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FINAL REPORT

Project No. 330-001-05X

ANALYSIS OF VORTAC SYSTEM ERROR ACCURACY OF STANDARDS USED BY RADIO (AVIONICS) REPAIR STATIONS

JUNE 1969

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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for

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

June 1969

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DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
National Aviation Facilities Experimental Center
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ABSTRACT

This report covers a survey which was conducted at 103 radio (avionics) repair stations throughout the United States on various models of signal generators used for the calibration of VOR, Localizer, and glide slope airborne navigation receivers. The survey includes data from four different models of VOR signal generators, four different models of localizer signal generators, and four different models of glide slope signal generators.

A statistical analysis is presented which enables prediction of error distributions for radio navigation test equipment used in radio repair stations.

The 97 VOR signal generators tested were within the limits of 1.32° and -1.84° (95 percent probability) when results were based on a statistical analysis.

The 100 localizer signal generators tested were within the limits of 71.18 and 120.49 μA deflection with a standard deflection (90 μA) signal applied, and +6.65 and -6.55 μA on centering when results were based on a 95 percent probability statistical analysis.

The 71 glide slope signal generators tested were within 62.85 and 97.17 μA deflection with a standard deflection (78 μA) signal applied, and +4.85 and -5.43 μA on centering when results were based on a 95 percent probability statistical analysis.

The report contains a description of the survey, discussion of the results, and recommends possible action to improve present avionics test equipment calibration methods used in the radio repair stations.

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INTRODUCTION

Purpose

The purpose of this project was to determine the statistical accuracy of test equipment used by radio (avionics) repair stations throughout the United States to calibrate and maintain airborne VOR, localizer, and glide slope navigation receiving equipment.

Background

One of the results of the Navigation Equipment Capability Analysis Program (NECAP) indicated that increased maintenance and scheduled recalibration of airborne navigation equipment would improve the navigational capabilities of general aviation aircraft. The observed two standard deviation (95 percent probability) of the bearing errors on the equipment was 5.12°. This value was reduced to 1.76° by recalibration of the airborne equipment using accurately calibrated test equipment.[1]

These findings made it desirable to ascertain to what extent these errors might be caused by the test equipment utilized by certificated and non-certificated radio (avionics) repair stations. Accordingly, Flight Standards Service initiated a form 2864 on April 15, 1967, requesting the System Research and Development Service (SRDS) to determine the accuracy of test equipment used for VOR receiver calibration at a representative number of repair stations. SRDS then established a project to determine the accuracy of the test equipment used in the calibration of VOR navigation receivers.

A meeting on April 17, 1967, between the Avionics Branch, FS-350, and the Short Distance Navigation Branch, RD-330, discussed preliminary details regarding this project, and provided a basis for further coordination meetings.

The original request by FS-350 specifically indicated an interest in VOR test equipment and did not consider localizer and glide slope test equipment. It was later decided, due to the possible impact of general aviation on use of Category II ILS approaches, to include the localizer and glide slope calibration equipment in this project.

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[1] NECAP II, project FS 66-250-57, SRDS 330-001-01N

Radio Technical Commission of Aeronautics (RTCA) documents, the United States Standard Flight Inspection Manual, and test equipment manuals were used as a basis for project planning. The Flight Standards Service compiled a list of randomly selected radio repair stations and their locations, which they supplied to the project manager for the field survey.[2] The project manager's selection required concurrence by the general aviation office of each region. They were informed that personnel from the National Aviation Facilities Experimental Center (NAFEC) would be conducting the tests, and that all data obtained were to be used for planning purposes and not for violation action against the repair station. The project personnel were required to contact the responsible General Aviation District Office (GADO) prior to visiting a station.

Each facility tested was provided a copy of the test results. If any test equipment problems were found, a reasonable effort was made by the project personnel to find the cause and assist in any corrective measures.

To conduct the field tests, a portable test set using a stable VOR/ILS airborne receiver as a transfer standard was fabricated. The objective was to limit the size and weight of the equipment required by the project personnel in order to expedite the project.

The general requirements were to collect and interpret statistical information on the accuracy of the VOR/ILS test equipment used by the repair stations. Results obtained would be used to determine the need for developing improved operational procedures for test equipment.

In VOR/ILS errors we deal almost entirely in probability of events, which are figured in terms of standard deviations or sigma values from a mean position. A distribution can be described primarily by using the mean and standard deviation. The mean is the value about which most of the observed values tend to centralize. The standard deviation is a measure of the dispersion or spread of the distribution about the mean. It can be estimated from the relationship

$$s = \sqrt{\sum (x-\bar{x})^2 / (n-1)}$$

where x is an individual value, $\bar{x}$ is the mean of a sample, and n is the number of observations.

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[2] Advisory Circular AC 140-1B, "Consolidated Listing of FAA Certificated Repair Stations."

For a normal distribution which can be characterized by its mean and standard deviation, it can be shown that 95 percent of the population will be within ± 2 standard deviations of the mean.

The 2 sigma (2 standard) deviation that is used in this study means that the probable occurrence of an event (in a normally distributed population) falling outside of the 2 sigma deviation value is 5 out of 100, and odds against are 20 to 1.

The detailed method of derivation of the statistical analysis used in the test results is covered in various books on probability and statistics and will not be repeated in this report.

Equipment Description:

Portable Test Set - The portable test set shown in figures 1 and 2 is a compact unit that is capable of testing the various types of VOR/ILS signal generators and associated equipment used in radio repair stations. The test set consists of

1. a Universal Precision Track Selector (479V-3) for omnibearing selection in 30° steps,
2. a Resolver Zeroing Panel (479X-2),
3. a model 427A voltmeter,
4. a receiver control unit,
5. panel meters to read course deviation, to-from, flag current, and input voltages,
6. a test function switch, and an
7. externally connected 51RV-1 VOR/ILS receiver used as a transfer standard.

A brief description of the test set equipment follows.

The 51RV-1 VOR/ILS receiver equipment accepts VOR, localizer, and glide slope signals and provides outputs to operate deviation, flag, and to-from indicators. The 51RV-1 consists of a 51X-4 VOR/LOC receiver, a 51V-4B glide slope receiver, a 344A-2 manual VOR/LOC instrumentation unit, a T-frame for

FIG. 1 PORTABLE TEST SET (FRONT VIEW) & CALIBRATION EQUIPMENT

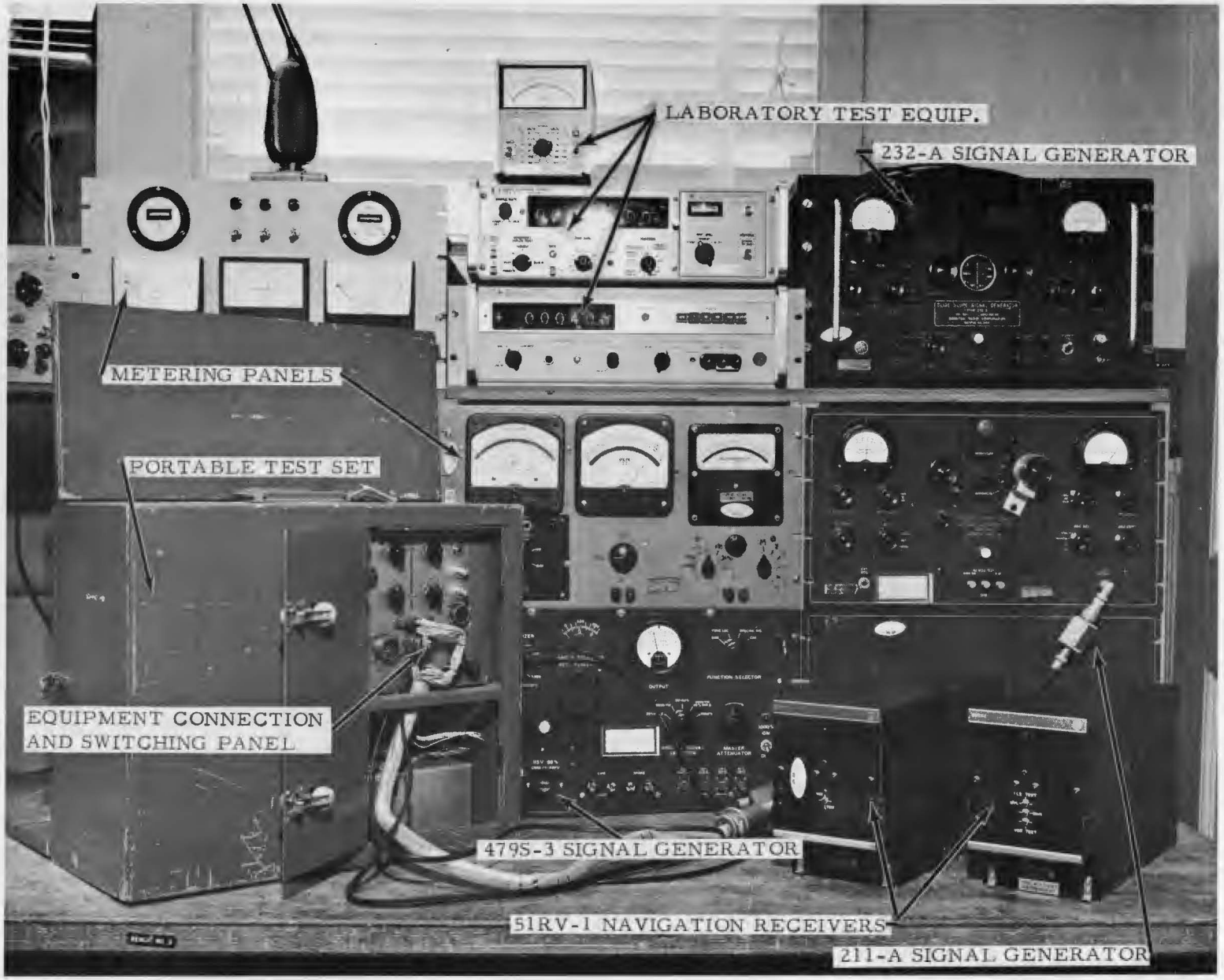

FIG. 2 PORTABLE TEST SET (READ VIEW) & CALIBRATION EQUIPMENT

support of these units, and a one-piece dust cover. Both receivers employ two out of five binary switching for frequency selection. Glide slope and localizer pairing is accomplished automatically with a common control unit. The 51X-4 receives the VOR/LOC RF carrier and detects the audio frequencies and sends them to the instrumentation unit. It is a completely solid-state, 200 channel, 50 kHz spacing, triple conversion receiver. The 51V-4B receives the glide slope RF carrier, detects and compares the 90 and 150 Hz modulation signals, and provides outputs to the glide slope deviation and flag alarm of the course indicator. It is a completely solid-state, 20 channel, 300 kHz spacing, dual conversion receiver. The 344A-2 compares the localizer 90 and 150 Hz modulation signals detected in the 51X-4 and provides a direct current output for the localizer deviation and flag alarm of the course indicator. In the FM circuitry of the 344A-2 the reference 30 Hz signal is demodulated from the 9960 Hz subcarrier. A comparator detects the phase difference of the reference and variable 30 Hz signals and provides dc outputs to the VOR deviation, flag alarm, and to-from of the course indicator. The 51RV-1 meets TSO-C36a, C40A, and C34a requirements.

The 51X-4 VOR/LOC receiver performance specifications are as follows:

1. sensitivity - 3 μV input for satisfactory navigation performance

2. selectivity - 40 kHz at 6 dB points and 68 kHz at 60 dB points with 3 dB or less ripple

3. spurious response - at least 70 dB down

4. AGC characteristics - 3 dB variation from 5 to 50,000 μV

5. navigation outputs - five deviation indicator loads four flag indicator loads, two to-from loads, and two Radio Magnetic Indicator (RMI) pointer loads

The 51V-4B glide slope performance specifications are as follows:

1. sensitivity - 20 μV input with a 2 dB audio ratio required to obtain 47 μA deflection

2. selectivity - 140 kHz minimum at 6 dB points, 450 kHz maximum at 60 dB points

3. spurious response - at least 60 dB down in the 0.09 to 1,500 MHz range

4. AGC characteristic - adjustable to vary audio rise from +5 percent to -15 percent when input is increased from 700 to 14,000 μV

5. navigation outputs - five deviation indicator loads and four flag indicator loads

The Universal Precision Track Selector 479V-3 is used in testing and adjusting navigation receivers and instrumentation units. It provides an accurate, stable, and quick method of obtaining omnibearing selector settings. Faulty equipment may cause an excessive direct current to flow through the resolver and seriously impair the accuracy of an omnibearing selector. The design of the 479V-3 is such that the runout error will not change under adverse conditions. The maximum runout error is $\pm 0.05^{\circ}$. It may be used with units using 30 Hz or 400 Hz resolver systems. The 479V-3 simulates a design center resolver as specified by the (RTCA) Committee SC-61. The 479V-3 is a combination of precisely tapped transformers and switching circuits to accurately simulate a standard resolver output. The desired setting is selected by a bearing degrees switch on the front panel that is calibrated in 30° increments. A selector switch on the front panel selects either 30 Hz or 400 Hz operation. In addition, the front panel contains a to-from indicator calibrated in microamperes. A locking-type potentiometer is located at the rear of the unit to index the 479V-3 in accordance with RTCA standards.

The 479X-2 Resolver Zeroing Panel provides a method whereby resolvers can be adjusted to give uniform results when the omnibearing selectors and omnibearing indicators using them are interchanged. The 479X-2 permits omniresolver zeroing procedures to be carried out, relying on conventional test equipment, such as voltmeters, oscilloscopes, and audio signal generators. The resolvers used in track selectors and bearing indicators associated

with the airborne VOR receiving equipment require a standard method of zeroing if instrument interchangeability is to be achieved. Standard conditions are obtained by the 479X-2 when the rotor is excited at 30 Hz, using a 2,000 ohm resistor in series with the rotor and generator. The induced voltage in the stator then leads the generator voltage. This phase relation has been standardized as 83°.

The dials of omnibearing selectors and omnibearing indicators should read 300° when the resolver zeroing occurs and a prescribed uniform phase shift through the resolver circuit is achieved. Since the resolver is a phase-shifting device, this uniform phase shift is achieved by displacing the resolver stator windings by a slight amount, provided the dial and resolver shaft are held in a fixed position and the resolver is excited in a manner which adequately simulates the excitation system used in the receiver.

The model 427A voltmeter is capable of making direct current measurements from ± 1 mV to $\pm 1,000$ V with an accuracy of ± 2 percent of full-scale and an input resistance of 10 MΩ. Alternating current measurements are from 10 Hz to 1 MHz and an input impedance of 10 MΩ.

Laboratory Test Equipment - The test equipment calibrated at the NAFEC Standards and Calibration Laboratory and used by project personnel to maintain and calibrate the portable test set is briefly described as follows.

The type 211-A signal generator is a precision signal source, designed specifically for use in the alignment of aircraft navigation receivers in the VHF range. The 211-A permits operation with low distortion and minimum phase shift between the modulating voltage and the modulated envelope of the carrier. It has self-contained monitoring circuits for RF level and modulating percentage, and a crystal calibrator circuit to use for frequency control check points. A regulated power supply contributes to its reliability as a stable signal source. The RF frequency accuracy is ± 0.1 percent of indicated frequency on the 211-A, the RF output accuracy is ± 0.5 dB of indicated output, and the crystal output is accurate to ± 0.0035 percent of the fixed frequency.

The type 479S-3 audio signal generator is designed to facilitate the test and calibration of omnirange navigation receivers for aircraft use. In conjunction with the 211-A signal generator it

provides a synthesis of signals encountered in reception and interpretation of omnirange and tone localizer facilities. The various components of these signals are also available separately or in combination for test purposes. All output voltages are generated mechanically and no amplification is required. The circuit provides for the selection of desired signals which will appear at the output jack either separately or in combination. Since the generators are rotated by 60 Hz, 115 V synchronous motors, the accuracy of any output signal is directly dependent upon the frequency stability of the external supply source. The 30 Hz reference and variable phases are accurate to $\pm 0.2^{\circ}$.

The type 232-A signal generator is a precision signal source designed primarily to test and calibrate glide slope receivers that are part of the aircraft instrument landing system. The generator accomplishes its function of test and calibration by reproducing the signal that exists along the glide slope, thus simulating operational conditions. It provides 20 crystal-controlled RF frequencies between 329.3 MHz and 335 MHz in 0.3 MHz increments. This RF signal is modulated with a dual signal of 90 and 150 Hz; therefore, an "above course " or "below course" signal may be simulated by varying the ratio of modulation of these tones, to each other, through a differential attenuator.

Field Test Equipment - A brief description of the equipment tested by project personnel at radio repair stations and not previously described follows (see figure 3).

The type H-14 signal generator provides simulated omni, phase localizer, and tone localizer signals for testing of VHF navigational equipment. The instrument will check 24 omni courses, omni course sensitivity, operation of to-from meter, operation of omni flag alarm, left-center-right on 90/150 Hz localizer including sensitivity, and flag alarm.

The H-14 generator provides signals of accurately known frequency, amplitude, and modulation for quantitative tests of VHF navigational receiving equipments. Two crystal-controlled frequencies are provided within the 108-132 MHz frequency band. One frequency is located in the omnirange band and the other in the localizer band. This makes possible testing of receiving equipment that automatically switches function with frequency. The radio frequency output terminates in a variable output of from 1 to 10,000 μV that is adjustable continuously by means of a calibrated

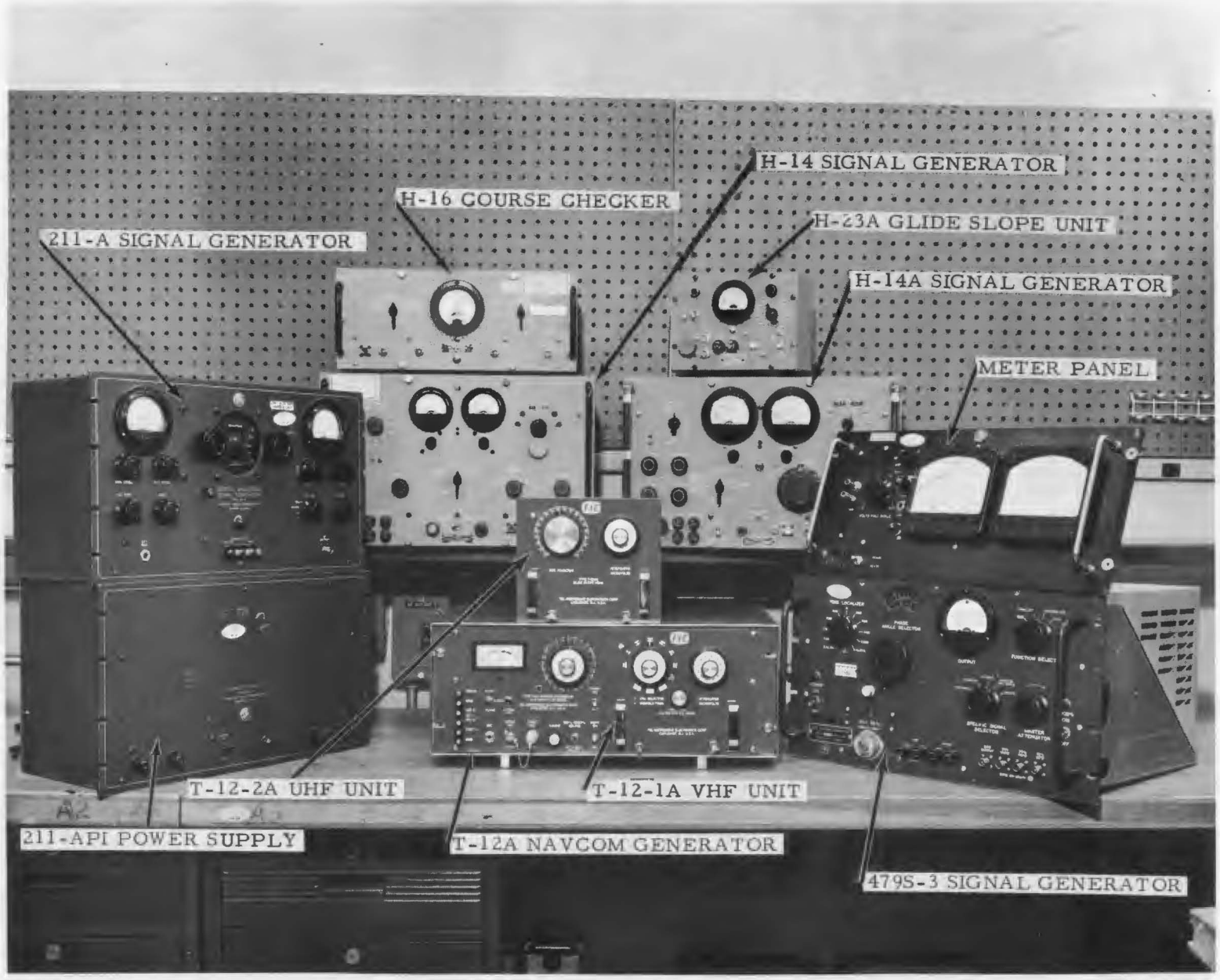

FIG. 3 NAVIGATION SIGNAL GENERATORS USED IN AVIONICS SHOPS

attenuator. Internally generated modulation is provided for omni, phase localizer, and amplitude localizer receiver testing. The modulation is generated by a dual tone wheel driven by a 1,800 r/min synchronous motor. A receptacle marked DEMOD is provided to permit use of the modulation voltages for bench test work. The DEMOD voltage is derived from the RF carrier, and the demodulating circuits are so designed that this voltage is the same in waveform and phase as the RF modulation when the load is essentially resistive. If the load is reactive, a phase shift will result, which must be taken into account when checking omni equipment. AMP/LOC modulation may be amplified and used to modulate a signal generator such as the H-23A for testing glide slope receivers. A modulation meter indicates 30 percent modulation of 9960 Hz, 30 percent modulation of 30 Hz, and 20 percent of 90 Hz superimposed on 20 percent of 150 Hz. The signal generator frequency accuracy is ± 0.005 percent, the omni track angle is $\pm 1/2^{\circ}$ at room temperature, the RF output is accurate to ± 2 dB, and the modulation accuracy is ± 2 percent. The generator must be used on a 60 Hz power supply due to the synchronous motor whose speed determines the frequency of the generated modulation voltages.

The type H-14A signal generator is basically similar to the H-14 generator, but with separate controls provided for 90 and 150 Hz modulation (ILS mode).

The type T-12A signal generator, including its associated T-12-1A VHF plug-in and T-12-2A UHF plug-in, is designed to test the VOR, localizer, and glide slope functions of aircraft receivers. The main chassis contains the power supplies, modulation signal generators, modulator, and metering circuits; the plug-in RF units provide the appropriate RF signals. The modulation signals are obtained from transistor switching circuits, in which transistors are either saturated or turned off, together with emitter follower coupling stages to insure a constant output amplitude. The 9960 Hz FM oscillator center frequency is accurate to ± 0.8 percent from 20 to 60° C, is frequency modulated by the 30 Hz reference phase signal, and has less than 1 percent amplitude modulation. An internal vernier in the reference signal lead sets the 0° bearing accuracy to less than 0.1°. The 30 Hz reference phase and variable phase VOR test signals are derived from the same oscillator operating at 720 P/S. The 720 P/S represents 24 steps of 15° each of the 30 Hz signal. The 90 and 150 Hz LOC signals are derived from a 900 P/S oscillator using the same techniques in generating the 30 Hz signals. The T-12-1A VHF plug-in unit operates in the range of 108 to 135.95 MHz. Two

50 ohm RF outputs are provided, one is a calibrated output utilizing a precision, piston type attenuator having a range of 0.3 to 100,000 μV, the other is an uncalibrated high level output approximately 1 V into a 50 ohm load. Special shielding keeps the leakage to less than 0.3 μV. For precise measurement of modulation percentage, a detector is included in the RF unit. Its output is available at a binding post on the T-12 main panel. A meter is used for the RF level calibration of the attenuator, and adjusting percentage of modulation. The T-12-2A UHF plug-in unit contains 20 crystals for the standard glide slope channels in the 329 to 335 MHz range. The output provisions are the same as for the T-12-1A VHF unit.

The 478A-1 ZIFOR (zero indicator for omni range) is a phase-comparing instrument used for ascertaining the proper zero, or north setting, of audio signal generators used for VOR testing. An accurate north setting is indicated when the 30 Hz variable phase signal and the 30 Hz modulation on the 9960 FM signal produced by the instrument are exactly in phase. The ZIFOR provides facilities for indicating the phase coincidence of these signals. The 9960 FM consists of a carrier frequency of 9960 Hz frequency modulated, with a deviation ratio of 16, by a 30 Hz reference phase signal. The ZIFOR allows test equipment to be zeroed within 0.1°, and is used to test the calibration of any VOR audio generator, such as the 479S series or the military equivalents. The normal operating input level is 1 V of 30 Hz variable phase and 1 V of 9960 FM signal. Maximum operating level is 4 V.

The type H-16 standard course checker provides a means for precisely measuring the accuracy of the phase relationship between the "reference phase" and the "variable phase" modulations on VOR signal generators or modulators. It will check 0° to, 15° to, 180° to, and indicate directly on the panel meter the amplitude and direction of the error up to a maximum of 4°. Accuracy is $\pm 0.1^{\circ}$ between 15° and 30° C when indicated deviation is within $\pm 1^{\circ}$. The set includes a self-checking circuit that insures long-term accuracy. Normal input level is 1.0 V each of 30 Hz and 9960 Hz.

The omnibearing selector type 336A-3 is a panel-mounted aircraft instrument used to select a specific VOR radial of a VOR ground station. The selector radial is presented as a direct reading number on a dial located on the instrument face. The meter movement above the dial indicates whether the selected radial is

toward or away from the ground station. The to-from switch to the left of the dial selects reciprocal courses. Inputs required are 30 Hz signal and $\pm 225\ \mu A$ dc signal from the navigation receiver for the to-from indicator. The bearing accuracy is $\pm 0.5^{\circ}$.

DISCUSSION

Calibration of Laboratory Standards

The Standards Laboratory Unit of the Standards and Calibration Laboratory Facility provides support for projects which require precise calibrations performed on equipment through the use of reference standards that have been calibrated by the National Bureau of Standards.

The Primary Reference Standards Laboratory of the Standards Laboratory Unit serves two functions. First, the laboratory maintains primary standards which are certified through calibration by the National Bureau of Standards. The primary standards thus certified are used in calibrating equipment which serves as the secondary standards that are used in the Test Equipment Calibration and Repair Unit. Second, the laboratory performs precise calibration of project support equipment that must be calibrated by use of primary standards. Because the calibrations are performed by use of the primary standards of the Primary Reference Standards Laboratory, the calibrations are accurate to the highest degree attainable outside of the National Bureau of Standards.

The 211-A, 479S-3, and 232-A signal generators described under Equipment Description were calibrated by the Test Equipment Calibration and Repair Unit.

Calibration of Field Standards

The 211-A, 479S-3, and 232-A signal generators calibrated by the Standards and Calibration Laboratory and considered as project laboratory standards, were used by project personnel to calibrate the 51RV-1 VOR/ILS receivers used with the portable test set.

The procedure outlined in the Receiver Overhaul Manual was used as a guide to develop the project calibration procedure for the 51RV-1 receivers. This procedure is outlined in the appendix. A typical calibration data sheet is shown as table I. These calibrations were closely maintained throughout the test period.

TABLE I

TYPICAL 51RV-1 VOR/ILS RECEIVER CALIBRATION

Date	: 9/25/67	Receiver Type	: 51RV-1
Line Voltage	: 27.5 Vdc	Power Supply B+	: 16.0 Vdc
Deviation Loads	: 5	Course Sensitivity	: 20.0°
AGC at 1 kμV	: 10 Vdc	9960 FM	: 0.3 Vac
30 Hz VAR	: 4.5 Vac	30 Hz REF	: 4.5 Vac
VOR Sensitivity for 240 μA Flag	: 0.9 μV	VOR Flag at 1 kμV	: 300 μA
		LOC Flag at 1 kμV	: 375 μA
LOC Sensitivity for 240 μA Flag	: 0.9 μV	GS Flag at 1 kμV	: 375 μA
GS Sensitivity for 240 μA Flag	: 19 μV		

VOR

OBS (degrees)	000	030	060	090	120	150	180	210	240	270	300	330
Azimuth "To" (deg.)	0.15	0.15	0.10	0.00	0.00	0.05	0.15	0.10	0.10	0.05	0.10	0.10
Azimuth "From" (deg.)	-0.10	-0.10	-0.15	-0.20	-0.20	-0.15	0.00	0.00	0.00	-0.05	-0.10	-0.10

ILS

Localizer (1,000 μV)			Glide Slope (700 μV)		
4 dB/90	4 dB/150	0 dB	2 dB/90	2 dB/150	0 dB
90 μA	90 μA	0 μA	78 μA	78 μA	0 μA

Standard Test Signals

RTCA paper 208-53/DO-52 entitled "Calibration Procedures for Signal Generators Used in the Testing of VOR and ILS Receivers" was used as the project test procedure standard for the calibration of the 211-A, 479S-3, and 232-A signal generators. RTCA paper 47-62/DO-114 entitled "Minimum Performance Standards for Airborne VOR Receiving Equipment Operating Within the Radio Frequency Range of 108-118 Mc," RTCA document No. DO-131 entitled "Minimum Performance Standards Airborne ILS Localizer Receiving Equipment," and RTCA document No. DO-132 entitled "Minimum Performance Standards - ILS Glide Slope Receiving Equipment," were used as the project test procedure standards for the measurements made on the 51RV-1 VOR/ILS test receivers.

Standard test signals used were in accordance with the above criteria and are as follows: Standard VOR test signal is an RF carrier, amplitude modulated simultaneously (1) 30 percent by a 9960 Hz subcarrier which is, in turn, frequency modulated at a deviation ratio of 16 by a 30 Hz "reference phase signal," and (2) 30 percent by a 30 Hz "variable phase signal" which can be varied in phase with respect to the reference phase signal. Standard VOR deflection is that deflection of the course deviation indicator produced when a standard VOR test signal, having an input level to the equipment under test of 100 μV, is changed 10° from that which produces an on-course indication.

The VOR receiver sensitivity is the minimum level in microvolts of a standard VOR test signal required to produce simultaneously (1) a deflection of the deviation indicator of at least 50 percent of standard deflection, and (2) erratic movement of the deviation indicator due to noise of not more than ± 5 percent.

Standard localizer test signal is an RF carrier amplitude modulated simultaneously with 90 Hz ± 0.3 percent and 150 Hz ± 0.3 percent signals so that the sum of their separate modulation percentages equals 40 ± 2 percent.

Standard localizer centering signal is a test signal in which the difference in depth of modulation of the 90 and 150 Hz signals is less than 0.1 dB (1.94 μA).

Standard localizer deviation signal is a test signal in which the difference in depth of modulation of the 90 and 150 Hz signals is 4 ± 0.1 dB (90 ± 1.94 μA).

Standard localizer deflection shall be 60 percent (90 μA) of center to full-scale deflection of the deviation indicator. The receiver shall be adjusted to produce standard deflection when the input is a standard localizer deviation signal of 1,000 μV.

Localizer Receiver Sensitivity: The minimum level in microvolts of a standard localizer deviation signal required to produce simultaneously (1) a deflection to the deviation indicator of at least 60 percent (54 μA) of standard deflection, and (2) erratic movement of the deviation indicator due to noise of not more than ±5 percent of standard deflection.

Standard glide slope test signal is an RF carrier amplitude modulated simultaneously with 90 Hz ±0.3 percent and 150 Hz ±0.3 percent signals of such levels that, when each signal is applied independently, the carrier is modulated 40 ±2 percent.

Standard glide slope centering signal is a test signal in which the difference in depth of modulation of the 90 and 150 Hz signals is less than 0.1 dB (1.94 μA).

Standard glide slope deviation signal is a test signal in which the difference in depth of modulation of the 90 and 150 Hz signals is 2 ±0.1 dB (78 ±1.94 μA).

Standard glide slope deflection shall be 52 percent (78 μA) of center to full-scale deflection of the deviation indicator. The receiver shall be adjusted to produce standard deflection when the input signal is a standard glide slope deviation signal of 700 μV.

Glide Slope Receiver Sensitivity: The minimum signal in microvolts of a standard glide slope deviation signal required to produce simultaneously (1) a deflection of the deviation indicator of at least 60 percent (45.8 μA) of standard deflection, and (2) erratic movement of the deviation indicator due to noise of not more than ±5 percent of standard deflection.

Field Tests

General Procedures: Prior to conducting tests in each FAA region the portable test set was completely checked for proper operation. Each 51RV-1 VOR/ILS receiver was connected to the test set and calibrated using the three project laboratory standard signal generators. All portable test set equipment was properly aligned and adjusted in accordance with the manufacturer's recommended practices.

Project technical personnel were responsible for the measurement and recording of the radio repair shop equipment performance, and the accuracy and calibration of the portable transfer standard test set. They also conducted the complete project, thereby insuring uniformity in the testing techniques and observance of monitoring methods of test signals for accuracies and repeatability.

Personnel in charge of the repair stations that were selected for testing were responsible for the calibration, adjustments, and operation of their avionics test equipment. Testing at repair stations was accomplished with maximum precautions to insure that the portable test set was not displaced from its original calibration.

Tests were made at each repair station with the objective of obtaining as accurate and sufficient data as possible consistent with the established time schedule. If any of the repair station's avionics test equipment were found to have problems, effort was made (if time allowed) to determine the possible cause. Test data measurements were obtained using as transfer standards the two 51RV-1 VOR/ILS receivers. Upon completion of the field tests in each region, the test set, including receivers, was again checked to determine if any changes had occurred in the equipment during that test period. Table I shows a typical chart of a laboratory calibration.

The laboratory maintenance tests and field tests were very rigid in order to maintain the most accurate project results. All tests were conducted under conditions of ambient room temperature, pressure, and humidity, and were conducted after an equipment warm-up period of not less than 30 minutes. Also, the input power required for the 51RV-1 receivers used with the portable test set was checked and controlled to maintain accuracy during tests.

Initial tests were made at selected facilities to provide the necessary guidance to complete the project procedures and portable transfer equipment. Once project procedures, test conditions, and test methods were standardized, they were maintained throughout the project.

In tests conducted at radio repair stations in the Eastern Region, a ZIFOR was carried by the project technician as a back-up device or to aid in making necessary adjustments to shop equipment. It was determined that the portable test set met all requirements and the use of a ZIFOR was discontinued.

Test Methods: The field tests established by the project manager and followed by the project technical personnel in accomplishing the survey of VOR, localizer, and glide slope avionic test equipment at certificated and non-certificated radio repair stations, were conducted as described below. The test equipment set-up is shown in figure 4. This same interconnection of equipment was used in the laboratory to calibrate the portable test set using the laboratory calibrated test equipment, and in the field to test the accuracy of the repair station equipment.

A test set cable was connected to each of the 51RV-1 VOR/ILS receivers. One cable provided power for receiver warm-up during calibration of the other receiver. To put all internal metering in the circuit and to check the portable test set, the following switch positions were set before applying dc power.

On the test set front panel the VOR/LOC/GS switch at VOR/LOC, the OBS-LOADS/INT-EXT switch at INT, the Universal Track Selector at 30 Hz and the voltmeter switch off. On the test set rear panel the VOR/LOC (CDI), GS (CDI), VOR/LOC (FLAG), and GS (FLAG) switches at N. The number of 1,000 ohm loads being used was determined and the rear panel load switch set. Specific cables for the shop test equipment under test were then connected to the rear panel "EXT OBS LOADS" plug. The shop test equipment was then connected to the rear panel VOR connector through a 6 dB pad. The test set's 11 fuses were checked before power was applied and adjusted to 27.5 Vdc. The equipment was then allowed to warm-up until the receiver reached a temperature of 35° C.

Tests were conducted at the selected repair station and data recorded in the following manner.

Preliminary Data on Facility - Name and location of facility. Category of facility (small, medium, large). VOR, localizer, and glide slope signal generator type and serial number. OBS model number. Time station test equipment and time 51RV-1 receiver turned on.

Preliminary Data on Each Receiver Using Station Test Generators - Line and B+ voltages, and receiver operating temperature. VOR sensitivity, course sensitivity, flag current - 30 Hz reference, 30 Hz variable, 9960 FM and AGC voltages at 1,000 μV signal level. Localizer and glide slope sensitivity and flag current.

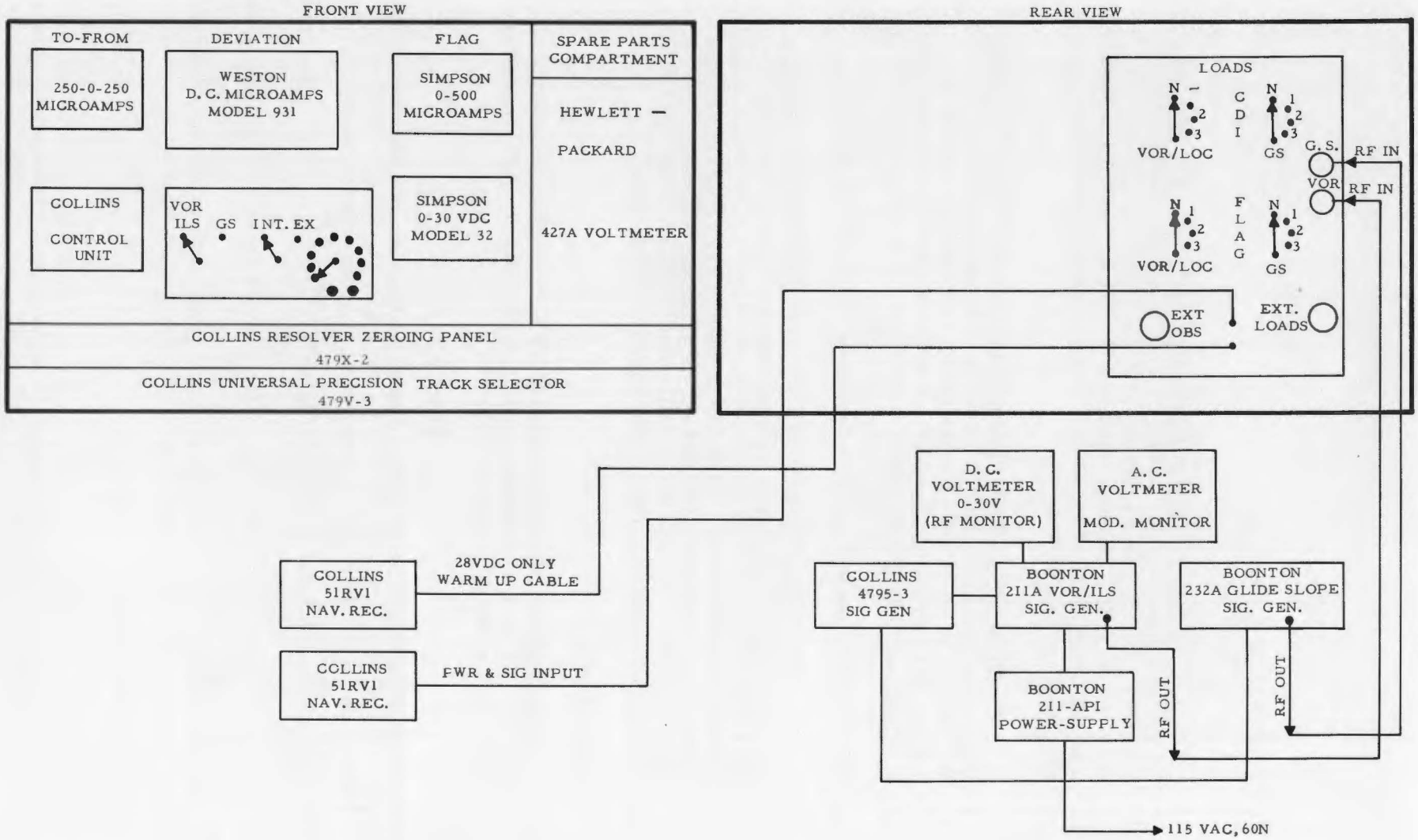

FIG. 4 PORTABLE TEST SET & TEST EQUIPMENT CONNECTION DIAGRAM

VOR Data of Station Signal Generator at 114.9 MHz and 30 Percent Modulation - Bearing indicated on test set of 51RV-1 receiver with RF input level of 1,000 μV. Data taken every 30° with station OBS. Bearing indicated on test set of 51RV-1 receiver with RF input level of 1,000 μV. Data taken every 30° with project precision track selector.

Localizer Data of Station Signal Generator at 110.1 MHz and 20 Percent Modulation - Localizer indicator centering at an RF input level of 1,000 μV when the 90 and 150 Hz modulation signals of 20 percent are equal. Localizer indicator deflection at 1,000 μV when the 90 Hz modulation signal is 4 dB greater than the 150 Hz signal. Localizer indicator deflection at 1,000 μV when the 150 Hz modulation signal is 4 dB greater than the 90 Hz signal.

Glide Slope Data of Station Signal Generator at 332 MHz and 40 Percent Modulation - Glide slope indicator centering at an RF input level of 700 μV when the 90 and 150 Hz modulation signals of 40 percent are equal. Glide slope indicator deflection at 700 μV when the 90 Hz modulation signal is 2 dB greater than the 150 Hz signal. Glide slope indicator deflection at 700 μV when the 150 Hz modulation signal is 2 dB greater than the 90 Hz signal.

Test Results

Laboratory: Tests were conducted at NAFEC to determine typical 51RV-1 receiver data, using various laboratory generators. The results obtained were as follows.

TABLE II

Gen. Type	000	030	060	090	120	150	180	210	240	270	300	330
479S-3/211-A	-.20	-.20	-.27	-.20	-.13	-.20	-.07	-.13	-.27	-.13	-.20	-.20
H-14	-.67	-.27	-.87	-.87	-.53	-.93	-.53	-.13	-1.00	-.53	-.40	-1.07
T-12A	-.40	-.53	-.53	-.60	-.53	-.53	-.33	-.33	-.53	-.60	-.53	-.53

TABLE II
(continued)

Gen. Type	Deflection (1 KμV)		Centering	Flag
	90→150	150→90		
479S-3/211-A	88	94	-3	400
H-14	84	80	-3	325
T-12A	90	96	-2	395

(All readings in microamperes)

Laboratory tests were conducted to compare the modulation percentages of various signal generators calibrated by the Standards Laboratory with the ILS precision calibrator type N-100 (see appendix). The 211-A generator was set for 20 percent modulation on 90 and 150 localizer using an ac VTVM. The RF was then connected to the N-100 and the modulation indicated was 20 percent with deflection low on the 90 Hz by 0.24 μA.

The 232-A generator was set for 40 percent modulation on the 90 and 150 Hz using an ac VTVM. When connected to the N-100, the modulation indicated was 40.25 percent with deflection high on the 90 Hz by 0.77 μA.

The H-14 generator when set for localizer operation indicated 19.5 percent modulation.

The survey of shop equipment indicated variations in the modulation levels of localizer and glide slope generators. A type AFM-1 radiometer was tested at NAFEC by measuring the modulation levels of the project generators and comparing to the calibrations provided by the Standards and Calibration Laboratory.

Generator	90 Hz	150 Hz	Mode
211-A	18.5 percent	18.5 percent	LOC
232-A	40.0 percent	40.0 percent	GS

Tests conducted by the Standards and Calibration Laboratory on this same unit indicated that it meets the manufacturer's specifications of 3 percent accuracy. A description of the type AFM-1 radiometer is included in the appendix.

Laboratory tests using a ZIFOR were conducted on the 479S-3/211-A signal generators at the start and end of the project to determine if there were any changes in the OBS readings. The results obtained were as follows.

TABLE III

Equipment	000	030	060	090	120	150	180	210	240	270	300	330
ZIFOR	0	+.05	+.30	+.18	.11	-.15	-.15	+.09	+.20	+.15	+.14	+.29
479S-3/211-A (start)	+.15	+.30	+.45	+.25	+.10	+.10	+.10	+.28	+.40	+.22	+.11	+.10
479S-3/211-A (end)	+.10	+.30	+.40	+.20	+.10	+.05	+.05	+.25	+.45	+.25	+.10	+.10

Field: The signal generator types, number tested, and the manufacturers are summarized in table IV. Of the 103 avionic shops tested, the data from 97 VOR, 100 localizer, 71 glide slope signal generators, and 45 omnibearing selectors are analyzed. The equipments tested, but excluded from the results, are indicated under General Comments.

VOR: Data were obtained for every generator with the project precision track selector and then with the facility OBS, if available. To obtain the shop signal generator data the test receiver error was subtracted from the results of these tests. The shop generator data were then subtracted from the OBS generator data to obtain the data for the OBS. Bearing data were recorded as positive or negative in degrees to the nearest 10th degree. It is these data that were used to obtain the statistical results indicated below.

The results of the statistical analysis of the VOR bearing data at twelve 30° increments for all of the 97 signal generators tested are given in table V. The largest two standard deviation was 1.66°. The average two standard deviation for all radials and conditions tested was 1.58°. The average mean was -0.26°. The range of bearing errors in this sample of VOR signal generators extends

TABLE IV

SUMMARY OF EQUIPMENT TYPES
REPRESENTED IN THE DATA SAMPLE

Type	Number Tested	Manufacturer
479S (MD-83A)	38	Collins Radio Co.
211-A (SG-1A)	38	Boonton Radio Co.
H-14	8	Aircraft Radio Corp.
H-14A (SG-66A)	44	Aircraft Radio Corp.
T-12/T-12-1A	10	Tel-Instrument Electronics Corp.
232-A (SG-2A)	44	Boonton Radio Co.
212-A	6	Boonton Radio Co.
H-23A	16	Aircraft Radio Corp.
T-12/T-12-2A	5	Tel-Instrument Electronics Corp.

TABLE V

VOR DATA FOR ALL SIGNAL GENERATORS

Sample size = 97

Statistic (degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	2.50	2.02	1.88	2.00	2.10	2.50	2.30	2.05	2.40	2.40	2.60	2.60
Minimum	-3.60	-3.50	-3.60	-3.30	-3.35	-2.55	-3.65	-3.10	-3.30	-3.25	-3.10	-3.30
Mean	-.27	-.25	-.36	-.29	-.26	-.30	-.26	-.21	-.25	-.25	-.23	-.24
Two Standard Deviation	1.56	1.50	1.58	1.52	1.52	1.56	1.56	1.48	1.66	1.66	1.60	1.66

Average two standard deviation = 1.58°
Average mean = -0.26°

from -3.65° to +2.60°. Results show that when the signal generators are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +1.29° and -1.83°.

Table VI lists the results of the statistical analysis of bearing data of 35 type 479S/211-A VOR signal generators. The largest two standard deviation was 1.42°. The average two standard deviation was 1.14°. The average mean was -0.03°. The range of bearing errors in this sample of VOR signal generators extends from -1.05° to +2.60°. Results show that when the signal generators are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +1.16° and -1.20°.

Table VII lists the results of the statistical analysis of bearing data of 44 type H-14A VOR signal generators. The largest two standard deviation was 1.60°. The average two standard deviation was 1.48°. The average mean was -0.55°. The range of bearing errors in this sample of VOR signal generators extends from -3.65° to +1.84°. Results show that when the signal generators are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +0.90° and -2.06°.

TABLE VI

VOR DATA FOR 479S/211-A SIGNAL GENERATORS

Sample size = 35

Statistic (degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	2.50	2.00	1.10	1.40	2.10	2.50	2.30	1.75	2.40	2.40	2.60	2.60
Minimum	-0.95	-0.80	-0.80	-0.70	-0.75	-0.85	-0.90	-1.00	-1.00	-1.05	-0.95	-0.90
Mean	-.02	0.0	-.05	0.0	-.01	-.03	-.04	-.08	-.05	-.07	0.0	.04
Two Standard Deviation	1.18	1.00	0.84	0.98	1.10	1.16	1.12	1.02	1.30	1.26	1.36	1.42

Average two standard deviation = 1.14°
Average mean = -0.03°

TABLE VII

VOR DATA FOR H-14A SIGNAL GENERATORS

Sample size = 44

Statistic (degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	1.47	1.47	1.62	1.54	1.49	1.70	1.47	1.47	1.84	1.74	1.67	1.60
Minimum	-3.60	-3.50	-3.60	-3.30	-3.35	-2.55	-3.65	-3.10	-3.30	-3.25	-3.10	-3.30
Mean	-.58	-.52	-.70	-.59	-.50	-.58	-.53	-.43	-.55	-.52	-.48	-.57
Two Standard Deviation	1.48	1.48	1.56	1.40	1.44	1.40	1.50	1.44	1.60	1.58	1.42	1.50

Average two standard deviation = 1.48°
Average mean = -0.55°

Table VIII lists the results of the statistical analysis of bearing data of eight type H-14 VOR signal generators. The largest two standard deviation was 1.82°. The average two standard deviation was 1.28°. The average mean was -0.83°. The range of bearing errors in this sample of VOR signal generators extends from -2.20° to +1.00°. Results show that when the signal generators are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +0.36 and -1.84°.

TABLE VIII

VOR DATA FOR H-14 SIGNAL GENERATORS

Sample size = 8

Statistic (degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	0.25	0.15	0.20	-0.60	-0.45	-0.15	0.20	0.80	0.90	1.00	0.0	0.30
Minimum	-1.40	-1.50	-1.80	-1.70	-1.65	-1.75	-1.65	-1.70	-1.60	-1.95	-2.20	-1.30
Mean	-.74	-.84	-.94	-1.03	-1.02	-1.07	-.79	-.66	-.63	-.71	-.83	-.72
Two Standard Deviation	1.10	1.02	1.28	1.00	0.88	1.08	1.48	1.48	1.56	1.82	1.44	1.12

Average two standard deviation = 1.28°
Average mean = -0.83°

Table IX lists the results of the statistical analysis of bearing data of 10 type T-12A/T-12-1A VOR signal generators. The largest two standard deviation was 1.60°. The average two standard deviation was 1.56°. The average mean was 0.60°. The range of bearing errors in this sample of VOR signal generators extends from -0.60° to +2.08°. Results show that when the signal generators are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +2.13° and -1.03°.

Table X lists the results of the statistical analysis of bearing data for the 45 signal generators and omnibearing selector combinations. Included in this analysis were the following OBS types: 479V-1, 479V-2, 479V-3, 336A-2, 336A-3, ID-249, ID-387, DA-11, MA-82F, and MN-97H. The largest two standard deviation was 1.72°. The average two standard deviation was 1.66°. The

TABLE IX

VOR DATA FOR T-12A/T-12-1A SIGNAL GENERATORS

Sample Size = 10

Statistic (degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	1.93	2.02	1.88	2.00	1.98	1.98	1.93	2.05	2.00	2.00	1.98	2.08
Minimum	-0.55	-0.55	-0.60	-0.40	-0.45	-0.45	-0.30	-0.30	-0.30	-0.40	-0.50	-0.40
Mean	.55	.53	.54	.60	.54	.59	.62	.65	.68	.66	.59	.63
Two Standard Deviation	1.58	1.60	1.60	1.58	1.58	1.54	1.52	1.58	1.50	1.52	1.60	1.58

Average Two Standard Deviation = 1.56°
Average Mean = 0.60°

TABLE X

VOR DATA FOR ALL SIGNAL GENERATORS
AND
OMNI-BEARING SELECTOR COMBINED

Sample Size = 45

Statistic (degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	2.00	2.05	1.85	1.85	1.90	1.90	1.85	1.80	1.80	1.85	1.90	1.85
Minimum	-2.30	-2.30	-2.50	-2.70	-2.85	-2.80	-2.65	-2.55	-2.75	-2.85	-2.75	-2.30
Mean	-.73	-.77	-.92	-.94	-.80	-.75	-.78	-.81	-.93	-.90	-.80	-.67
Two Standard Deviation	1.60	1.64	1.66	1.70	1.58	1.64	1.62	1.66	1.72	1.72	1.60	1.72

Average Two Standard Deviation = 1.66°
Average Mean = -0.82°

average mean was -0.82°. The range of bearing errors in this sample of VOR/OBS combinations extends from -2.85° to +2.05°. See figure 5. Results show that when the signal generator OBS combinations are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +0.87° and -2.33°.

Table XI lists the results of the statistical analysis of bearing data for the 45 omnibearing selectors that were tested. The largest two standard deviation of bearing errors was 1.48°. The average two standard deviation was 1.36°. The average mean was -0.54°. The range of bearing errors in this sample of omnibearing selectors extends from -2.75° to +1.40°. See figure 5. Results show that when omnibearing selectors are set at 0° there is a 95 percent probability that they will indicate a deviation within the limits of +0.85° and -1.75°.

Localizer: Localizer data were obtained for the 90 Hz signal 4 dB greater than the 150 Hz signal (right deflection), and then subtracted from the test set standard deflection of 90 μA. Similarly, data were obtained for the 150 Hz signal 4 dB greater than the 90 Hz signal (left deflection), and when both the 90 Hz and the 150 Hz signals were equal (centering).

Table XII lists the results of the statistical analysis of the localizer deflection data for the 100 signal generators tested. The range of deflection data is this sample of generators indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a right deflection within the limits of 71.89 and 120.49 μA. When the 150 Hz signal is greater than the 90 Hz there is a 95 percent probability that the signal generators will indicate a left deflection within the limits of 71.18 and 119.94 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +6.65 and -6.55 μA.

Table XIII lists the results of the statistical analysis of the localizer deflection data of 38 type 479S/211-A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a right deflection within the limits of 83.08 and 112.08 μA. When the 150 Hz signal is greater than the 90 Hz there is a 95 percent probability that the signal

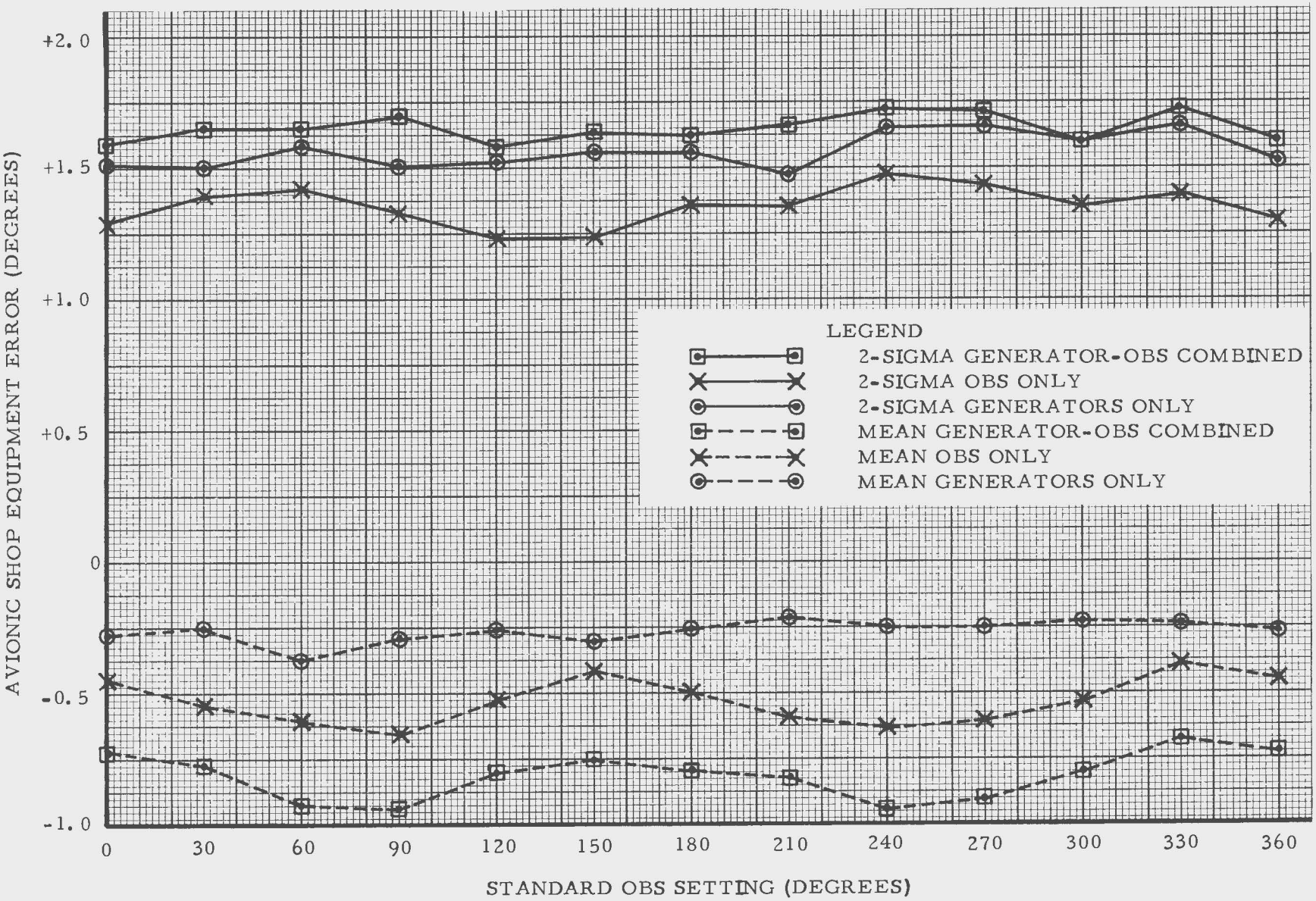

FIG. 5 SIGNAL GENERATORS AND OBS STANDARD DEVIATION CURVES - ALL TYPES

TABLE XI

DATA FOR ALL OMNI-BEARING SELECTORS
TESTED WITH VOR SIGNAL GENERATORS

Sample Size = 45

Statistic (Degrees)	000°	030°	060°	090°	120°	150°	180°	210°	240°	270°	300°	330°
Maximum	1.20	1.25	1.05	1.00	1.10	1.10	1.20	1.20	1.25	1.25	1.40	1.30
Minimum	-2.50	-2.45	-2.55	-2.45	-2.15	-1.95	-2.45	-2.55	-2.75	-2.65	-2.25	-2.45
Mean	-.45	-.54	-.61	.66	-.52	-.42	-.49	-.58	-.63	-.60	-.53	-.39
Two Standard Deviation	1.30	1.40	1.42	1.34	1.24	1.24	1.36	1.36	1.48	1.44	1.36	1.40

Average Two Standard Deviation = 1.36°
Average Mean = -0.54°

TABLE XII

LOCALIZER DATA FOR ALL SIGNAL GENERATORS

Sample Size = 100

Statistic	Deflection (μA)		Centering (μA)
	90 > 150 (R)	150 > 90 (L)	90 = 150
Maximum	42.00	32.00	10.00
Minimum	-37.00	-24.00	-11.00
Mean	6.19	5.56	0.05
Two Standard Deviation	24.30	24.38	6.60

TABLE XIII

LOCALIZER DATA FOR 479S/211-A SIGNAL GENERATORS

Sample Size = 38

Statistic	Deflection (μA)		Centering (μA)
	90>150 (R)	150>90 (L)	90 = 150
Maximum	29.00	28.00	5.00
Minimum	-6.00	-7.00	-10.00
Mean	7.58	7.82	-0.38
Two Standard Deviation	14.50	17.64	5.68

TABLE XIV

LOCALIZER DATA FOR H-14A SIGNAL GENERATORS

Sample Size = 43

Statistic	Deflection (μA)		Centering (μA)
	90>150 (R)	150>90 (L)	90 = 150
Maximum	34.00	32.00	10.00
Minimum	-22.00	-24.00	-5.00
Mean	3.42	3.14	0.43
Two Standard Deviation	22.74	27.30	5.82

generators will indicate a left deflection within the limits of 80.18 and 115.46 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +5.30 and -6.06 μA.

Table XIV lists the results of the statistical analysis of the localizer deflection data of 43 type H-14-A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a right deflection within the limits of 70.68 and 116.16 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate a left deflection within the limits of 65.84 and 120.44 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +6.25 and -5.39 μA.

Table XV lists the results of the statistical analysis of the localizer deflection data of eight type H-14 signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a right deflection within the limits of 46.84 and 155.16 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate a left deflection within the limits of 56.92 and 133.08 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +13.52 and -14.28 μA.

Table XVI lists the results of the statistical analysis of the localizer deflection data of 11 type T-12A/T-12-1A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a right deflection within the limits of 74.67 and 122.79 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate a left deflection within the limits of 78.00 and 117.28 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +5.52 and -4.80 μA.

TABLE XV

LOCALIZER DATA FOR H-14 SIGNAL GENERATORS

Sample size = 8

Statistic	Deflection (μA)		Centering (μA)
	90>150(R)	150>90(L)	90=150
Maximum	42.00	32.00	8.00
Minimum	-37.00	-20.00	-11.00
Mean	11.00	5.00	-0.38
Two Standard Deviation	54.16	38.08	13.90

TABLE XVI

LOCALIZER DATA FOR T-12A/T-12-1A SIGNAL GENERATORS

Sample size = 11

Statistic	Deflection (μA)		Centering (μA)
	90>150(R)	150>90(L)	90=150
Maximum	32.00	20.00	7.00
Minimum	-13.00	-17.00	-2.00
Mean	8.73	7.64	0.36
Two Standard Deviation	24.06	19.64	5.16

Glide Slope: Glide slope data were obtained for the 90 Hz signal 2 dB greater than the 150 Hz signal (down deflection), and then subtracted from the test set standard deflection signal of 78 μA. Similarly, data were obtained for the 150 Hz signal 2 dB greater than the 90 Hz signal (up deflection), and when both the 90 Hz and 150 Hz signals were equal (centering).

Table XVII lists the results of the statistical analysis of the glide slope deflection data for the 71 signal generators tested. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a down deflection within the limits of 62.85 and 95.21 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate an up deflection within the limits of 63.37 and 97.17 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +4.85 and -5.43 μA.

Table XVIII lists the results of the statistical analysis of the glide slope deflection data of 44 type 232-A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a down deflection within the limits of 63.68 and 94.60 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate an up deflection within the limits of 66.48 and 93.52 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +4.06 and -4.34 μA.

Table XIX lists the results of the statistical analysis of the glide slope deflection data of 16 type H-14A/H-23A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a down deflection within the limits of 58.76 and 101.12 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate an up deflection within the limits of 58.17 and 106.45 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +5.91 and -7.33 μA.

TABLE XVII

GLIDE SLOPE DATA FOR ALL SIGNAL GENERATORS

Sample size = 71

Statistic	Deflection (μA)		Centering (μA)
	90>150(D)	150>90(U)	90=150
Maximum	29.00	29.00	6.00
Minimum	-21.00	-20.00	-11.00
Mean	1.03	2.27	-0.29
Two Standard Deviation	16.18	16.90	5.14

TABLE XVIII

GLIDE SLOPE DATA FOR 232-A SIGNAL GENERATORS

Sample size = 44

Statistic	Deflection (μA)		Centering (μA)
	90>150(D)	150>90(U)	90=150
Maximum	29.00	24.00	4.00
Minimum	-18.00	-17.00	-4.00
Mean	1.14	2.00	-0.14
Two Standard Deviation	15.46	13.52	4.20

TABLE XIX

GLIDE SLOPE DATA FOR H-14A/H-23A SIGNAL GENERATORS

Sample size = 16

Statistic	Deflection (μA)		Centering (μA)
	90>150(D)	150>90(U)	90=150
Maximum	16.00	29.00	3.00
Minimum	-21.00	-20.00	-11.00
Mean	1.94	4.31	-0.71
Two Standard Deviation	21.18	24.14	6.62

Table XX lists the results of the statistical analysis of the glide slope deflection data of six type 212-A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a down deflection within the limits of 70.96 and 91.04 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate an up deflection within the limits of 66.08 and 95.92 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +6.55 and -6.21 μA.

Table XXI lists the results of the statistical analysis of the glide slope deflection data of five type T-12A/T-12-2A signal generators. The range of deflection data in this sample of generators is indicated in the table. Results show that when the 90 Hz signal is greater than the 150 Hz signal there is a 95 percent probability that the signal generators will indicate a down deflection within the limits of 68.80 and 86.80 μA. When the 150 Hz signal is greater than the 90 Hz signal there is a 95 percent probability that the signal generators will indicate an up deflection within the limits of 67.66 and 84.74 μA. When the 90 Hz and 150 Hz signals are equal there is a 95 percent probability that the signal generators will indicate a deflection within the limits of +7.96 and -7.16 μA.

TABLE XX

GLIDE SLOPE DATA FOR 212-A SIGNAL GENERATORS

Sample size = 6

Statistic	Deflection (μA)		Centering (μA)
	90>150(D)	150>90(U)	90=150
Maximum	12.00	14.00	4.00
Minimum	-2.00	-6.00	-5.00
Mean	3.00	3.00	0.17
Two Standard Deviation	10.04	14.92	6.38

TABLE XXI

GLIDE SLOPE DATA FOR T-12A/T-12-2A SIGNAL GENERATORS

Sample size = 5

Statistic	Deflection (μA)		Centering (μA)
	90>150(D)	150>90(U)	90=150
Maximum	6.00	3.00	6.00
Minimum	-6.00	-8.00	-3.00
Mean	-0.20	-1.80	0.40
Two Standard Deviation	9.00	8.54	7.56

General Comments

Of the 103 radio repair stations included in this survey, the data obtained from 97 VOR and 100 Localizer signal generators were used. Data taken from some generators were not used for the following reasons: (1) improper operation of VOR test equipment due to mechanical problems at three shops; (2) incorrect adjustment of VOR equipment potentiometers at one shop (correct adjustment reduced the bearing error from 10.3° to 0.30°); (3) one FAA avionics shop was used only for preliminary tests; (4) at two shops, the localizer generator could not be adjusted to provide the correct percentage of modulation; and (5) one localizer generator was not used due to indications of equipment malfunction.

Other problems encountered were: (1) RF attenuator dial not properly set; (2) inability to obtain meter setting (red line) on RF monitor meter or 20 percent modulation on 90 or 150 Hz; and (3) failure of localizer function due to inability to balance 90 or 150 Hz modulation.

Glide slope data were not used for the following reasons: (1) at one shop the generator could not be set for standard modulation; (2) at two shops the generators were very unstable during the tests; and (3) at one shop the indications were that the equipment was malfunctioning.

Many of the shops checked set the glide slope generator percentage of modulation at 45 percent for the test. This was corrected to 40 percent on the second test. A copy of the current procedures was shown to these operators. Data from the incorrect setting were used in order not to bias the test results. One equipment manufacturer believed 45 percent modulation to be the current procedure.

The radio repair stations that have course checkers appear to have either errors in the equipment or they do not operate them properly. Of the 18 course checkers tested in the field, 11 did not agree with the project equipment at the 0° and 180° points.

Of 37 panel meters (flag and cross pointer) in operation and tested, 25 cross pointers and 30 flags were found to be accurate (± 1 μA of test set). Seven flag meters were inaccurate with a maximum error of ± 18 μA. Twelve cross pointers meters were inaccurate with a maximum error of ± 30 μA.

CONCLUSIONS

Based on the tests conducted and the data obtained at surveyed radio (avionics) repair stations, it is concluded that:

1. This study enables prediction of VOR/ILS population error distributions for radio repair station test equipment.

2. VOR signal generators used in repair stations to calibrate airborne receivers provide average bearing indications within $\pm 1.58^{\circ}$ (95 percent of the time).

3. Localizer signal generators used in repair stations to calibrate airborne receivers provide deflection indications within ± 24.38 μA (95 percent of the time), and centering indications within ± 6.6 μA (95 percent of the time).

4. Glide slope signal generators used in repair stations to calibrate airborne receivers provide deflection indications within ± 16.90 μA (95 percent of the time), and centering indications within ± 5.14 μA (95 percent of the time).

5. Omnibearing selectors used in the calibration of airborne VOR receivers provide average bearing indications within $\pm 1.36^{\circ}$ (95 percent of the time).

6. Calibration procedures as detailed in RTCA 208-53/DO-52 are not being followed by all shops.

7. Failure to follow current manufacturer's equipment instructions contributes to the test equipment inaccuracies at a number of facilities.

8. Most of the signal generators in use are capable of greater accuracy than is being attained. It would have been desirable if time and funds permitted, to have determined what increased accuracy could be obtained by proper equipment calibration.

9. Most of the shop technicians are capable and well informed regarding VOR signal generators, but their techniques on certain phases of localizer and glide slope work could be improved.

10. Most of the smaller shops are not equipped to check the accuracy of their own equipment.

11. Increased surveillance of the testing of shop equipment would improve the accuracy of calibration.

12. A requirement exists for a more frequent survey of radio repair stations similar to the type covered by this report.

13. A wide divergence exists between the shops equipment, accuracy, maintenance and technique of operation.

14. The results at some shops indicate good calibration of shop signal generators. Most shops use good shop practices and maintain their equipment in good condition.

15. The use of different zero reference standards by signal generator manufacturers and field personnel requires the establishment of a single standard.

RECOMMENDATIONS

Based on the tests conducted and the data obtained at surveyed radio (avionics) repair stations, it is recommended that:

1. The statistical analysis of the measurements performed at sample repair stations and contained in this report be utilized as representative overall accuracy data for test equipment used to calibrate and maintain airborne VOR, Localizer,and Glide Slope navigation receiving equipment throughout the United States.

2. All signal generators be calibrated, using the procedures in RTCA Paper 208-53/DO-52, December 8, 1953, and that this document and all other pertinent documents be updated to include the latest technical information and equipment.

3. Current manufacturer's equipment instructions be utilized by repair stations that test and calibrate signal generators.

4. Repair stations that test and calibrate signal generators be able to trace their test equipment calibration back to the manufacturer's standard.

5. Field inspectors emphasize their surveillance of the localizer and glide slope adjustment techniques used by repair stations.

6. A low cost reliable solid-state course checker be developed that could be used by each shop to check calibration accuracy of its VOR test equipment. This device should be capable of being easily checked by the field inspector.

7. Field inspectors increase their surveillance of the shop test equipment calibration checks and inspections.

8. A program be developed that would require a specific time period between testing of signal generators and portable standards.

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The project manager acknowledges the contributions made by Ralph Ladd, RD-330; Matthew Naimo and Harold Postel for their development of the portable test set and extensive laboratory and field data; the NAFEC Standards and Calibration Laboratory for their calibration of project test equipment; the FAA, Southern Region, for the technical assistance of Homer Henrioud; and Vincent Merel for the mathematical analysis.

At every radio repair station the visiting team found the GADO and station personnel eager to cooperate in the tests. The assistance of the many people who worked enthusiastically to make the field tests successful is sincerely appreciated.

APPENDIX I

Calibration Procedure for 51RV-1

The following calibration procedure was used to adjust and evaluate the various parameters required to maintain reliable operation of the 51RV-1 Navigation Receiver in the VOR, Localizer, and Glide Slope modes.

Calibration of all modes: Energize receiver and test equipment and allow a minimum of one hour warm-up before starting calibration.

After one half-hour, set the battery voltage at receiver to 27.5 volts direct current (VDC).

VOR Calibration: Set receiver frequency to 114.9 MHz.

Set 211-A RF generator to 114.9 MHz XTAL, and adjust RF level to Red Line (26 VDC on external meter), RF attenuator to 1000μV and modulation to external.

Set 479S-3 Function Selector to CAL, Specific Signal Selector alternately to 30 VAR, and 9960 FM, and then adjust each modulation level into the RF generator for 5.62 volts alternating current (VAC) using the external meters.

Switch the 479S-3 Function Selector to ODR.

After the one hour warm-up check that RF level is 26 VDC and 30 VAR and 9960 FM are each 5.62 VAC. These levels and the 27.5 VDC will be checked frequently during calibration to insure accuracy.

With Standard Test Conditions (STC) into receiver, set NAV ADJ (R104) to obtain 0.5 VAC at TP-3.

Connect external metering to REF jack (JI) and adjust VOR REF level (R64) to obtain 4.5 VAC.

Connect external metering to VAR jack (J2) and adjust VOR VAR level (R101) to obtain 4.5 VAC.

Set OBS to 270°, and set 479S-3 PAS to 270°.

Adjust VOR zero for Zero crosspointer.

Set OBS to 90°.

Adjust VOR Ø BAL (R91) for zero crosspointer.

Repeat (9) thru (12) for zero crosspointer.

Set OBS to 330° and 479S-3 PAS to 330°.

Adjust VOR TRACK (R61) for zero crosspointer.

Repeat (9) thru (15) for exact zero crosspointer.

Reset OBS and 479S-3 PAS to 270°.

Adjust VOR FLAG (R58) to obtain 300 µA flag current.

Swing 479S-3 PAS 10° each side of 270°.

Crosspointer should read 150 µA on each side, if not, adjust VOR SENS. (R59) to obtain exactly 150 µA for 10° on each side.

Rotate OBS and PAS clockwise in 30° increments, reading error on 479S-3 dial.

Localizer Calibration: Set receiver frequency to 110.1 MHz.

Set 211-A RF generator to 110.1 MHz XTAL, and adjust RF level to Red Line (26 VDC), RF attenuator to 1000 µV and modulation to external.

Set 479S-3 Function Selector to Tone LOC, and the Specific Signal Selector to 90-150.

Set 479S-3 Tone Localizer to CAL 90 and adjust RF generator modulation level to 20 percent (3.75 VAC on external meter).

Set 479S-3 Tone Localizer to CAL 150 and adjust 150 level, if necessary, to 20 percent (3.75 VAC on external meter).

Check back and forth that 90 and 150 are each 20 percent.

Set 479S-3 Tone Localizer to 0 dB.

Adjust LOC Centering (R52) for zero on crosspoint meter.

Adjust LOC FLAG (R42) to obtain 375 µA flag current.

Observe that flag current is less than 175 μA in CAL 90 and CAL 150.

Set the 479S-3 Tone Localizer to ±4 dB and adjust LOC sensitivity (R53) to obtain 90 μA on crosspoint meter.

Set the 479S-3 Tone Localizer to -4 dB and observe that crosspoint meter reads 90 μA ±2 μA.

Glide Slope Calibration: Set receiver frequency to 332.0 MHz.

Set 232-A RF generator to 332.0 MHz XTAL and adjust the RF to Red line, RF attenuator to 700 μV, and modulation level of 90 and 150 are each 40 percent. (RF output and modulation should be calibrated by external meters as described in 232-A Instruction Manual.)

Check back and forth that 90 CAL and 150 CAL are each 40 percent.

Set Tone Ratio to 0 dB.

Adjust BAL (R73) for zero on crosspoint meter.

Adjust FLAG (R77) for 375 μA flag current.

Observe that flag current is less than 200 μA in CAL 90 and CAL 150.

Set Tone Ratio to ±2 dB and adjust deflection sensitivity to obtain 78 μA on crosspoint meter.

Set Tone Ratio to 2 dB and observe that crosspoint meter reads 78 μA ±0.5 μA.

Set RF attenuator to 14,000 μV.

Set Tone Ratio to ±2 dB and adjust course softening control (R54) to obtain 78 μA on crosspoint meter.

Set Tone Ratio to 2 dB and observe that crosspointer reads 78 μA ±2 μA.

Type N-100 ILS Test Set

The ILS Test Set N-100 instrument incorporates a receiver, reference signal generator, and a measurement channel; and is designed to accept the ILS localizer and glide slope signals in either the AF or the RF form. The two

received tones of the localizer beam are of identical amplitude if the center meter reads zero. Readings to left or right of the center zero indicate a difference in depth of modulation (DDM) of the common carrier by each of the two tones. Deviation from the correct angle of descent is indicated in a similar manner using the glide slope signal. The meter does not indicate the difference in field strength of the two overlapping lobes of the ILS aerial radiation pattern, because a high degree of automatic gain control (agc) is incorporated in the receiver, which prevents it responding to changes in level of the combined carrier. It is the difference in depth of modulation of the ILS combined carrier by each of the two tones that the N-100 compares and the meter is calibrated in percentage DDM.

Input Signal	Localizer	Glide Slope
RF	100 µV to 100 mV rms at 108 to 112 MHz	100 µV to 100 mV rms at 328 to 336 MHz
AF	1 V to 100 rms	1 V to 100 V rms
Tone Frequencies	90 and 150 Hz ±1 percent, phase locked	90 and 150 Hz ±1 percent, phase locked
RF Modulation depth	Each tone 15 to 25 percent at zero DDM	Each tone 30 to 50 percent at zero DDM
DDM	Up to 20 percent	Up to 40 percent
Zero DDM	±0.01 percent (0.1 µA) on AF signals	±0.02 percent (0.15 µA) on AF signals
	±0.02 percent (0.2 µA) on RF signals	±0.04 percent (0.30 µA) on RF signals
Offset DDM Accuracy	±3 percent *FSD on all scales	±3 percent FSD on all scales
Modulation Depth Accuracy	±0.5 percent relative to 100 percent	±1 percent relative to 100 percent

*Full scale deflection

The instrument is calibrated according to a normalized definition of DDM generally accepted for localizer and glide slope use, i. e.;

DDM $= (E_{90} - E_{150})/5$ X 100 percent for localizer

DDM $= (E_{90} - E_{150})/2.5$ X 100 percent for glide slope

which assumes that:

Modulation depth = $((E_{90} + E_{150})/2E_c)$ X 100 percent is correctly set at 20 percent or 40 percent respectively.

Thus, the N100 used in conjunction with any ILS installation will give an indication of distance or angular displacement which is independent of the modulation depth of the particular system.

A standard aircraft receiver gives indications which vary in direct proportion to modulation depth where the standard modulation depth is 20 percent for localizer and 40 percent for glide slope; to convert this reading to microamps the result should be multiplied by 9.7 for localizer and 8.4 for glide slope.

In the ICAO recommendations for receiver testing, the tones are increased and decreased by equal logarithmic increments from the mean, e. g. 90 Hz + 2 dB, 150 Hz - 2 dB, and the mean modulation depth (A+B)/2 increases as the offset is increased. However, to obtain reading of true DDM (i. e., receiver indication) under these conditions, the N100 is set up at zero DDM only and then the offset DDM is read without readjustment of the set level control.

Type AFM1 AM-FM Modulation Meter

The AM-FM Modulation Meter, Type AFM1, provides accurate measurement of the modulation percentage of amplitude-modulated signals, and of the peak deviation of frequency-modulated signals. The basic carrier-frequency range is from 3 to 320 MHz where less than 10 millivolts are required for operation. The equipment can be used to over 1000 MHz on harmonics. Readings can be made from 0.1 percent to 100 percent on AM and from ±100 Hz to ±300 kHz on FM. The instrument has been designed to measure amplitude-modulation on frequency-modulated signals and vice versa. The Modulation Meter has provision for a crystal-controlled local or external oscillator, which reduces the spurious FM to about ±10 Hz.

AMPLITUDE MODULATION - Ranges are 3, 10, 30, and 100 percent AM full scale. Accuracy is 3 percent of full scale to over 95 percent modulation.

Frequency response is 30 Hz to 25 kHz within ±1 dB. Residual reading is less than 0.1 percent AM. Distortion is less than 0.5 percent to 95 percent AM.

FREQUENCY MODULATION - Ranges are ±3, ±10, ±100, and ±300 kHz deviation full scale. Accuracy is 3 percent of full scale. Frequency response is 30 Hz to 25 kHz within ±1 dB. Residual reading varies from about 10 Hz at low carrier frequencies to about 60 Hz at high frequencies. Distortion is less than 0.5 percent up to ±300 kHz.

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Unclassified Report

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I. Jack A. Muller
II. Project No. 330-001-05X
III. Report No. NA-69-22 (RD-69-26)

Descriptors
Navigation Aids
Radio Navigation
Airways
Navigation

This report covers a survey which was conducted at 103 radio (avionics) repair stations throughout the United States on various models of signal generators used for the calibration of VOR, localizer, and glide slope airborne navigation receivers. The survey includes data from four different models of VOR signal generators, four different models of localizer signal generators, and four different models of glide slope signal generators. A statistical analysis is

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presented which enables prediction of error distributions for radio navigation test equipment used in radio repair stations The 97 VOR signal generators tested were within the limits of 1.32° and -1.84° (95 percent probability) when results were based on a statistical analysis. The 100 localizer signal generators tested were within the limits of 71.18 and 120.49 μA deflection with a standard deflection (90 μA) signal applied, and +6.65 and -6.55 μA on centering when results were based on a 95 percent probability statistical analysis. The 71 glide slope signal generators tested were within 62.85 and 97.17 μA deflection with a standard deflection (78 μA) signal applied, and +4.85 and -5.43 μA on centering when results were based on a 95 percent probability statistical analysis. The report contains a description of the survey, discussion of the results, and recommends possible action to improve present avionics test equipment calibration methods used in the radio repair stations.

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