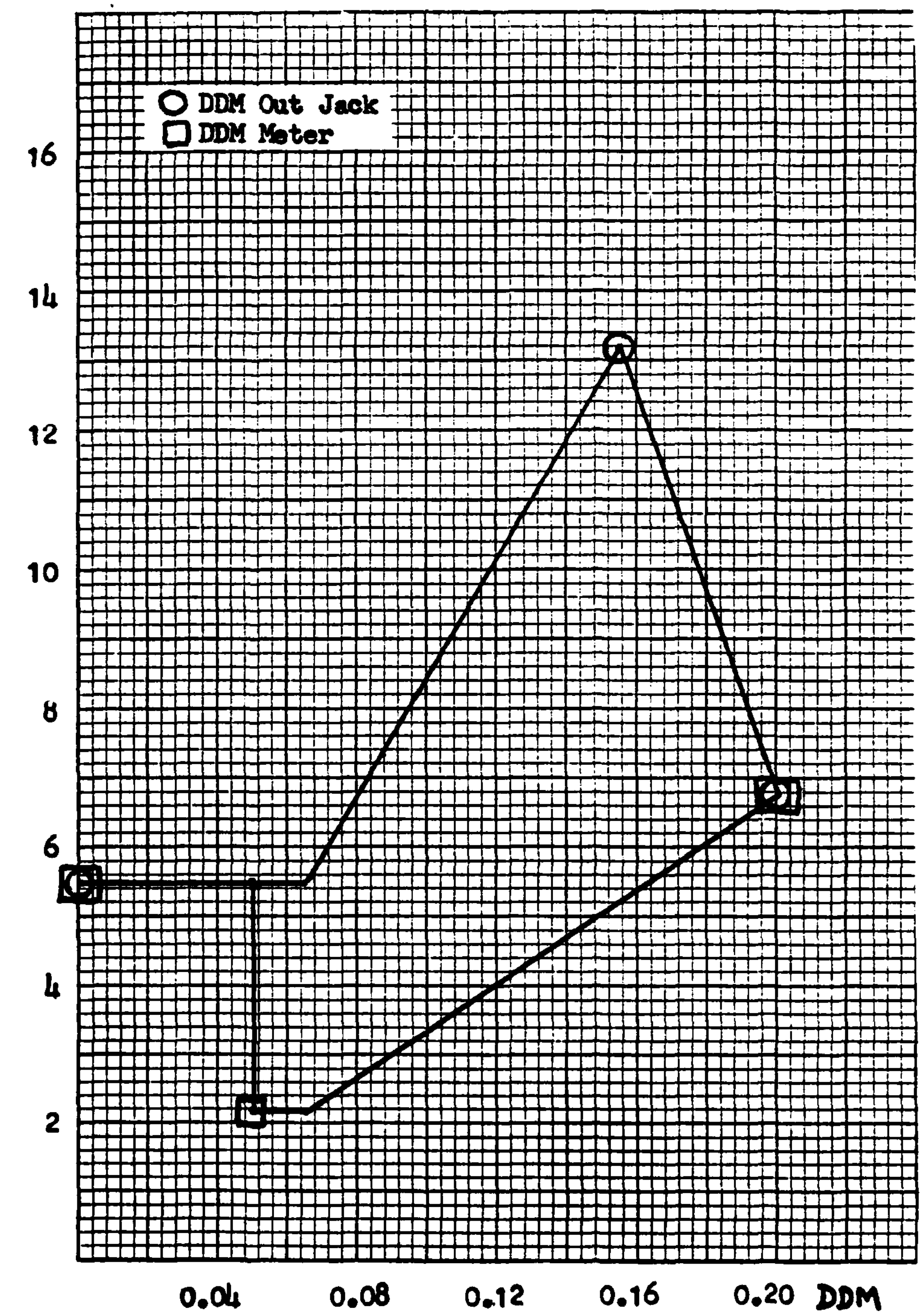


Fig. IV-3. Cat II Localizer/AN/GRM-112 Accuracies.

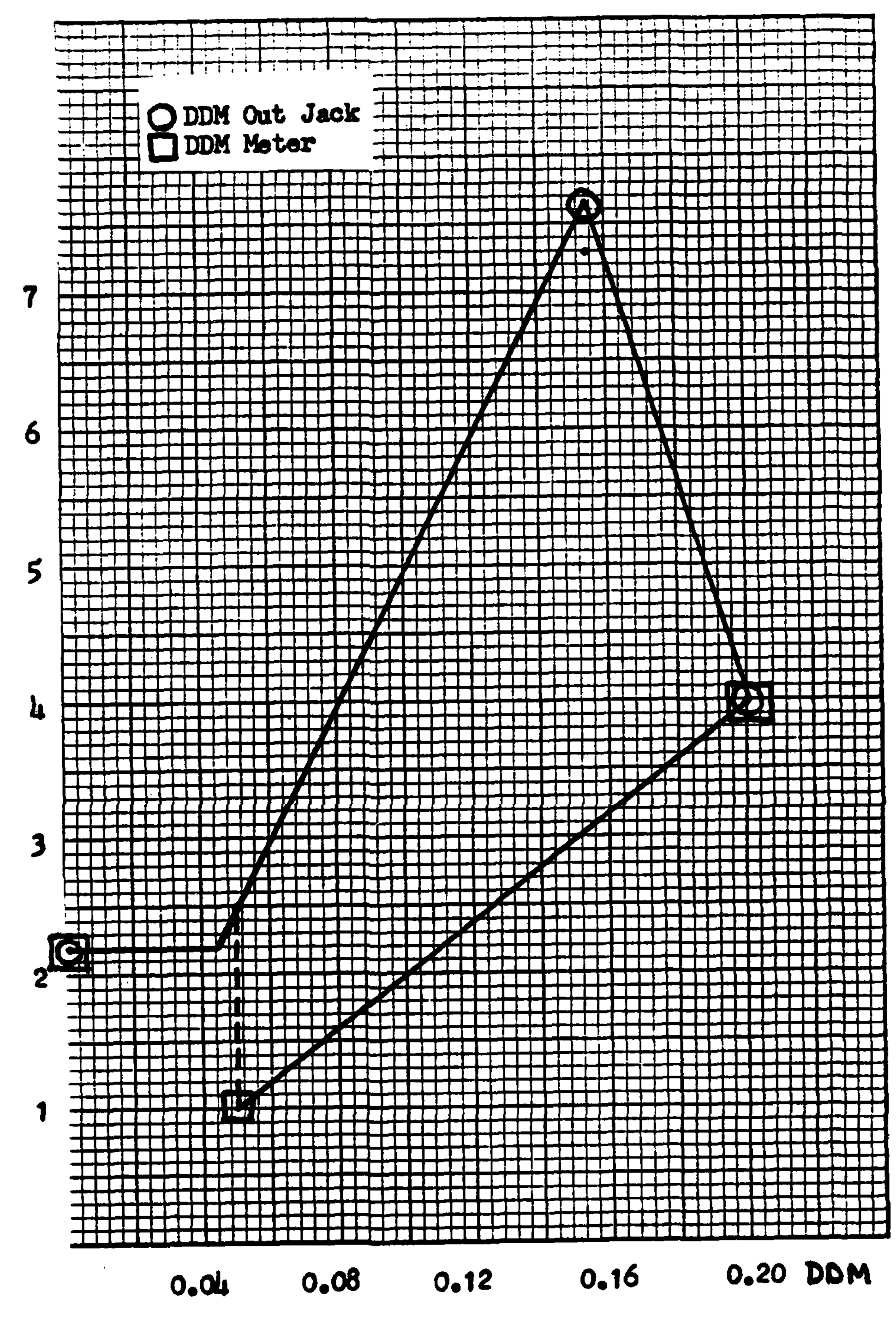


Fig. IV-4. Cat III Localizer/AN/GRM-112 Accuracies.

Glide Slope Station On-Path DDM Accuracy. The required alignment accuracy of the glide slope on-path signal is specified by AFM 55-8 as being within $\pm$ 0.05 degrees of the nominal glide path angle. Using Eq(41), i.e 0.35 degrees = 0.0875 DDM, this specification is equivalent to 0 $\pm$0.0125 DDM.

On-path measurements are made using the AN/GRM-112. The on-path (0 DDM) accuracy of the AN/GRM-112 was given in Table III-2 as $\pm$0.002 DDM. Since this accuracy is 6.25 times better than the glide slope required accuracy, this test instrument is considered adequate for on-path measurements.

Glide Slope Station Off-Path DDM Accuracy: The ICAO Category III glide slope specification for angular displacement sensitivity was given in chapter III as 0.0875 DDM = 0.12θ with a tolerance of $\pm 0.02\theta$, where θ is the nominal glide-path angle. This specification corresponds to a requirement to maintain this sensitivity to within $\pm$16.7% of the ideal value.

Off-path measurements are made using the AN/GRM-112 whose accuracy specifications are given in Table III-2. A plot comparing the AN/GRM-112 accuracy to the glide slope accuracy specification is shown in figure IV-5. From the figure it is not readily apparent as to how glide slope accuracy compares with the AN/GRM-112 accuracy. Figure IV-6 is included to better show this relationship. From the figure, it is clear that the AN/GRM-112 is adequate for all glide slope DDM measurements.

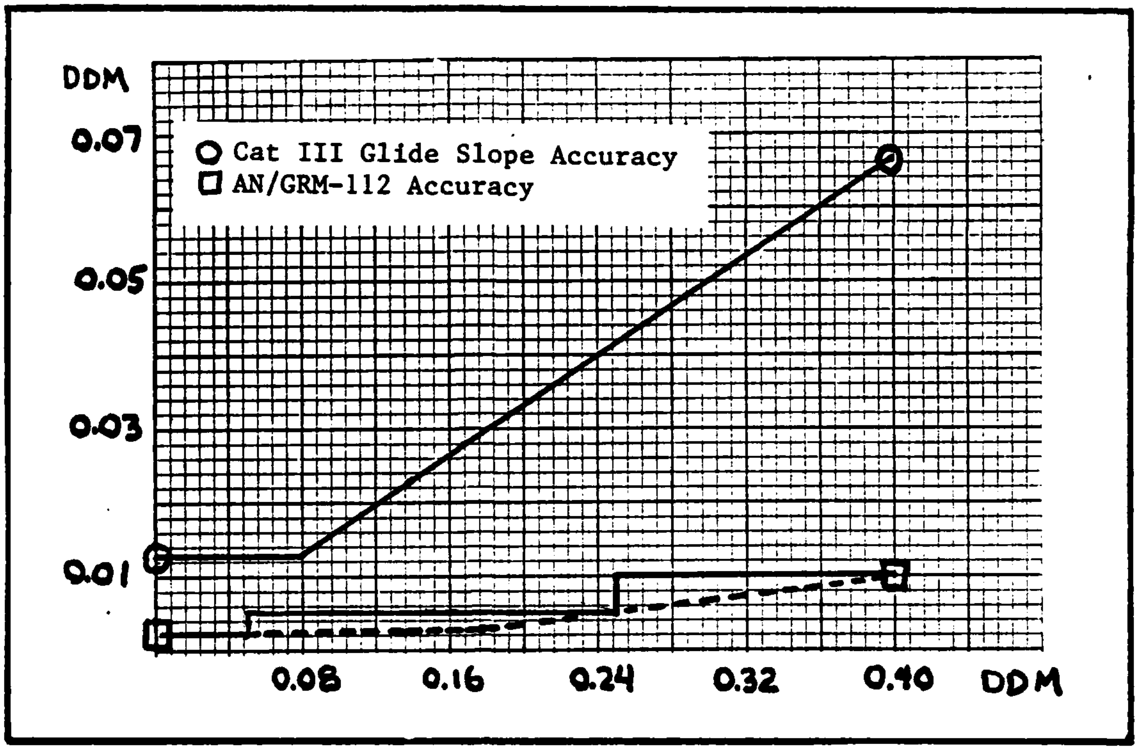


Fig. IV-5. Glide Slope & AN/GRM-112 Accuracies.

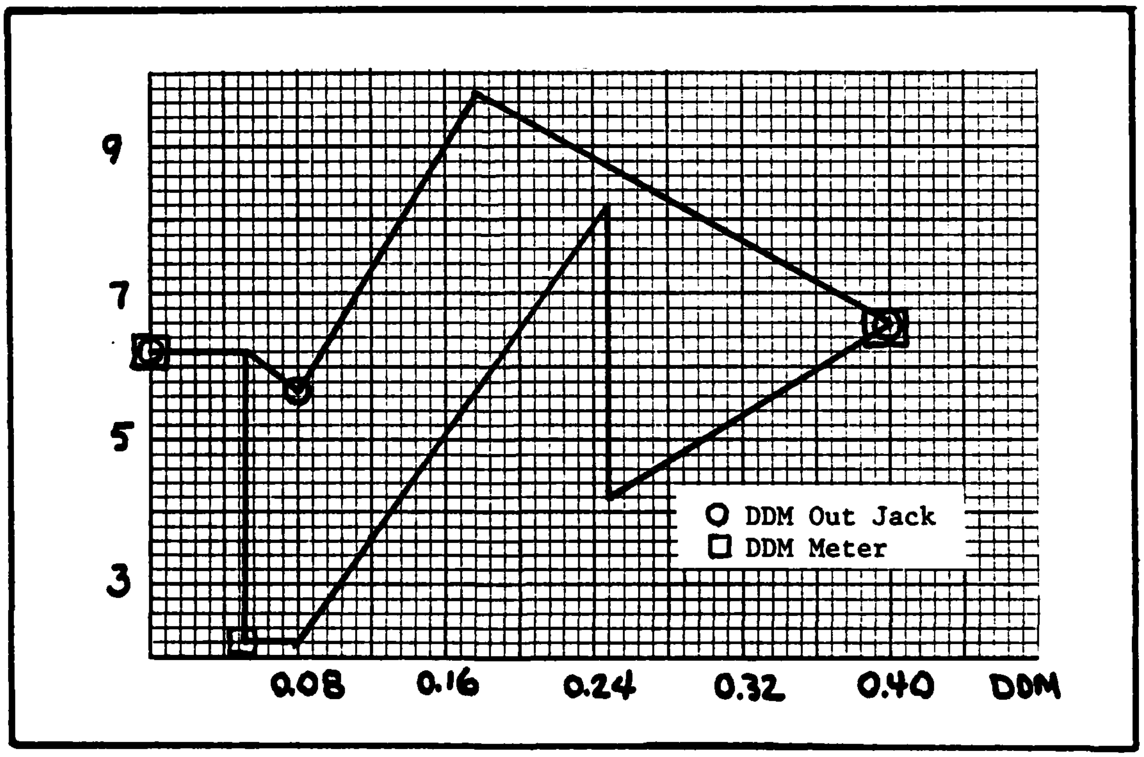


Fig. IV-6. Plot of Glide Slope/AN/GRM-112 Accuracies.

Airborne Localizer Receiver On-Course DDM Accuracy. Requirements concerning the maximum tolerable on-course (centering) error were given by ARINC and by RTCA as 0.0031 DDM and 0.0046 DDM, respectively. The 479S-6, Collins ILS Signal Generator, is used in the alignment of ILS receiver equipment. The on-course accuracy of the 479S-6 was given in Table III-3 as ±0.00056 DDM. This accuracy is 5.5 times better than that of the ARINC requirement and 8.2 times better than that of the RTCA requirement. The 479S-6 on-course accuracy is considered adequate for localizer receiver maintenance.

Airborne Localizer Receiver Off-Course DDM Accuracy: Accuracy requirements, based on ARINC and RTCA design criteria, are plotted in figure IV-7 along with the accuracy specification of the Collins 479S-6. From the figure, it is not readily apparent as to how the 479S-6 DDM accuracy specification compares with the localizer receiver accuracy requirements. To better show this relationship, figure IV-8 is included. This figure presents a plot of the ratio of the most stringent localizer receiver DDM accuracy requirement to the DDM accuracy specification of the ILS signal generator (i.e., ARINC requirements to 479S-6 specification). It is clear from figure IV-8 that the 479S-6 does not have sufficient accuracy to achieve a 4:1 margin over the normal range of DDM values encountered.

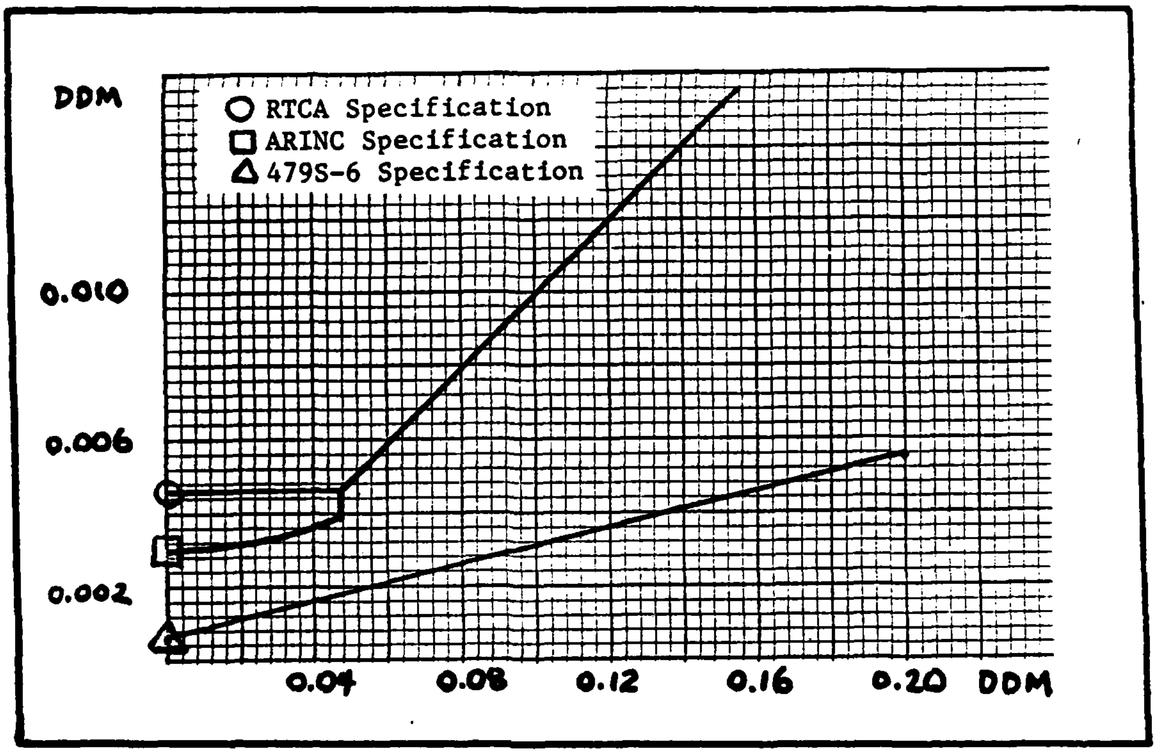


Fig. IV-7. Localizer Receiver & 479S-6 Accuracies.

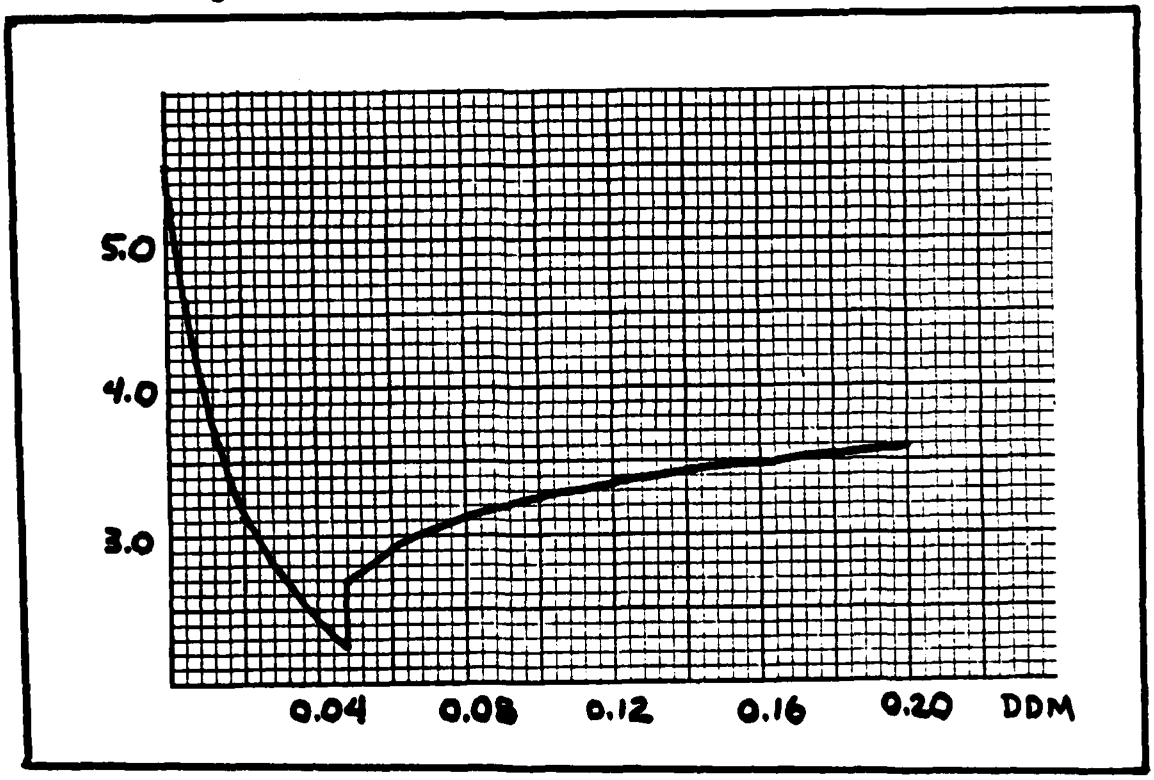


Fig. IV-8. Ratio of ARINC/479S-6 Accuracies.

<u>Airborne Glide Slope Receiver On-Path DDM Accuracy</u>. The glide slope receiver on-path maximum inaccuracy was given as ±0.007 DDM for ARINC designs and ±0.0118 DDM for RTCA designs. The accuracy of the Collins 479S-6 ILS signal generator on-path signal was given in Table III-3 as ±0.00102 DDM. The generator accuracy is nearly 7 times better than that of the ARINC requirement and 11.5 times better than that of the RTCA requirement. The 479S-6 is considered adequate for maintaining the on-path accuracy of glide slope receivers.

<u>Airborne Glide Slope Receiver Off-Path DDM Accuracy</u>. Accuracy requirement based on ARINC and RTCA design criteria are plotted in figure IV-9, along with the accuracy specification of the Collins 479S-6. It should be noted that there exists a discontinuity in the RTCA requirement at 0 DDM. This is because the off-path requirement does not converge to the on-path value at 0 DDM. From the figure, it is not readily apparent as to how the 479S-6 accuracy compares with glide slope receiver accuracy. Figure IV-10 is included to better show this relationship. The figure is a plot of the ratio of the most stringent glide slope receiver accuracy requirement to the accuracy specification of the ILS signal generator (i.e., RTCA requirement to 479S-6 specifications). From figure IV-10, it is seen that the 479S-6 does not have sufficient accuracy to achieve a 4:1 accuracy margin over the RTCA requirement for the normal range of DDM values encountered.

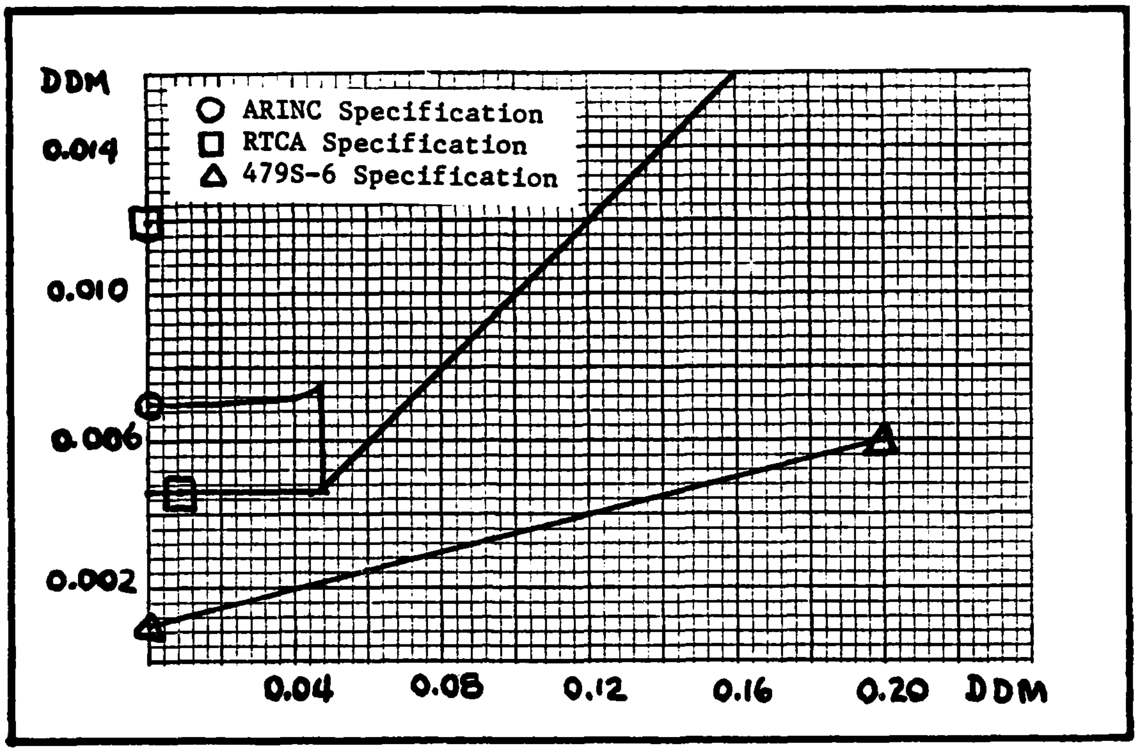


Fig. IV-9. Glide Slope Receiver & 479S-6 Accuracies.

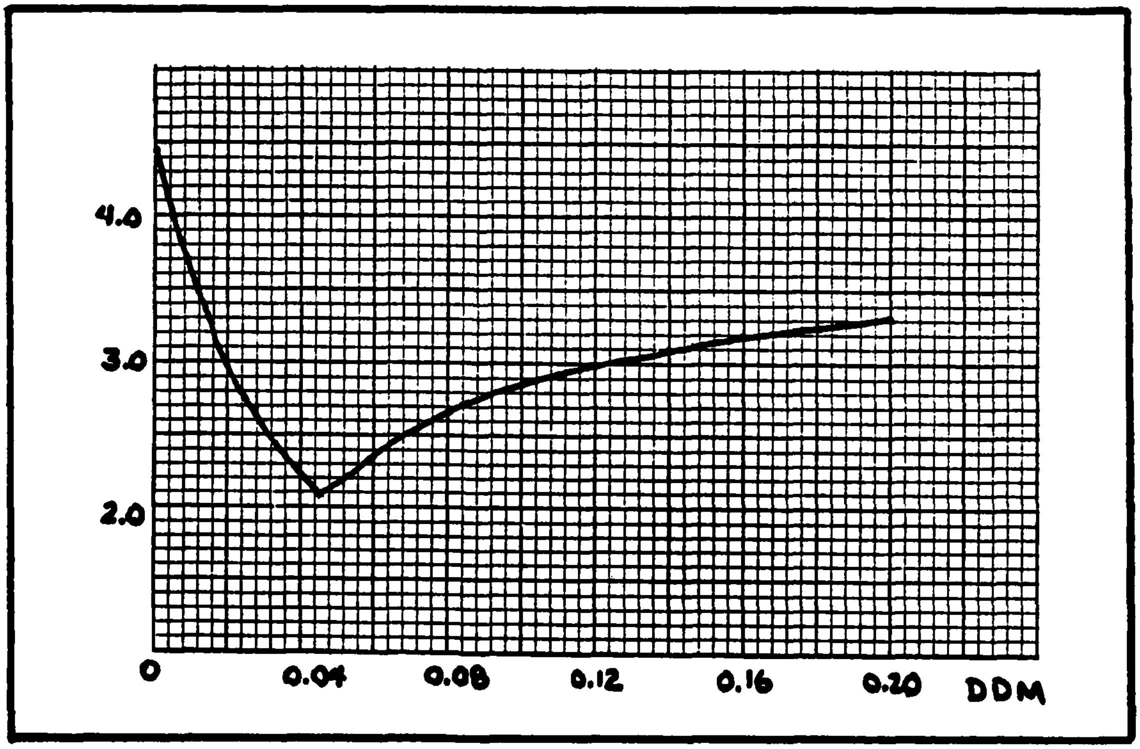


Fig. IV-10. Ratio of RTCA/479S-6 Accuracies.

Assessment of ILS Modulation Factor and DDM Calibration Hierarchies.

In the previous assessment, test instrument adequacy was determined by comparing system accuracy requirements to test instrument accuracy specifications. If the test instrument specification was at least 4 times better than the system specification, the instrument was considered adequate. The underlying assumption made in the previous analysis was that the test instrument was calibrated to it's accuracy specification. This assumption may prove to be unjustified. In the following paragraphs, the ILS calibration hierarchy for modulation factor and DDM is identified and analyzed.

Modulation Factor Calibration Hierarchy Analysis.

The calibration hierarchy for modulation factor is pictured in figure IV-11. The maintenance test instrument may be either the 5301 modulation meter or the AN/GRM-112 receiver test set.

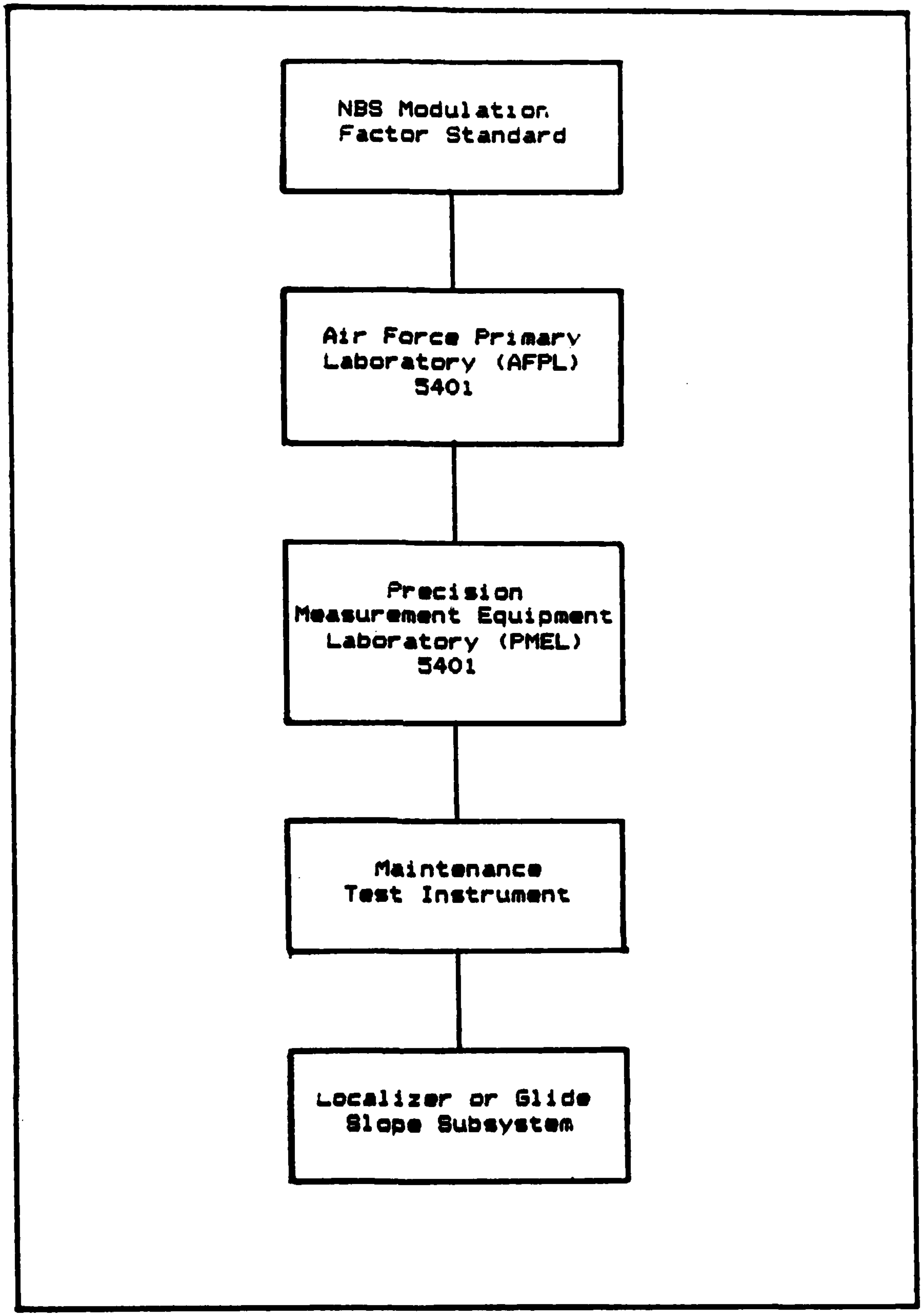
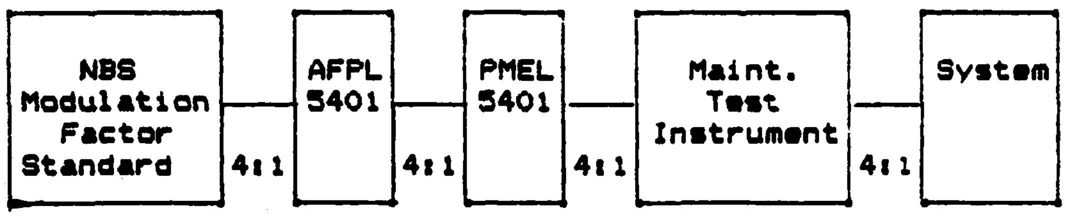


Fig. IV-11. Modulation Factor Calibration Hierarchy.

If the NBS Modulation Factor Standard is calibrated to the accuracy specified in Table III-5, and if a 4:1 accuracy margin exists between each level in the hierarchy, i.e. the measurement uncertainty of higher level instruments ia 4 times better than that of the instrument directly below it, then the following accuracies at the specified modulation factors will be achieved:

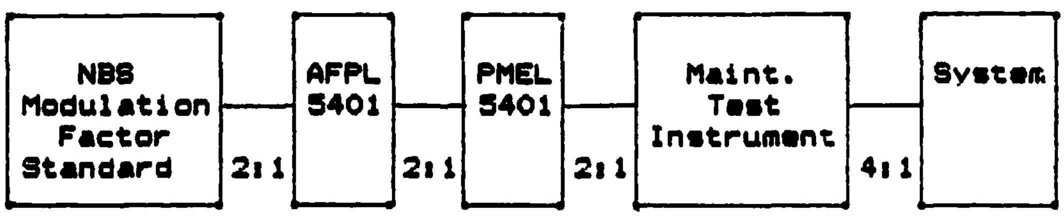


Modulation Factor	Limits of Accuracy (±) NBS Mod St	AFPL 5401	PMEL 5401	Maint Instrument	System
0.20000	0.00033	0.00132	0.00528	0.02112	0.08448
0.40000	0.00054	0.00216	0.00864	0.03456	0.13824

Fig. IV-12. Calibration Hierarchy & Accuracies.

The maximum tolerable modulation factor inaccuracies of the localizer and glide slope modulation factors are 0.01 and 0.025, respectively. From figure IV-12, it is seen that the achieved system accuracies, 0.08448 and 0.13824, are clearly unacceptable. In order to meet system accuracy requirements and also maintain a 4:1 margin between test instruments, the NBS Modulation Factor Standard measurement uncertainty would have to be no more than ± 0.000039 modulation factor units for localizer signal measurements and ± 0.000097 modulation factor units for glide slope signal measurements. Achieving these accuracies from the current NBS instrument design is not possible. It can also be shown that in requiring the 4:1 accuracy margin, all test instruments in the hierarchy will have to be improved upon since none have sufficient accuracy to achieve the level of accuracy required. An alternative may be to modify the requirement such that a 2:1 margin is permitted between levels in the hierarchy.

If the calibration requirement is tightened such that 2:1 accuracy margin is required between all calibration levels except between the maintenance test instrument and the system, the accuracies of figure IV-13 are achieved.



	Limits of Accuracy (±)				
Modulation Factor	NBS Mod Std	AFPL 5401	PMEL 5401	Maint Instrument	System
0.20000	0.00033	0.00066	0.00132	0.00264	0.01056
0.40000	0.00054	0.00108	0.00216	0.00432	0.01728

Fig. IV-13. Calibration Hierarchy & Accuracies.

It is clear that if the calibration accuracies of figure IV-13 can be achieved, both localizer and glide slope accuracy requirements will be met. The next logical question is: Can these accuracies be achieved? In order to answer this question, it is necessary to investigate the capabilities of each test instrument in the hierarchy to determine if each can be expected to achieve the level of accuracy being demanded of it. The starting point in such an investigation is with the AFPL-5401.

AFPL-5401 Modulation Factor Accuracy Assessment. The AFPL-5401 specified accuracy is $\pm$0.001 modulation factor units for modulation factors between 0.1 and 0.5. From figure IV-13, the accuracy required of the AFPL-5401 is 0.00066 for localizer signals and 0.00108 for glide slope signals. The AFPL-5401 accuracy specification shows that it is capable of achieving the required level of accuracy to assess glide slope signals; however, for localizer signals, the needed accuracy is nearly twice that of the equipment specification. The only way to find out for certain if this instrument can be calibrated to the required level is to perform the calibration and evaluate it's ability to hold the higher accuracy.

PMEL-5401 Modulation Factor Accuracy Assessment. The PMEL-5401 specified accuracy is the same as that of the AFPL-5401. At the PMEL level, the accuracy required of the 5401, i.e. 0.00132 for localizer signal measurements and 0.00216 for glide slope signal measurements, should be easily met.

5301 Modulation Factor Accuracy Assessment. The 5301 accuracy specification for modulation factors from 0 to 80% is ±0.005 modulation factor units (or ±0.5%). For this instrument to meet system accuracy requirements, it will have to be calibrated such that it's limits of accuracy are ±0.0025 for localizer signal measurements and ±0.00625 for glide slope signal measurements. To determine whether this level can be achieved will involve actually performing the calibration and evaluating the test instrument's ability to hold the higher accuracy.

AN/GRM-112 Modulation Factor Accuracy Assessment. The AN/GRM-112 accuracy specification is given as ±0.005 and ±0.01 DDM for localizer and glide slope signal measurements, respectively. The modulation factor accuracy requirement of the system is ±0.01 and ±0.025 modulation factor units for localizer and glide slope signal measurements. Since the test instrument is required to have an accuracy that is at least 4 times better than the system, the test instrument accuracy requirment is ±0.0025 and ±0.00625 for localizer and glide slope measurements, respectively. It is clear that in order for the AN/GRM-112 to meet the system accuracy requirements, it's accuracy will have to be calibrated to the test instrument requirements.

Currently, the calibration procedure for the AN/GRM-112 does not evaluate modulation factor accuracy. The calibration procedure evaluates DDM accuracy using the Collins 479S-6 as the calibration instrument. Signals generated by the Collins, although very accurate with respect to DDM, are accurate to only 2.5% of the modulation factor (ref to Table III-3 for accuracy specifications). Assuming that a 2:1 accuracy margin is achieved between the 479S-6 and the AN/GRM-112, the modulation factor accuracy of the AN/GRM-112 will be ±0.01 for localizer signal measurements and ±0.02 for glide slope signal measurements; neither of which is acceptable for ILS support. To assure adequate modulation factor calibration accuracy, the AN/GRM-112 should be calibrated against the PMEL-5401.

DDM Calibration Hierarchy Analysis:

The DDM calibration hierarchy is pictured in figure IV-14. There are two paths that are analyzed: Path one begins at the ILS receiver and is traced to the NBS voltage standard. Path two starts with the localizer and glide slope subsystems and ends with the same NBS standard.

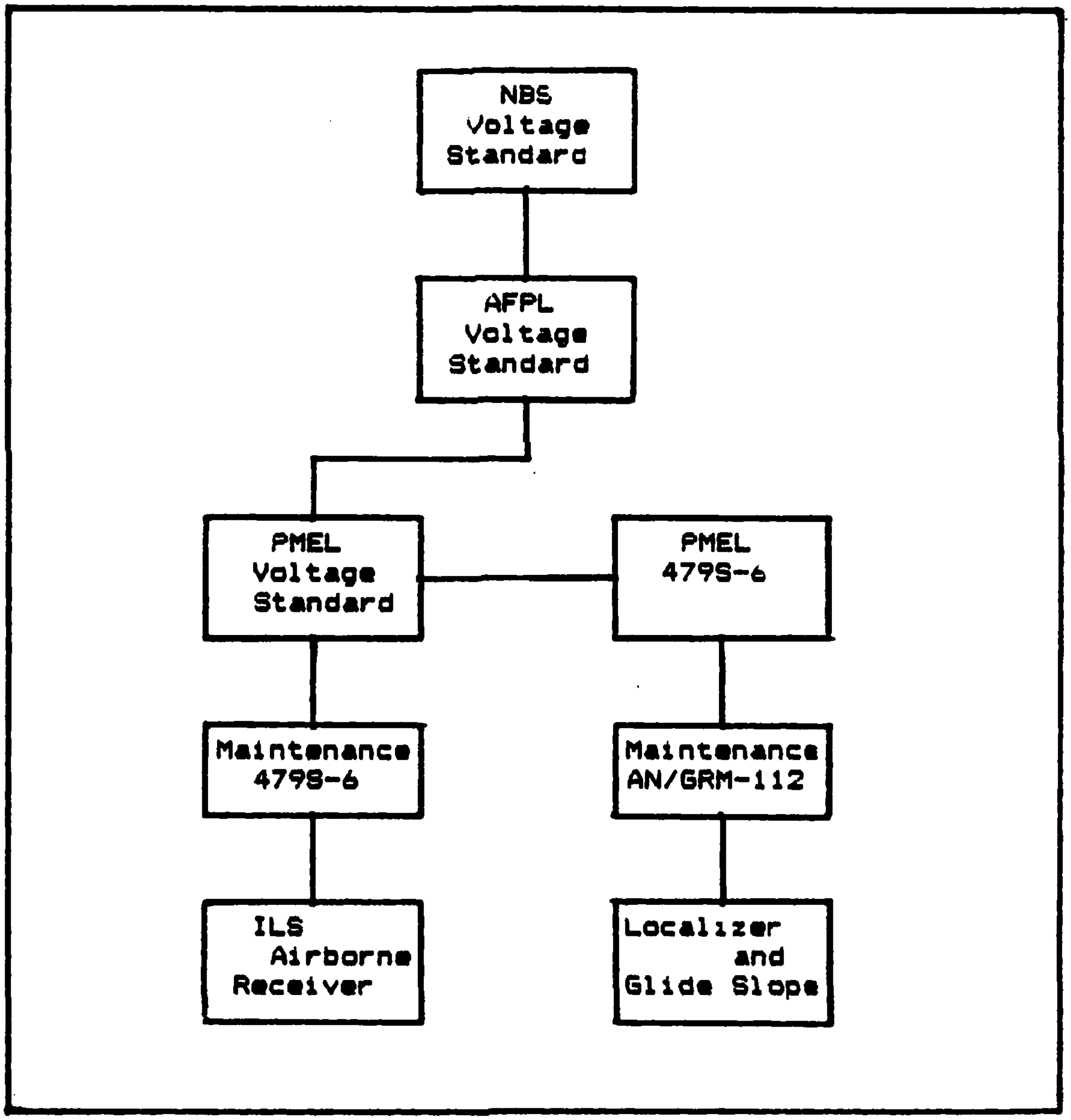
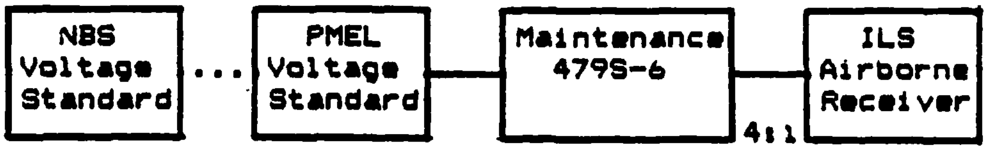


Fig. IV-14. ILS DDM Calibration Hierarchy.

ILS Receiver DDM Hierarchy. If between each level within the hierarchy it is required tha the uncertainty of measurement of the calibration instrument be at least 4 times better than that of the instrument being calibrated, and if the 479S-6 is calibrated to the specifications of Table III-3, then the accuracies specified in figure IV-15 for DDM values listed will be achieved. These selected DDM values are presented because they represent the most commonly measured values.



	Limits of Accuracy (±)			
Localizer DDM	479S-6 Spec.	Receiver Achieved	Required ARINC	Required RTCA
0.000	0.00056	0.00224	0.0031	0.0046
0.046	0.00171	0.00684	0.0039	0.0046
0.093	0.00289	0.01156	0.0093	0.0093
0.155	0.00444	0.01776	0.0155	0.0155
Glide Slope DDM				
0.000	0.00102	0.00408	0.0070	0.0118
0.045	0.00215	0.00860	0.0048	0.0045
0.091	0.00330	0.01320	0.0091	0.0091
0.175	0.00540	0.02160	0.0175	0.0175

Fig. IV-15. ILS Receiver DDM Calibration Hierarchy.

Comparing the limits of accuracy of the receiver with those required by RTCA or ARINC, it is seen that only at 0 DDM does the receiver meet either of the required specifications. In order to meet ARINC and RTCA requirements, either the accuracy tolerance between the PMEL 479S-6 and the ILS receiver will have to be tightened, i.e the 4:1 margin will have to be reduced, or the calibration tolerances on the 479S-6 will have to be decreased.

If the accuracy tolerances between the 479S-6 and the ILS receiver are reduced from 4:1 to 2:1, then all ILS receiver accuracy requirements will be met. This change will have no impact on the PMEL; however, maintenance tolerances will necessarily have to be tightened in the appropriate ILS receiver maintenance Technical Orders.

If the 479S-6 calibration tolerances are to be reduced in order to meet receiver requirements, the voltage ratio values used in the calibration procedure of sections 4.2.9.3 and 4.2.10.3 of T.O. 33A1-8-843-1 will necessarily have to be modified to include off-course measurements of the 479S-6 signal at the DEMOD output such that the following voltage ratio values are achieved:

Section 4.2.9.3 ratio values:

Localizer		Limits (DEMOD)	
DDM	Nominal	Minimum	Maximum
0.000	1.00000	0.99613	1.00388
0.046	1.25989	1.25368	1.26613
0.093	1.60586	1.58628	1.62575
0.153	2.26531	2.21447	2.31778
0.200	3.00000	2.90244	3.10256

Section 4.2.10.3 ratio values:

Glide Slope DDM	Nominal	Limits (DMOD) Minimum	Maximum
0.000	1.00000	0.99563	1.00438
0.045	1.11921	1.11605	1.12237
0.091	1.25670	1.24948	1.26396
0.175	1.56000	1.54220	1.57805
0.400	3.00000	2.90244	3.10256

The above limits were calculated from the smallest of the receiver required accuracies of figure IV-15, and using Eq(33), which is repeated here:

$$R = [M + DDM]/[M - DDM] \quad (33)$$

where M = total modulation factor, which is 0.4 for localizers and 0.8 for glide slope subsystems. The maximum ratio limit was calculated by adding the ideal DDM value to the plus DDM tolerance limit and inserting this value into the equation above. Similarly, the minimum ratio limt was calculated by adding the ideal DDM value to the minus DDM tolerance limit.

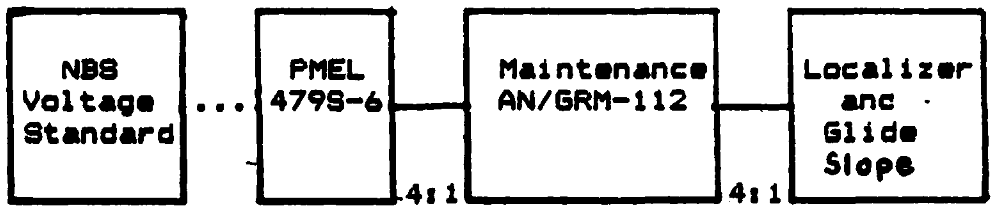
Whether the 479S-6 is capable of being calibrated to this level of accuracy will have to be determined in the laboratory.

Localizer/Glide Slope DDM Hierarchy. The DDM calibration hierarchy for localizer and glide slope subsystems in depicted in Fig. IV-16. The PMEL DDM reference standard is the Collins 479S-6, ILS signal generator.

As shown in the figure, this instrument is calibrated in the PMELs using instruments that are traceable to the NBS voltage standard.

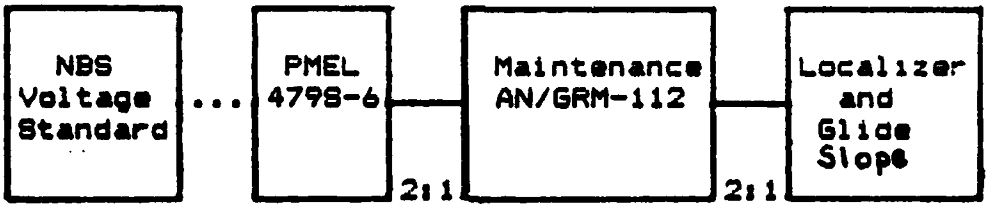
In analyzing this hierarchy, it is assumed that the 479S-6 is calibrated to the accuracy specifications given in Table III-3 and that the limits of accuracy between each test instrument in the hierarchy are 4 times better than the instrument below it. Under these conditions, the accuracy limits shown in Fig. IV-16 will be achieved. Comparing the achieved limits to the required limits, it is apparent that the test instruments calibrated to the levels shown are not adequate to achieve Cat III requirements for accuracy.

If the calibration is tightened to 2:1 at all levels, then the values shown in Fig. IV-17 will be achieved.



Localizer DDM	Limits of Accuracy (±) PMEL 479S-6	Maint. AN/GRM-112	Localizer Achieved	Cat III Required
0.000	0.00056	0.00224	0.00896	0.0044
0.046	0.00171	0.00684	0.02736	0.0046
0.093	0.00289	0.01156	0.04624	0.0093
0.155	0.00444	0.01776	0.07104	0.0155
0.200	0.00556	0.02224	0.08896	0.0200
Glide Slope DDM				
0.000	0.00102	0.00408	0.01632	0.0125
0.045	0.00215	0.00860	0.03440	0.0125
0.091	0.00330	0.01320	0.05280	0.0152
0.175	0.00540	0.02160	0.08640	0.0292
0.400	0.01102	0.04408	0.17632	0.0667

Fig. IV-16. Localizer/Glide Slope DDM Calibration Hierarchy & Limits of Accuracy.



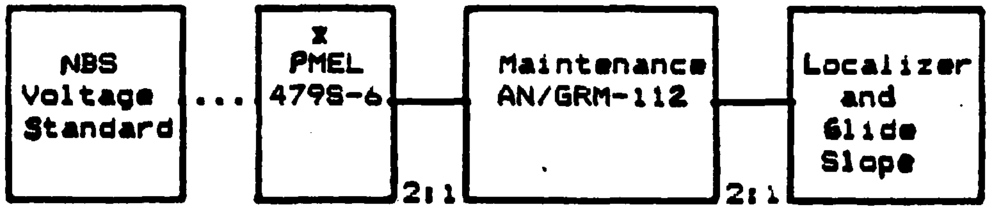
Limits of Accuracy (±)

Localizer DDM	PMEL 4798-6	Maint. AN/GRM-112	Localizer Achieved	Cat III Required
0.000	0.00056	0.00112	0.00224	0.0044
0.046	0.00171	0.00342	0.00684	0.0046
0.093	0.00289	0.00578	0.01156	0.0093
0.155	0.00444	0.00888	0.01776	0.0155
0.200	0.00556	0.01112	0.02224	0.0200
Glide Slope DDM				
0.000	0.00102	0.00204	0.00408	0.0125
0.045	0.00215	0.00430	0.00860	0.0125
0.091	0.00330	0.00660	0.01320	0.0152
0.175	0.00540	0.01080	0.02160	0.0292
0.400	0.01102	0.02204	0.04408	0.0667

Fig. IV-17. Localizer/Glide Slope DDM Calibration Hierarchy & Limits of Accuracy.

Comparing the localizer achieved accuracy limits with the required limits, it is seen that the achieved limits are adequate at 0 DDM but fall short of meeting system requirements at all other DDM values, while glide slope achieved accuracy limits meet all system requirements.

It may be possible to correct this deficiency by calibrating the PMEL 479S-6 to the tighter tolerances discussed earlier in the analysis of the ILS receiver DDM calibration hierarchy (ref to page IV-24). If the tighter limits are achievable, such a calibration will yield the accuracies shown in Fig. IV-18.



Limits of Accuracy (±)

Localizer DDM	PMEL 479S-6	Maint. AN/GRM-112	Localizer Achieved	Cat III Required
0.000	0.00077	0.00154	0.00308	0.0044
0.046	0.00098	0.00196	0.00392	0.0046
0.093	0.00233	0.00466	0.00932	0.0093
0.155	0.00387	0.00774	0.01548	0.0155
0.200	0.00500	0.01000	0.02000	0.0200
Glide Slope DDM				
0.000	0.00175	0.00350	0.00700	0.0125
0.045	0.00113	0.00226	0.00452	0.0125
0.091	0.00227	0.00454	0.00908	0.0152
0.175	0.00438	0.00876	0.01752	0.0292
0.400	0.01000	0.02000	0.04000	0.0667

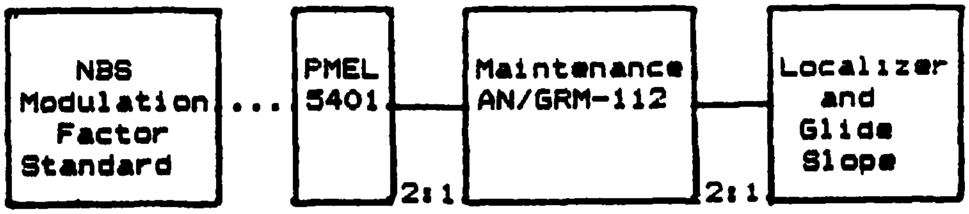
* 479S-6 calibrated to tolerances specified for ILS receiver hierarchy.

Fig. IV-18. Localizer/Glide Slope DDM Calibration Hierarchy & Limits of Accuracy.

If the tighter calibration tolerances cannot be achieved, the DDM calibration of the AN/GRM-112 may be accomplished using the PMEL-5401 as the reference instrument instead of the 479S-6.

Though the 5401 is incapable of measuring DDM directly, it is possible to derive DDM from modulation factor measurements since, by definition, DDM is the difference in the AM factors. The uncertainty in the accuracy of DDM derived in this manner depends upon the uncertainty associated with the individual AM factors. The derivation of the DDM measurement uncertainty of the PMEL-5401 is presented in Appendix B.

The accuracy limits achievable through calibration against the PMEL-5401 are shown in Fig. IV-19. The values given are based upon establishing 2:1 calibration tolerances between each level within the hierarchy, i.e. the calibrated instrument accuracy limits are twice that of the calibrating instrument.



Localizer DDM	PMEL 5401	Maint. AN/GRM-112	Localizer Achieved	Cat III Required
	Limits of Accuracy (±)			
0.000	0.00064	0.00128	0.00256	0.0044
0.046	0.00064	0.00128	0.00256	0.0046
0.093	0.00068	0.00136	0.00272	0.0093
0.155	0.00076	0.00152	0.00304	0.0155
0.200	0.00084	0.00168	0.00336	0.0200
Glide Slope DDM				
0.000	0.00140	0.00280	0.00700	0.0125
0.045	0.00144	0.00288	0.00576	0.0125
0.091	0.00144	0.00288	0.00576	0.0152
0.175	0.00152	0.00304	0.00608	0.0292
0.400	0.00200	0.00400	0.00800	0.0667

Fig. IV-19. Modified DDM calibration Hierarchy & Limits of Accuracy.

If each instrument can achieve the level of accuracy called out in Fig. IV-19, then all Cat III system requirements will be met. In comparing the level of DDM accuracy of the PMEL-5401 to the PMEL 479S-6 (refer to Fig. IV-17 for 479S-6 specifications), it is clear that for off-course measurement accuracy the hierarchy of Fig. IV-19 is superior.

V. CONCLUSIONS AND RECOMMENDATIONS.

Conclusions

In the previous chapter, instrument landing system DDM and modulation factor calibration hierarchies were identified and calibration accuracies were evaluated in order to determine whether test instrument accuracy was adequate to support ILS's. The evaluation revealed several shortcomings in the calibration accuracies required of ILS test instruments. These shortcomings are summarized as follows:

1. Modulation Factor Measurements:

   a. The Crescent 5301 modulation factor measurement accuracy specification is only two times better than that of the localizer requirement. The desired accuracy margin is 4:1 or better.

   b. The Wilcox AN/GRM-112 modulation factor measurement accuracy falls short of the desired 4:1 accuracy margin. It's accuracy is only 2 times better than the localizer requirement and 2.5 times better than that of the glide slope.

   c. The modulation factor calibration hierarchy assessment showed that in order to achieve a 4:1 accuracy margin between each test instrument in the hierarchy, all test instrument accuracies would have to be improved considerably. Such improvements may be beyond the capabilities of the test instruments.

2. DDM Measurements:

a. The Collins 479S-6 does not achieve the desired 4:1 margin over the required accuracy specifications of ILS localizer and glide slope receivers.

b. Measurement readings obtained from the DDM meter on the Wilcox AN/GRM-112 fall short of the desired 4:1 accuracy margin for all categories of ILS localizer and glide slope operations. For Cat III localizers, measurement readings obtained from the DDM Out jack also fall short of the desired 4:1 margin. In general, the AN/GRM-112 is adequate for maintaining Cat I and Cat II localizers and all categories of glide slope as long as the measurement readings are obtained from a digital voltmeter connected to the DDM Out jack.

c. In assessing the localizer/glide slope DDM calibration hierarchy, it was found that in order to obtain a 4:1 accuracy margin, the 479S-6 and the AN/GRM-112 will have to be calibrated to levels of accuracy which are more demanding than these instruments may be capable of achieving.

Recommendations

In addressing each of these problem areas, various options were discussed. The following listing presents the author's recommendations:

1. Modulation Factor Measurements:

a. In order to achieve the necessary margin of accuracy to meet the 4:1 rule, either the 5301 modulation meter will have to be calibrated

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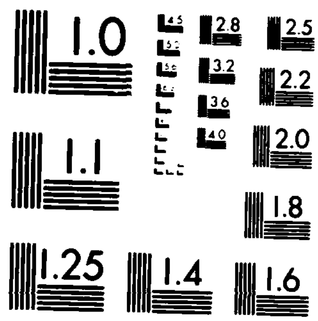

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

to a level exceeding it's accuracy specification or a better meter will have to be procured. With regard to the 5301, the author's recommendation is presented in "1b." below.

b. The AN/GRM-112 can do all that the 5301 can do, and more. However, as in "1a.", a similar problem exists with the Wilcox AN/GRM-112. The measurement accuracy of the AN/GRM-112 may be improved considerably if it is calibrated against the PMEL-5401. It is suggested that, if the AN/GRM-112 can be calibrated to the desired 4:1 margin, consideration be given to the elimination of the 5301 requirement.

c. With regard to the problem of achieving the desired 4:1 accuracy margin between all levels in the modulation factor calibration hierarchy, it is suggested that the requirements be modified to those described in Fig. IV-13, in which the 4:1 requirement is relaxed to 2:1 for all laboratory calibrations. In doing so, the maintenance instrument will have the necessary accuracy margin to meet system requirements. This recommendation depends upon whether or not the AFPL-5401 can achieve the more stringent calibration tolerance.

2. DDM Measurements:

a. To achieve the desired 4:1 accuracy margin between the 479S-6 and the airborne ILS receivers, it is recommended that the calibration procedure be modified using the values given on page IV-24.

b. The suggestions of "1b." should provide the necessary accuracy improvement for measurements obtained from the DDM Out jack of the AN/GRM-112. It is suggested that the AN/GRM-112 be modified to have a digital display (like the 5301). This will enhance resolvability; which is a major source of measurement uncertainty for modulation factor measurements.

c. The localizer/glide slope DDM calibration accuracies may be improved significantly if the 479S-6 can be successfully calibrated as proposed in "2a". If, however, this is not possible, the hierarchy of Fig. IV-19 may provide adequate accuracies, assuming again that the accuracies of Fig. IV-19 can be achieved.

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APPENDIX A
Excerpt from AFM 55-8

CHAPTER 300. SUPPLEMENTAL INFORMATION

SECTION 301 GLOSSARY OF ABBREVIATIONS, ACRONYMS, DEFINITIONS, AND SYMBOLS

301.1 Definitions and Symbols. The use of italics within a definition denotes another definition contained within this section.

Actual Glidepath Alignment or Actual Glidepath Angle. The straight line arithmetic mean of all deviations around the *on-path* position derived in ILS zone 2.

Actual Course (Alignment). The straight line arithmetic mean of all deviations around the *on-course* position derived from the area in which alignment was taken.

AFIS Corrected Error Trace. A graphical presentation of deviation about the mean of all points measured in ILS Zone 2 for glidepaths and zones 2 and 3 for localizers.

Automatic Gain Control (AGC). A process of electronically regulating the gain in the amplification stages of a receiver so that the output signal tends to remain constant though the incoming signal may vary in strength.

AGC Current or Voltage. A current or voltage responding to the action of the AGC circuit that may be interpreted in terms of signal intensity.

Air Traffic Control Radar Beacon System (ATCRBS). The general term of the ultimate in functional capability afforded by several automation systems. Each differs in functional capabilities and equipment. ARTS IA, ARTS II, ARTS III, and ARTS IIIA (see AIM).

Airway/Federal Airway. A control area or portion thereof established in the form of a corridor, the centerline of which is defined by navigational aids (refer to FAR Part 71, AIM).

Alignment. Coincidence of a positional or directional element with its nominal reference.

Alignment, Azimuth. The azimuth or actual magnetic bearing of a course.

Alignment, Elevation. The actual angle above a horizontal plane originating at a specific point of a course used for altitude guidance.

Alignment Error. The angular or linear displacement of a positional or directional element from its normal reference.

Alignment Error, Azimuth. The difference in degrees between the position of a selected course and the correct magnetic azimuth for this course.

Note: The error is positive when the course is clockwise from the correct azimuth.

Alignment Error, Elevation. The difference in degrees between the measured angle of the course and the correct angle for the course.

Note: The error is positive when the course is above the correct angle.

Altitudes:

Absolute Altitude. The altitude of the aircraft above the surface it is flying (AC 00-6A). It may be read on a radio/radar altimeter.

Calibrated Altitude. Indicated altitude corrected for static pressure error, installation error, and instrument error.

Indicated Altitude. The altitude as shown by an altimeter on a pressure or barometric altimeter. It is altitude as shown uncorrected for instrument error and uncompensated for variation from standard atmospheric conditions (AIM).

Pressure Altitude. Altimeter read on the altimeter when the instrument is adjusted to indicate height above the standard datum plane (29.92" Hg.) (AC 61-27 latest revision).

True Altitude. The calibrated altitude corrected for nonstandard atmospheric conditions. It is the actual height above mean sea level (AC 61-27 and AFM 51-37).

Ampere. A unit of electric current such as would be given with an electromotive force of one volt through a wire having a resistance of one OHM. See Symbols. See Crosspointer.

Amplitude (Peak). The maximum instantaneous value of a varying voltage or current measured as either a positive or negative value.

Anomalous Propagation. Weather phenomena resulting in a layer in the atmosphere capable of reflecting or refracting electromagnetic waves either toward or away from the surface of the earth.

Angle Voltage. The alignment points of the azimuth and elevation electronic cursors are expressed in angle voltage or dial divisions.

Antenna. A device used to radiate or receive electromagnetic signals.

Antenna Reflector. That portion of a directional array, frequently indirectly excited, which reduces the field intensity behind the array and increases it in the forward direction.

Area Navigation (RNAV). A method of navigation that permits aircraft operations on any desired course within the coverage of station referenced navigation signals or within the limits of self-contained system capability (AIM).

Area VOT. A facility designed for use on the ground or in the air. It may be located to provide the test signal to one or more airports.

Attenuation. The reduction in the strength of a signal, expressed in decibels (dB).

Average Course Signal. The course determined by drawing the mean of the maximum course deviations due to roughness and scalloping.

Azimuth. A direction at a reference point expressed as the angle in the horizontal plane between a reference line and the line joining the reference point to another point, usually measured clockwise from the reference line.

Bearing. The horizontal direction to or from any point usually measured clockwise from true north or some other reference point (see Non-Directional Beacon) (AIM).

Bearing Error Report. A SAFI report automatically printed by a computer to provide the flight inspector with a facility error graph, vertical polarization value, navigation modulation information, signal level, analysis of sector flown, and history of past flight inspections of the facility.

Bends. Slow excursions of the course.

Blind Speed. The rate of departure or closing of a target relative to the radar antenna at which cancellation of the primary target by MTI circuits in the radar equipment causes a reduction or complete loss of signal (AIM).

Blind Zones (Blind Spots). Areas from which radio transmissions and/or radar echoes cannot be received.

Broadband. Nonautomated signal processing.

Capture Effect. A system in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies.

Change/Reversal in Slope of the Glide Path. A long term (1,500 feet or more) change in the direction of the *on-path* position as determined by the graphic averaging of the short term (roughness, high frequency scalloping) deviations as represented by the differential/corrected error trace.

Checkpoint. A geographical point on the surface of the earth whose location can be determined by reference to a map or chart.

Circular Polarization (CP). An electromagnetic wave for which the electronic and/or the magnetic field vector at a point describes a circle.

Note: Circular Polarization reduces or eliminates echoes from precipitation.

Clearance. The preponderance of the modulation signal appropriate to the area on one side of the reference line or point to which the receiver is positioned, over the modulation signal appropriate to the area on the other side of the reference line.

Close-in Courses. That portion of a course or radial which lies within 10 miles of the station.

Code Train. A series of pulses of similar characteristics and specific spacing. Applicable to the group of pulses transmitted by a transponder each time it replies to an interrogator.

Common digitizer data reduction program (CD). A computer data recording of raw narrowband radar data (minimal filtering ability is provided).

Cone of Ambiguity. Airspace over a VOR or TACAN station, conical in shape, in which the To/From ambiguity indicator is changing positions.

Cooperating Aircraft. Aircraft which cooperate by flying courses required to fulfill specific portions of the flight inspection and which meet the requirements for a small aircraft.

Cosecant-Squared Beam. A radar beam pattern designed to give approximately uniform signal intensity for echoes received from distant and nearby objects. The beam intensity varies as the square of the cosecant of the elevation angle.

Crosspointer [Deflection Indicator Current (ICAO)]. An output current proportional to: ILS—Difference in depth of modulation measured in microamperes. VOR/VORTAC/TAC—The difference in phase of two transmitted signals measured in degrees of two audio navigation components for a given displacement from a navigation aid.

Course Coincidence. The measured divergence of the designated radials of two adjacent facilities in the airway structure. (ICAO Document 8071).

Course Displacement. The difference between the actual course alignment and the correct course alignment. (ICAO Document 8071).

Course Error. The difference between the course as determined by the navigational equipment and the actual measured course to the facility. This error is computed as a plus or minus value, using the actual measured course to the facility as a reference.

Course Line Computer. Airborne equipment which accepts bearing and distance information from receivers in an aircraft, processes it, and presents navigational information enabling flight on courses other than directly to or from the ground navigation aid being used. (Used in Area Navigation—RNAV.)

Course Roughness. Rapid irregular excursions of the course usually caused by irregular terrain, obstructions, trees, power lines, etc.

Course Scalloping. Rhythmic excursions of the electromagnetic course or path.

Course Width (Course Sensitivity). The angular deviation required to produce a full-scale course deviation indication of the airborne navigation instrument.

Coverage. The designated volume of airspace within which a signal-in-space of specified characteristics is to be radiated.

Designed Procedural Azimuth. The azimuth determined by the procedure specialist that defines the desired position of a course or bearing.

DF Course (Steer). The indicated magnetic direction of an aircraft to the DF station and the direction the aircraft must steer to reach the station.

DF Fix. The geographical location of an aircraft obtained by the direction finder.

Difference in Depth of Modulation (DDM). The percentage modulation of the larger signal minus the percentage modulation of the smaller signal.

Discrepancy. Any facility operating parameter which is not within the given tolerance values (prescribed in the U.S. Standard Flight Inspection Manual) as determined by flight inspection measurements.

Displaced Threshold. A threshold located on the runway at a point other than the designated beginning of the runway (AIM).

Distance Measuring Equipment (DME). Electronic equipment used to measure, in nautical miles, the slant range of the aircraft from the navigation aid. (AIM).

Doppler VOR (DVOR). VOR using the Doppler frequency shift principle.

Dual—Frequency Glidepath System. An ILS glidepath in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies within the particular glidepath channel, e.g., Capture Effect Glidepath.

Dual—Frequency Localizer System. A localizer system in which coverage is achieved by the use of two independent radiation frequencies within the particular localizer VHF channel.

* *Expanded Service Volume (ESV).* That additional volume of airspace beyond the service volume requested by the FAA's Air Traffic Service or FIFO's procedure specialist and approved by frequency management of the Airway Facilities Division and flight inspection for operational use. *

Facility (Flight Facility). Any ground placed electronic equipment used to assist pilots in air navigation, landing approaches, or to direct air traffic movements. Flight facilities include navaids, communications and traffic control facilities.

Fixed Map. A background map on the radar display produced by one of the following methods:

(1) Engraved marks on an overlay illuminated by edge lighting.

(2) Engraved fluorescent marks on an overlay illuminated by means of ultraviolet light.

(3) Projected on the display by means of film and a projector mounted above and in front of the scope.

(4) Electronically mixed into the display as generated by a "mapper" unit.

Flag (Flag Alarm). A warning device in certain airborne navigation equipment and flight instruments indicating: (1) instruments are inoperative or otherwise not operating satisfactorily, or (2) signal strength or quality of the received signal falls below acceptable values. (AIM)

Flag Alarm Current. The d.c. current flowing in the Flag Alarm Circuit, usually measured in microamperes, which indicates certain characteristics of the modulation of the received signal.

Flight Data Tape. The magnetic tape on which digitized facility performance data is recorded during a SAFI flight. This is commonly called the output tape.

Flight Inspection (Flight Check). Inflight investigation and evaluation of air navigation aids and instrument flight procedures to ascertain or verify that they meet established tolerances and provide safe operations for intended use.

Note: *Flight checked* describes the procedure to accomplish the function of flight inspection. The two terms are interchangeable.

Flight Tape. The digitized magnetic tape that controls navigation of the aircraft and tuning of preselected facilities on SAFI flights. This is commonly called the input tape.

Glidepath. See: ILS—Glidepath.

Glidepath Angle. The angle between the downward extended straight line extension of the ILS glidepath and the horizontal.

Glidepath Structure. Characteristics of a glidepath including bends, scalloping, roughness and width.

Glide Slope. A facility which provides vertical guidance for aircraft during approach and landing.

Glide Slope Intercept Altitude. The true altitude (MSL) proposed or published in approved let-down procedures at which the aircraft intercepts the glidepath and begins descent. (FAA Order 1000.15 latest revision)

* *Graphical Average Path.* The average path described by a line drawn through the mean of all crosspointer deviations. This will usually be a curved line which follows long term trends (1,500 feet or greater) and averages shorter term deviations. *

Ground Point of Intecept (GPI). A point in the vertical plane on the runway centerline at which it is assumed that the *downward straight line extension* of the glide path intercepts the runway approach surface baseline. (FAA Order 8260.3 latest revision.)

Hertz (Hz). A unit of frequency of electromagnetic waves which is equivalent to one cycle per second. See Symbols in this chapter.

Kilohertz (kHz). A frequency of 1000 cycles per second.

Megahertz (MHz). A frequency of one million cycles per second.

Gigahertz (GHz). A frequency of one billion cycles per second.

Hole (Null). An area of signal strength below that required to perform the necessary function or furnish the required information, which is completely surrounded by stronger signal areas of sufficient strength to perform required functions.

ILS-Back-Course Sector. The *course sector* which is the appropriate reciprocal of the front *course sector.*

ILS-Commissioned Angle—Glide Slope. The glidepath angle calculated by a qualified procedure specialist which meets obstruction criteria (FAA Order 8260.3 latest revision). This nominal angle may be increased to meet additional criteria, i.e., engineering, noise abatement, site deficiencies, etc.

ILS-Commissioned Width—Localizer. The nominal width of a localizer. In practice the width is computed by using the criteria prescribed in Section 217 of FAA Order OA P 8200.1. (latest revision)

ILS-Course Sector. A sector in a horizontal plane containing the course line and limited by the loci of points nearest to the course line at which 150μA is found.

ILS-Differential Corrected Trace. The trace on the recording which is the algebraic sum of the Radio Telemetering Theodolite (RTT) crosspointer (DDM) and the aircraft receiver crosspointer (DDM) and which is produced by the differential amplifier within the airborne Theodolite Recording System.

ILS-Downward Straight Line Extension. The mean location of the ILS glidepath in zone 2.

ILS-Facility Reliability. The probability that an ILS ground installation radiates signals within the specified tolerances.

ILS-Front Course Sector. The course sector which is situated on the same side of the localizer as the runway.

ILS-Glidepath. The locus of points in the vertical plane (*containing the runway centerline) at which the DDM is zero, which of all such loci is the closest to the horizontal plane.

* Note: Offset ILS's do not contain the runway centerline.

ILS-Glidepath Sector. The sector in the vertical plane containing the ILS glidepath and limited by the loci of point nearest to the glidepath at which 150μA occurs.

Note: The ILS glidepath sector is located in t... vertical plane containing the localizer *on-course* signal and is divided by the radiated glidepath called upper sector and lower sector, referring respectively to the sectors above and below the path.

ILS-Glidepath Sector Width (Normal Approach Envelope). The width of a sector in the vertical plane containing the glidepath and limited by the loci of points above and below the path at which reading of 150μA is obtained.

ILS-Half Course Sector. The sector, in a horizontal plane containing the course line and limited by the loci of points nearest the course line at which 75μA occurs.

ILS-Localizer Back Course Zone 1. The distance from the coverage limit to 4 miles from the localizer antenna.

ILS-Localizer Back Course Zone 2. From 4 miles from the localizer antenna to one mile from the localizer antenna.

ILS-Localizer Back Course Zone 3. One mile from the localizer antenna to 3,000 feet from the localizer antenna.

ILS-Localizer Clearance Sector 1. From 0° to 10° each side of the center of the localizer *on-course.*

ILS-Localizer Clearance Sector 2. From 10° to 35° each side of the center of the localizer *on-course.*

ILS-Localizer Clearance Sector 3. From 35° to 90° each side of the center of the localizer *on-course.*

ILS-Localizer Course Sector Width. The sum of the angular distances either side of the center of the course required to achieve full scale (150μA) crosspointer deflection.

ILS-Lowest Coverage Altitude (LCA). That altitude which is final approach fix altitude, glidepath intercept altitude, or 500 feet above all obstructions, whichever is higher.

ILS-Performance Category I. An ILS which provides acceptable guidance information from the coverage limits of the ILS to the point at which the localizer course line intersects the glidepath at a height of 100 feet or less above the horizontal plane containing the runway threshold.

ILS-Performance Category II. An ILS which provides acceptable guidance information from the coverage limits of the ILS to the point at which the localizer course line intersects the glidepath at a point above the runway threshold.

ILS-Performance Category III. An ILS which, with the aid of ancillary equipment where necessary, provides guidance information from the coverage limit of the facility to, and along, the surface of the runway.

ILS-Point "A". An imaginary point on the glidepath/localizer *on-course* measured along the runway centerline extended, in the approach direction, 4 nautical miles from the runway threshold.

ILS-Point "B". An imaginary point on the glidepath/localizer *on-course* measured along the runway centerline extended, in the approach direction, 3,500 feet from the runway *threshold.*

ILS Point "C". A point through which the *downward extended straight portion* of the glidepath (at the commissioned angle) passes at a height of 100 feet above the horizontal plane containing the *runway threshold.* Note: Localizer only, LDA's, and SDF only facilities, Point C is the missed approach point.

ILS Point "D". A point 12 feet above the runway centerline and 3,000 feet from the runway threshold in the direction of the localizer.

ILS Point "E". A point 12 feet above the runway centerline and 2,000 feet from the stop end of the runway in the direction of the *runway threshold.*

ILS Reference Datum. A point at specified height located vertically above the intersection of the runway centerline and the *runway threshold* through which the *downward extended straight line* portion of the ILS glidepath passes.

ILS-Zone 1. The distance from the coverage limit of the localizer/glidepath to Point "A" (four miles from the *runway threshold*).

ILS-Zone 2. The distance from Point "A" to Point "B".

ILS-Zone 3. CAT I-The distance from Point "B" to Point "C" for evaluations of Category I ILS. *CAT II and III.*-The distance from Point "B" to the *runway threshold* for evaluations of Category II and III facilities.

ILS-Zone 4. The distance from runway threshold to Point "D".

ILS-Zone 5. The distance from Point "D" to Point "E".

Initial Point (IP). A point at which the SAFI system starts gathering facility performance data.

In-Phase. Applied to the condition that exists when two signals of the same frequency pass through their maximum and minimum values of like polarity at the same time.

Interrogator. The ground-based surveillance radar transmitter-receiver which normally scans in synchronism with a primary radar, transmitting discrete radio signals which repetitiously request all transponders, on the mode being used, to reply. The replies are displayed on the radar scope. Also applied to the airborne element of the TACAN/DME system. (AIM)

Localizer type Directional Aid (LDA). A facility of comparable utility and accuracy to a LOC, but which is not part of a full ILS and may not be aligned with the runway. (FAA Order 8260.3 latest revision)

Localizer (LOC). The component of an ILS which provides lateral guidance with respect to the runway centerline. (FAA Order 8260.3 latest revision)

Localizer Zones. See *ILS-Zones* or *ILS-Localizer Back Course Zones.*

Lock-On. The condition during which usable signals are being received by the airborne equipment and presentation of steady azimuth and/or distance information starts.

Lowest Coverage Altitude (LCA). See *ILS-Lowest Coverage Altitude (LCA).*

Maximum Authorized Altitude (MAA). A published altitude representing the maximum usable altitude or flight level for an airspace structure or route segment. It is the highest altitude on a Federal airway, Jet route, area navigation low or high route, or other direct route for which an MEA is designated in FAR Part 95, at which adequate reception of navigation and signals is assured.

Microampere(s). (Microamps)—One millionth of an ampere (amp). In practice, seen on a pilot's omnibearing selector (OBS), oscillograph recordings and/or flight inspection meters, as a deviation of the aircraft's position in relation to a localizer on-course (zero DDM) signal or glidepath on-path (zero (DDM) signal), e.g., "5 microamperes (μA) right" (localizer); "75μA low" (glidepath). See Crosspointer and Symbols in this section.

Microwave Landing System (MLS). An instrument landing system operating in the microwave spectrum (5.0–5.25 GHz or 15.4–15.7 GHz frequency bands).

Milliampere (mA). One one-thousandth of an ampere.

Minimum Crossing Altitude (MCA). The lowest altitude at certain fixes at which a aircraft must cross when proceeding in the direction of a higher minimum en route IFR altitude (MEA). (AIM) (See Minimum En Route IFR Altitude)

Minimum Decent Altitude (MDA). The lowest altitude, expressed in feet above mean sea level, to which descent is authorized on final approach or during circle-to-land maneuvering in execution of a standard instrument approach procedure where no electronic glidepath is provided. (AIM)

Minimum En Route IFR Altitude (MEA). The lowest published altitude between radio fixes which assures acceptable navigational signal coverage and meets obstacle clearance requirements between those fixes. The MEA prescribed for a Federal airway or segment thereof, area navigational low or high route, or other direct route applies to the entire width of the airway, segment, or route between the radio fixes defining the airway, segment or route. (AIM) (FAR Parts 91 and 95).

Minimum Holding Altitude (MHA). The lowest altitude prescribed for a holding pattern which assures navigational signal coverage, communications, and meets obstacle clearance requirements. (AIM)

Minimum Obstruction Clearance Altitude (MOCA). The lowest published altitude in effect between radio fixes on VOR airways, off-airway routes, or route segments which meets obstacle clearance requirements for the entire route segment and which assures acceptable navigation signal coverage only within 25 nautical miles of a VOR. (AIM) (Refer to FAR Parts 91 and 95.)

Minimum Radar Range. The shortest distance from the radar at which the aircraft can be clearly identified on each scan of the radar antenna system.

Minimum Reception Altitude (MRA). The lowest altitude at which an intersection can be determined. (AIM) (Refer to FAR Part 95)

Minimum Vectoring Altitude (MVA). The lowest MSL altitude at which an IFR aircraft will be vectored by a radar controller, except as otherwise authorized for radar approaches, departures, and missed approaches. The altitude meets IFR obstacle clearance criteria. It may be lower than the published MEA along an airway or J-route segment. It may be utilized for radar vectoring only upon the controllers' determination that an adequate radar return is being received from the aircraft being controlled. Charts depicting minimum vectoring altitudes are normally available only to the controllers and not to pilots. (AIM)

Missed Approach Point (MAP). A point prescribed in each instrument approach procedure at which a missed approach procedure shall be executed if the required visual reference does not exist. (AIM: See Missed Approach and Segments of an Instrument Approach Procedure.)

Mode. The letter or number assigned to a specific pulse spacing of radio signals transmitted or received by ground interrogator or airborne transponder components of the Air Traffic Control Radar Beacon System (ATCRBS). Mode A (military Mode 3) and Mode C (altitude reporting) are used in air traffic control. (See Transponder, Interrogator, Radar.) (AIM)

> ICAO—Mode (SSR) Mode. The letter or number assigned to a specific pulse spacing of the interrogation signals transmitted by an interrogator. There are four modes: A, B, C, and D—corresponding to four different interrogation pulse spacings.

Moving Target Indicator (MTI). Electronic circuitry that permits the radar display presentation of only targets which are in motion. A partial remedy for ground clutter.

Narrowband Radar Display. Computer generated display of radar signals.

National Flight Data Center (NFDC). A facility in Washington, D.C., established by FAA to operate a central aeronautical information service for the collection, validation, and dissemination of aeronautical data in support of the activities of government, industry, and the aviation community. The information is published in the National Flight Data Digest. (AIM: See National Flight Data Digest.)

NAVAID. Any facility used in, available for use in, or designated for use in aid of air navigation, including landing areas, lights, any apparatus or equipment for disseminating weather information, for signaling, for radio direction finding, or for radio or other electronic communication, and any other structure or mechanism having a similar purpose for guiding or controlling flight in the air or the landing or takeoff of aircraft. (Re: Federal Aviation Act of 1958, as amended.) (AIM)

Nondirectional Beacon/Radio Beacon (NDB). An L/MF or UHF radio beacon transmitting nondirectional signals whereby the pilot of an aircraft equipped with direction finding equipment can determine his bearing to or from the radio beacon and "home" on or track to or from the station. When the radio beacon is installed in conjunction with the Instrument Landing System marker, it is normally called Compass Locator. (AIM)

Nonprecision Approach Procedure/Nonprecision Approach. A standard instrument approach procedure in which no electronic glide slope is provided; e.g., VOR, TACAN, NDB, LOC, ASR, LDA, or SDF approaches. (AIM)

Notices to Airmen/Publication. A publication designed primarily as a pilot's operational manual containing current NOTAM information (see Notices to Airmen—NOTAM) considered essential to the safety of flight as well as supplemental data to other aeronautical publications. (AIM)

Notices to Airmen/NOTAM. A notice containing information (not known sufficiently in advance to publicize by other means) concerning the establishment, condition, or change in any component (facility, service, or procedure of, or hazard in the National Airspace System) the timely knowledge of which is esential to personnel concerned with flight operations. (AIM)

(1) NOTAM(D)—A NOTAM given (in addition to local dissemination) distant dissemination via teletype writer beyond the area of responsibility of the Flight Service Station. These NOTAMS will be stored and repeated hourly until canceled.

(2) NOTAM(L)— A NOTAM given local dissemination by voice (teletypewriter where applicable), and a wide variety of means such as: TelAutograph, teleprinter, facsimile reproduction, hot line, telecopier, telegraph, and telephone to satisfy local user requirements.

(3) FDC NOTAM—A notice to airmen, regulatory in nature, transmitted by NFDC and given all-circuit dissemination.

ICAO-NOTAM. A notice, containing information concerning the establishment, condition, or change in any aeronautical facility, service, procedure, or hazard, the timely knowledge of which is essential to personnel concerned with flight operations. (AIM)

Null. That area of an electromagnetic pattern where the signal has been intentionally cancelled or unintentionally reduced to an unacceptable level.

Obstacle. An existing object, object of natural growth, or terrain at a fixed geographical location, or which may be expected at a fixed location within a prescribed area, with reference to which vertical clearance is or must be provided during flight operation. (AIM)

Obstacle Clearance. The vertical distance between the lowest authorized flight altitude and a prescribed surface within a specified area. (FAA Order 8260.19 latest revision)

Obstruction. An object which penetrates an imaginary surface described in FAR Part 77. (AIM) (Refer to FAR Part 77.)

Omnibearing Selector (OBS). An instrument capable of being set to any desired bearing of an omnirange station and which controls a course deviation indicator.

On-Course. The locus of points in the horizontal plane in which a zero or on-course reading is received.

On-Path. Same as on-course but in the vertical plane. See ILS-Glidepath.

Operational Advantage. An improvement which benefits the users of an instrument procedure. Achievement of lower minimums or authorization for a straight-in approach with no derogation of safety are examples of an operational advantage. Many of the options in TERP's are specified for this purpose. For instance, the flexible final approach course alignment criteria may permit the ALS to be used for reduced visibility credit by selection of the proper optional course. (FAA Order 8260.3 latest revision)

Orbit Flight. Flight around a station at predetermined altitude(s) and constant radius.

Oscilloscope. An instrument for showing visually, graphic representations of the waveforms encountered in electrical circuits.

Out of Tolerance Condition. See Discrepancy.

Planned View Display (PVD). A display presenting computer generated information such as alphanumerics or video mapping.

Polarization Error. The error arising from the transmission or reception of a radiation having a polarization other than that intended for the system.

Primary Area. The area within a segment in which full obstacle clearance is applied. (FAA Order 8260.3 latest revision)

Quadradar. Ground radar equipment named for its four presentations.

(1) Height Finding
(2) Airport Surface Detection
(3) Surveillance
(4) Precision Approach.

Radar Bright Display Equipment (RBDE). Equipment at the ARTCC which converts radar video to a bright raster scan (TV type) display.

Radar/Radio Detecting and Ranging. A device which, by measuring the time interval between transmission and reception of radio pulses and correlating the angular orientation of the radiated antenna beam or beams in azimuth and/or elevation, provides information on range, azimuth and/or elevation of objects in the path of the transmitted pulses.

(1) *Primary Radar.* A radar system in which a minute portion of a radio pulse transmitted from a site is reflected by an object and then received back at that site for processing and display at an air traffic control facility.

(2) *Secondary Radar/Radar Beacon/ATCRBS.* A radar system in which the object to be detected is fitted with cooperative equipment in the form of a radio receiver/transmitter (transponder). Radar pulses transmitted from the searching transmitter/ receiver (interrogator) side are received in the cooperative equipment and used to trigger a distinctive transmission from the transponder. This reply transmission, rather than a reflected signal, is then received back at the transmitter/receiver site for processing and display at an air traffic control facility. (See Transponder, Interrogator.) (AIM)

ICAO-Radar. A radio detection device which provides information on range, azimuth and/or elevation or objects.

1. *Primary Radar.* A radar system which uses reflected radio systems.

2. *Secondary Radar.* A radar system wherein a radio signal transmitted from a radar station initiates the transmission of a radio signal from another station.

Radar Resolution-Azimuth. The angle in degrees by which two targets at the same range must be separated in azimuth in order to be distinguished on a radar scope as individual returns.

Radar Resolution-Range. The distance by which two targets at the same azimuth must be separated in range in order to be distinguished on a radar scope as individual returns.

Radar Route. A flight path or route over which an aircraft is vectored. Navigational guidance and altitude assignments are provided by ATC. (See Flight Path, Route.) (AIM)

Radial. A magnetic bearing extending from a VOR/VORTAC/TACAN navigation facility. (AIM)

Range, Azimuth, Radar, Reinforced Evaluator (RARRE). An IBM 9020 radar diagonistic program which is used to evaluate narrowband radar.

Receiver Check Point. A specific point designated and published, over which a pilot may check the accuracy of his aircraft equipment, using signals from a specified station.

Recorder Event Mark. A galvo mark on a recorder related to a position or time, required for correlation of data in performance analysis.

Reference Radial. A radial, essentially free from terrain and side effects, designated as a reference for measuring certain parameters of facility performance.

Reference Voltage (VOR Reference voltage). A 30 Hz voltage derived in the reference phase channel of the aircraft VOR receiver.

RHO/THETA Position. Coordinate position described by distance and angle.

Ring-Around. A display produced on the scope by front, side, or back antenna lobes of the secondary radar system. It appears as a ring around the radar location and may occur when an aircraft transponder replies to ground interrogations while in close proximity to the antenna site.

Rotation (Correct Rotation). A condition wherein the transmitted azimuth angle increases in a clockwise direction.

Roughness. Rapid irregular excursions of the electromagnetic course or path.

Runway Environment. The runway threshold or approved lighting aids or other markings identifiable with the runway. (FAA Order 8260.3)

Runway Threshold. The beginning of that portion of the runway usable for landing. (AIM) (When used for flight inspection purposes, displaced threshold(s) or threshold mean the same thing.)

Scalloping. See Course Scalloping. (FAA Order 1000.15 latest revision).

Search (DME/TACAN). Rapid movement of the distance or bearing indicators during the period in which either is unlocked. (FAA Order 1000.15 latest revision)

Secondary Area. The area within a segment in which Required Obstruction Clearance (ROC) is reduced as distance from the prescribed course is increased. (FAA Order 8260.3 latest revision)

Segment. The basic functional division of an instrument approach procedure. The segment is oriented with respect to the course to be flown. Specific values for determining course alignment, obstacle clearance areas, descent gradients, and obstacle clearance requirements are associated with each segment according to its functional purpose. (FAA Order 8240.3 latest revision)

Semi-Automatic Flight Inspection (SAFI). Evaluation of NAVAIDs by periodic check flights of aircraft specially equipped for the purpose.

Sensing (Correct Sensing). A condition wherein the ambiguity indicator gives the correct To/From indication.

Service Volume/SV. That volume of airspace surrounding a NAVAID within which a signal of usable strength exists and where that signal is not operationally limited by co-channel interference.

Note: For VOR/TACAN/DME and ILS, the following definitions are used:

Standard Service Volume (SSV)—That volume of airspace defined by the national standard.

Expanded Service Volume (ESV)—An approved service volume outside of the standard service volume.

Operational Service Volume (OSV)—The airspace available for operational use. It includes the following:

- The SSV excluding any portion of the SSV which has been restricted.
- The ESV.

Short-Term Excursions. Excursion characteristics of a navigation on-course or on-path signal which includes scalloping, roughness, and other aberrations but excludes bends.

Side Bands. The separated and distinct signals that are radiated whenever a carrier frequency is modulated. In terms of most air navigation facilities, double sidebands are present. This means that frequencies above and below the carrier frequency differing by the amount of the modulating frequencies are present. These sidebands contain intelligence for actuating navigation instruments.

Simplified Directional Facility/SDF. A NAVAID used for nonprecision instrument approaches. The final approach course is similar to that of an ILS localizer.

Slant Range. The line-of-sight distance between two points not at the same elevation.

Standard VOT. A facility intended for use on the ground only (See VHF Omnidirectional test range).

Structure. Excursion characteristics of a navigation on-course or on-path signal which includes bends, scalloping, roughness and other aberrations.

Structure Below Path. An angular measurement of clearance below path.

Subclutter Visibility. A performance characteristic of the system to detect a moving target in the presence of relatively strong ground clutter.

Symbols.

G 10^{9} times (a unit); giga
M 10^{6} times (a unit); mega
k 10^{3} times (a unit); kilo
h 10^{2} times (a unit); hecto
dk 10 times (a unit); deca
d 10^{-1} times (a unit); deci
c 10^{-2} times (a unit); centi
m 10^{-3} times (a unit); milli
μ 10^{-6} times (a unit); micro
n 10^{-9} times (a unit); nano
$\mu\mu$ 10^{-12} times (a unit); micromicro

Symmetry. (ILS)—ICAO: Displacement sensitivity. A ratio between individual width sectors (90Hz and 150Hz) expressed in percent.

TACAN Distance Indicator (TDI). A unit of airborne equipment used to indicate distance from a selected facility.

Target of Opportunity. An itinerant aircraft operating within the coverage area of the radar and which meets the requirements for a small aircraft as described in FAA Order 8200.1 (latest revision) Section 215.

Target Return. The return signal transmitted by a beacon-equipped aircraft in reply to the ground facility interrogator. Also, indication shown on a radar display resulting from a primary radar return.

Terminating Point (TP). A point at which the preprogrammed part of a SAFI flight is completed.

Threshold. See *Runway Threshold.*

Touchdown Zone (TDZ). The first 3,000 feet of runway beginning at the threshold. (FAA Order 8260.3 latest revision)

Touchdown Zone Elevation. The highest runway centerline elevation in the touchdown zone.

Tracking. Condition of continuous distance or course information.

Track Deviation Report. A SAFI report that depicts actual aircraft position with reference to programmed track, progress on track, altitude and heading.

Transponder. The airborne radar beacon receiver/transmitter portion of the Air Traffic Control Radar Beacon System (ATCRBS) which automatically receives radio signals from interrogators on the ground, and selectively replies with a specific reply pulse or pulse group only to those interrogations being received on the mode to which it is set to respond. (See Interrogator.) (AIM)

Trend. The general direction or incline of a segment of the glidepath which persists for a distance of 1,500 feet or more along the approach course.

Un-Lock. Condition at which the airborne interrogator (TACAN) discontinues tracking and starts search.

Usable Distance. The maximum distance at a specified altitude at which the facility provides readable identification and reliable bearing or glidepath information under average atmospheric condition.

Variable Voltage (VOR Variable Voltage). A 30 Hz voltage derived in the variable phase channel of the aircraft VOR receiver.

Vertical Angle. An angle measured upward from a horizontal plane.

VHF Omnidirectional test range (VOT). A radio transmitter facility in the terminal area electronic navigation systems, radiating a VHF radio wave modulated by two signals having the same phase relationship at all azimuths. It enables a user to determine the operational status of a VOR receiver. (See *Standard VOT* and *Area VOT.*)

Video Map. An electronic displayed map on the radar display that may depict data such as airports, heliports, runway centerline extensions, hospital emergency landing areas, NAVAIDS and fixes, reporting points, airway/route centerlines, boundaries, handoff points, special use tracks, obstructors, prominent geographic features, map alignment indicators, range accuracy marks, and minimum vectoring altitudes. (AIM)

Visual Descent Point (VDP). The visual descent point is a defined point on the final approach procedure from which normal descent from the MDA to the runway touchdown point may be commenced, provided visual reference is established. (AIM)

VORTAC. A facility composed of azimuthal information from both VOR and TACAN, plus distance information of TACAN.

VOT—Standard. See *Standard VOT.*

VOT—Area Use. See *Area VOT.*

VOT Reference Point. A point on or above an airport at which the signal strength of a VOT is established and subsequently checked (applies to both standard and area VOT's).

Waveform. The shape of the wave obtained when instantaneous values of an a.c. quantity are plotted against time in rectangular coordinates.

Waveguide. A hollow pipe, usually of rectangular cross section, used to transmit or conduct RF energy.

Wavelength. The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. Equal to the velocity divided by the frequency.

9960 Hz Voltage. A voltage derived from the VOR 9960 amplitude modulation by the reference channel of the VOR receiver. The 9960 Hz AM is a subcarrier which is frequency modulated by the 30 Hz reference. Also referred to as the 10 kHz subcarrier.

301.2 Abbreviations, Acronyms, and Letter Symbols

NOTE: The following abbreviations and acronyms are used (or will be used in the future) throughout this manual. The sources for these abbreviations and acronyms are as follows:

(1) FAA Order 1000.15 (Latest Revision)

(2) Dictionary of Electronic Abbreviations Signs and Symbols (Odyssey Press)

(3) U.S. Government Printing Office Style Manual

(4) FAA Order 8260.3 (Latest Revision)

A : Ampere (2)
a.c. : alternating current (3)
AC : advisory circular (1)
ADF : automatic direction finding (1)
ADP : automatic data processing (3)
AFB : Air Force base (2)
AFC : automatic frequency control (1)
AFIS : automated flight inspection system
AGC : automatic gain control (1)
AGL : above ground level
AIM : Airmen's Information Manual (1)
ALS : approach lighting system (1)
ALSF : approach lighting system with sequenced flashing lights (4)
am. : ammeter
AM : amplitude modulation (2)
amp : Ampere
ANF : air navigation facility (2)
APPCON : approach control
ARAC : Army radar approach control
ARG : auxiliary reference group
ARR : automated flight inspection system reference radial
ARSR : air route surveillance radar (1)
ARTCC : air route traffic control center (1)
ARTS : automated radar terminal system (1)
ASR : airport surveillance radar (1)
ATC : air traffic control (1)
ATCRBS : Air Traffic Control Radar Beacon System (1)
ATIS : Automatic Terminal Information Service (1)
AVN : Aviation Standards National Field Office
az : azimuth (2)
Az-El : azimuth-elevation (2)
BCM : back course marker
bcn : beacon
BFTA : beacon false target analysis
BRITE : brite radar indicator tower equipment
BUEC : backup emergency communications (1)
c : centi ($=10^{-2}$)
C : Celsius (2)
°C : degrees Celsius (2)
cal : calibrate, calibrated (2)
CAS : calibrated airspeed (1)
CAT : category
CCW : counterclockwise (2)
CD : common digitizer (1)
CDI : course deviation indicator
CDU : control display unit
chan : channel
CIC : combat information center (2)
CL : centerline (2)
COMDIG : common digitizer data reduction
COMLO : compass locator
CONUS : continental United States
CP : circular polarization (1)
CW : clockwise
d : deci ($=10^{-1}$) (2)
DAME : distance azimuth measuring equipment
dB : decibel (2)
dbm : decibel referred to 1 milliwatt (2)
dbw : decibel referred to 1 watt (2)
d.c. : direct current (3)
DDM : difference in depth of modulation (1)
DF : direction finding (1)
DH : decision height (1)
disc : discrepancy (2)
DME : distance measuring equipment (1)
DOD : Department of Defense (3)
DOT : Department of Transportation (3)
DVOR : doppler very high frequency omnidirectional range
E. : East
ECM : electronic counter measures (1)
e.g. : exempli gratia (for example) (3)
el : elevation (2)
ESV : expanded service volume

et al. : et alibi (and elsewhere); et alii (and others) (3)
etc. : etcetera (and the rest; and so forth) (3)

F : Fahrenheit (2)
°F : degrees Fahrenheit (2)
FAA : Federal Aviation Administration (1)
FAC : final approach course
FAF : final approach fix
FAP : final approach point
FAR : Federal Aviation Regulations (1)
FIFO : flight inspection field office
fig. : figure (3)
FSNFO : Flight Standards National Field Office (has been changed to AVN)
FM : fan marker (1)
FM : frequency modulation (2)
FSS : flight service station (1)
FTC : fast time constant (1)

G : giga (= 10^9) (2)
galv : galvanometers (2)
GCA : ground controlled approach (1)
GHz : gigahertz (1)
govt. : government (2)
GPI : ground point of intercept
GS : glide slope (1)
GSI : glide slope intercept altitude (point)

h : hecto (= 10^2); hour
H : *homer (1)*
HAA : height above airport elevation (4)
HAT : height above touchdown (1)
HF : high frequency (1)
HF/DF : high frequency/direction finding (2)
HIRLS : *high intensity runway lighting system*
Hz : Hertz (1)

IAC : initial approach course (4)
IAF : initial approach fix (4)
IAS : *indicated airspeed (1)*
IC : intermediate course (4)
ICAO : International Civil Aviation Organization (1)
ID : identification (2)
i.e. : id est (that is) (3)
IF : intermediate fix (4)
IFR : Instrument Flight Rules (1)
ILS : instrument landing system (1)
IM : inner marker (1)
INS : inertial navigation system
IO : input-output (2)
ips : inches per second (2)
ISLS : improved side lobe suppression (1)
ISMLS : interim standard microwave landing system

k : kilo (= 10^3) (2)
kHz : kilohertz (1)
KIAS : knots indicated airspeed
kn : knots (3)
kW : kilowatt (2)

lat. : latitude (3)
LCA : lowest coverage altitude
LDA : localizer directional aid (1)
LDIN : *lead-in lights (1)*
LF : low frequency (1)
LMM : compass locator at middle marker (1)
LOC : localizer (1)
LOM : compass locator at outer marker
long. : *longitude*
LORAN : long-range navigation (2)
LOS : line of site
LP : linear polarization (1)
LRCO : limited remore communications outlet (1)

m : meter or milli (= 10^{-3}) (2)
M : mega (= 10^6) (2)
mA : milliampere (1)
MAA : maximum authorized altitude
MALS : medium intensity approach lights—5000cp (1)
MALSF : medium intensity approach lights; sequenced flashing lights
MALSR : same as MALSF; runway alignment indicator lights
MAP : missed approach point (1)
MB : marker beacon
MCA : minimum crossing altitude (1)
MDA : minimum descent altitude (1)
MEA : minimum en route altitude (1)
MF : medium frequency (1)
MHA : minimum holding altitude (1)
MHz : megahertz (1)
MIRL : medium intensity runway lights
MLS : microwave landing system (1)
MM : middle marker (1)
MOCA : minimum obstruction clearance altitude
MRA : minimum reception altitude (1)

MRG : main reference group
MSL : mean sea level (1)
MTI : moving target indicator(1)
MSAW : minimum safe altitude warning
MUA : maximum usable altitude (1)
mV : millivolt (2)
MVA : *minimum vectoring* altitude (1)
MVAR : magnetic variation

n : nano ($= 10^{-9}$) (2)
N. : North (2)
NA : not applicable (2) or not authorized (when applied to instrument approach procedures)
NAS : National Airspace System (1)
NAVAID : air navigation facility (1)
NDB : nondirectional beacons (2)
NFDC : National Flight Data Center (1)
nm : nautical mile (3)
NOTAM : Notice to Airmen (1)

OBS : omnibearing selector (1)
ODALS : omnidirectional approach lighting system (1)
OM : outer marker
orb. : orbit (2)

PAPI : precision approach path indicator
PAR : precision approach radar (1)
PPI : plan position indicator
PRF : pulse-repetition frequency (2)
PT : procedure turn (1)
PVD : plan view display

QARS : quick analysis of radar site

RADAR *or*
radar : radio range and detecting (2)
RAIL : runway alignment indicator light (1)
RAPCON : radar approach control (1) (USAF)
RARRE : range, azimuth radar reinforced evaluator
RATCC : radar approach control center (USN) (2)
RBDE : radar bright display equipment (1)
RCAG : remore, center air/ground communication facility (1)
RCO : remote communication outlet (1)
RDH : runway datum height
REIL : runway end identifier light (1)
RF : radio frequency (2)
RFI : radio frequency interference (2)
RMI : radio magnetic indicator (1)
RML : radar microwave link (1)
RNAV : area navigation
ROC : required obstruction clearance
RPI : runway point of intercept (4)
RPM : revolutions per minute (2)
RRP : runway reference point (1)
R/T : receiver-transmitter
RVR : runway visual range (1)
RVV : runway visual value

s : second (2)
S. : South (3)
SAFI : semiautomatic flight inspection system (1)
SALS : short approach light system (1)
SAVASI : simplified abbreviated visual approach slope indicator system
SDF : simplified directional facility (1)
sec : second (2)
SECRA : secondary radar (1)
SIAP : standard instrument approach procedure
SID : standard instrument departure (1)
SLS : side lobe suppression (1)
SSALF : simplified short approach light system; sequenced flashing lights
SSALR : same as SSALF; runway alignment indicator lights
STAR : standard terminal arrival rôute (1)
STC : sensitivity time control (1)
STOL : short takeoff and landing (1)

TACAN : tactical air navigation (1)
TAR : test analysis report
TCH : threshold crossing height (1)
TDI : TACAN distance indicator (1)
TDZ : touchdown zone (4)
TDZL : touchdown zone lights
TERPS : terminal instrument procedures (4)
TH : threshold
TRACON : terminal radar approach control (1) (FAA)
TRACALS : traffic control and landing systems
T-VASI : T (configuration)—visual approach slope indicator
TVOR : terminal VOR (1)
TWEB : transcribed weather broadcast equipment (1)

μ : micro (2)
UDF : ultra high frequency direction finder (1)

UHF : ultra high frequency (1)
USA : United States Army (3)
USAF : United States Air Force (3)
USN : United States Navy (3)
USSFIM : United States Standard Flight Inspection Manual

v : volt (2)
var. : variation (2)
VASI : visual approach slope indicator (1)
VDF : very high frequency direction finder (1)
VDP : visual descent point (4)
VFR : visual flight rules (1)
VHF : very high frequency (1)
VLF : very low frequency (1)
VOR : very high frequency omnidirectional range (1)
VORDME : very high frequency omnidirectional range, distance measuring equipment
VOT : very high frequency omnidirectional range test (1)
V/STOL : vertical/short takeoff and landing (1)
VORTAC : very high frequency omnidirectional range, tactical air navigation

W : watt (2)
W. : West (3)

xmtr : transmitter (2)

Z : zulu time (Greenwich mean time) (1)

APPENDIX B

Derivation of
NBS Modulation Factor Standard
DDM Measurement Uncertainties.

The NBS Modulation Factor Standard is described in detail in reference 2. This instrument is incapable of measuring DDM directly, however, DDM can be determined indirectly since, by Eq(28), DDM is the difference between the 90Hz and 150Hz AM factors. The uncertainty of measurements derived in this manner is dependent upon the uncertainty associated with each of the AM factors.

Measurement errors can be composed of both systematic errors and random errors. Systematic errors are those errors that can be predicted on an individual measurement basis. The cause of a systematic error may be known but may not have been eliminated for reasons such as expediency (Ref 14:55). Random errors are those which cannot be predicted on an individual basis. For random errors, statistical analysis is needed to gain insight into the manner in which the errors are distributed.

In arriving at the DMM measurement uncertainty of the NBS Modulation Factor Standard, the random errors and systematic errors (which were obtained from reference C) were combined on a route-sum-square (RSS) basis using:

$$U_{DDM} = \pm [U_{90R}^2 + U_{150R}^2 + (U_{90S} - U_{150S})^2]^{\frac{1}{2}}$$

where: U_{DDM} = DDM Measurement Uncertainty.

U_{90R} = 90Hz Modulation Factor Random Error.

U_{150R} = 150Hz Modulation Factor Random Error.

U_{90S} = 90Hz Modulation Factor Systematic Error.

U_{150S} = 150Hz Modulation Factor Systematic Error.

Note that in combining the errors, the random errors are combined with the difference in the systematic errors (using the RSS method). This is permitted, as discussed by Sorger (Ref 11:3.4-2), since the effects due to systematic errors tend to be reduced when subtracting one modulation factor from the other. Table B-1 shows the results of calculating the DDM uncertainty for the NBS Modulation Factor Standard at selected DDM values.

Using the values calculated for the DDM uncertainty of the NBS Modulation Factor Standard, it is now possible to estimate the DDM uncertainties throughout the modulation factor calibration chain. If a 2:1 accuracy margin is required between each instrument in the chain, the values of Fig. B-1 are achieved.

Table B-1

NBS Modulation Factor Standard
DDM Measurement Uncertainty

Localizer DDM	Modulation Factor M90	Modulation Factor M150	Random Error M90	Random Error M150	Systematic Error M90	Systematic Error M150	DDM Uncertainty
0.000	0.2000	0.2000	0.00011	0.00011	0.00031	0.00031	0.00016
*0.046	0.2230	0.1770	0.00011	0.00011	0.00033	0.00030	0.00016
*0.093	0.2465	0.1535	0.00011	0.00011	0.00035	0.00028	0.00017
*0.155	0.2775	0.1225	0.00012	0.00010	0.00037	0.00026	0.00019
0.200	0.3000	0.1000	0.00012	0.00010	0.00039	0.00025	0.00021
Glide Slope DDM							
0.000	0.4000	0.4000	0.00025	0.00025	0.00048	0.00048	0.00035
*0.045	0.4225	0.3775	0.00025	0.00025	0.00050	0.00046	0.00036
*0.091	0.4455	0.3545	0.00025	0.00024	0.00052	0.00044	0.00036
*0.175	0.4875	0.3125	0.00026	0.00022	0.00056	0.00040	0.00038
0.400	0.6000	0.2000	0.00029	0.00018	0.00067	0.00031	0.00050

* indicates that values shown for random and systematic errors were obtained by interpolating between values given in reference C.

	Limits of Uncertainty (±)		
Localizer DDM	NBS Standard	AFPL 5401	PMEL 5401
0.000	0.00016	0.00032	0.00064
0.046	0.00016	0.00032	0.00064
0.093	0.00017	0.00034	0.00068
0.155	0.00019	0.00038	0.00076
0.200	0.00021	0.00042	0.00084
Glide Slope DDM			
0.000	0.00035	0.00070	0.00140
0.045	0.00036	0.00072	0.00144
0.091	0.00036	0.00072	0.00144
0.175	0.00038	0.00076	0.00152
0.400	0.00050	0.00100	0.00200

Fig. B-1. ILS DDM Hierarchy & Accuracies Derived from NBS Modulation Factor Standard.

VITA

Dennis Michael McCollum was born 14 December 1945. He graduated from Cleveland High School, Portland Oregon in 1963 and entered the USAF. He attended college part-time at McMurry College, Abilene Texas; Ellsworth AFB branch of Black Hills State College, Ellsworth AFB, South Dakota; and South Dakota School of Mines & Technology (SDSM&T), Rapid City, South Dakota. In October 1974, he began full-time studies at SDSM&T under the Airman's Education and Commissioning Program, graduating in December 1976 with a Bachelor of Science degree in electrical engineering. He received his commission through the Air Force's Officer Training School in March 1977 and attended technical training at Keesler AFB, Mississippi. Following technical training, he was assigned to the Communication-Electronics Officer Course where he served as an instructor until Dec 1980. From Jan 1981 until entering the School of Engineering in Jun 1982, he was assigned to the 1954th Radar Evaluation Squadron, Hill AFB, Utah, where he served in the Evaluation Operations Brach as Chief of the Evaluation Technology Section. He is a member of Tau Beta Pi and Eta Kappa Nu.

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EVALUATION OF INSTRUMENT LANDING SYSTEM DDM CALIBRATION ACCURACIES.
Instrument landing system (ILS) accuracy is highly dependent upon the accuracy of the test instrumentation used in maintaining it. In an effort to upgrade calibration support to Air Force instrument landing systems, the Air Force Measurement Standards Laboratory requested an independent study be done on modulation factor and DDM accuracies. In this thesis report, ILS accuracy requirements are analyzed along with the accuracy specifications of test instrumentation. The report provides a short tutorial on ILS concepts in chapter II. In chapter III, modulation factor and DDM accuracy specifications have been compiled from various sources. The evaluation, in chapter IV, looks at the adequacy of ILS test instruments and the ILS modulation factor and DDM calibration hierarchies. Based on the decision criteria used, it shows that existing instrumentation cannot adequately support all categories of ILS. The significant results of the evaluation are summarized in chapter V along with the author's recommendations.

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