MOUNTAIN-TOP VOR SITE FLIGHT TESTS

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SUMMARY

In an effort to improve the operation of VOR facilities in mountainous terrain, two mountain-top sites were specially prepared and experimental VOR stations were installed for flight testing. The two installations are at Malad City, Idaho and Ukiah, Calif. These sites were prepared on the basis of a detailed theoretical study conducted at the Technical Development and Evaluation Center to determine the most practical and economical means of preparing a mountain-top site to secure good VOR performance.

The results of these flight tests indicate that very satisfactory VOR performance can be obtained in mountainous terrain by careful selection and preparation of mountain-top sites.

INTRODUCTION

One of the prerequisites for proper VOR operation is a reasonably good site. Such a site is one which is free from adjacent objects such as wires, buildings, trees, hills or mountains, any of which may attenuate or reflect radio-frequency energy to produce course deviation indicator fluctuations, course errors or shadow areas.

Most of the terrain throughout the country is of such a nature that satisfactory sites are available; however, one notable exception is the Rocky Mountain area of the western United States. In mountainous areas, sites are usually located in valleys and mountain passes due to the difficulty of providing access roads and power at mountain-top locations. One of the primary effects of mountains on VOR performance in such cases is the production of large shadow areas off airways, wherein insufficient signal strength exists for proper operation of an omnirange receiver. These shadow areas greatly reduce the VOR service area. It logically followed that to improve the service area, it would be necessary to install certain facilities on mountain tops.

In conformance with TDEC recommendations, CAA Regions Six and Seven each selected a suitable mountain-top site and constructed a circular level area on the mountain top in the center of which was installed a VOR antenna array. The antenna pedestals were placed on the ground with the circular-leveled mountain top acting as the counterpoise.

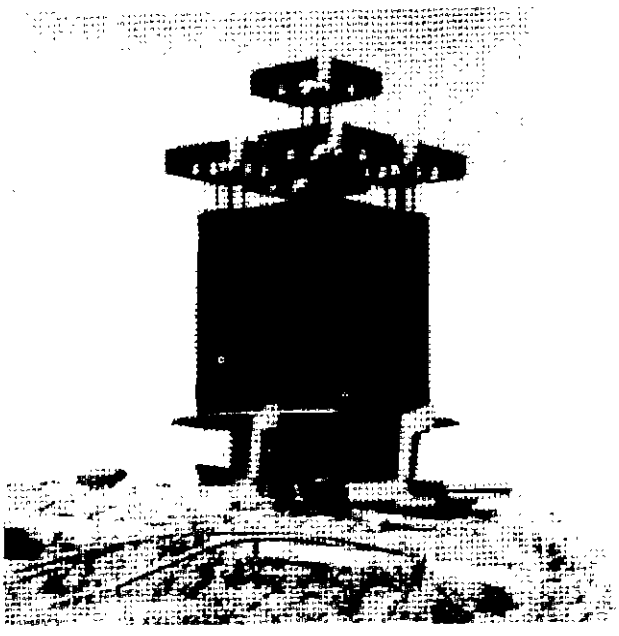
The Region Seven mountain-top site is located at Malad City, Idaho and the Region Six site is at Ukiah, Calif. In each case, a VOR facility had previously been installed at a site other than a prepared mountain top, with resulting unsatisfactory VOR performance.

VOR AT MALAD CITY, IDAHO

At Malad City, Idaho, a mountain-top site (42° 12' Lat., 112° 27' 30" Long., Alt. 6,468 feet msl) was selected which is higher than any other terrain for a radius of approximately 12 miles. This location was chosen on the basis of panoramic data and accessibility.

Prior to any preparation of the site, a standard 5-loop antenna array was installed temporarily on the mountain top and flight tested. Figs. 1A and 1B are views of the antenna installation and the mobile transmitting equipment as they were used during the initial flight tests. The topography of the Malad City site and the area which was leveled in the final preparation of this site is shown in Fig. 2. A flight check of the unprepared site was conducted on August 16, 1950, in a Region Seven patrol aircraft. The flight testing included theodolite flight calibration, flight on eight radials to a distance of 30 miles from the VOR and distance range determination. The results of these tests revealed errors of ±2.6°, and radials had an average scalloping of ±0.6°. The distance range of the VOR was in excess of 125 miles at the minimum instrument altitude of 11,000 feet msl. There was evidence, at times during the radial flight checks, of partial cancellation of the signal. This signal cancellation was evident in the VOR receiver audio system, accompanied by erratic action of the flag alarm. The flag alarm appeared intermittently on six of the eight radials.

The scalloping recorded on each par-



(A) View Looking East at 5-Loop Antenna Array

(B) View From a Point South of Site Showing Portable Transmitter

Fig. 1 Malad City, Idaho Mountain-Top VOR. Unprepared Site, 5-Loop Antenna Array.

ticular radial is listed as comparative data in the table of results of the final flight checks conducted on the prepared mountain-top site.

Following the initial flight test on August 16, 1950, the mountain top was altered to provide a circular level area approximately 300 feet in diameter. In the center of this leveled area, a standard 35-foot diameter solid counterpoise was installed flush with the ground, and a standard 5-loop VOR antenna array was erected at the center of the counterpoise.

The flight testing of the VOR was conducted on September 16, 17 and 18, 1950, in TDEC airplane N182. First the standard 5-loop VOR antenna was flight checked, and at the conclusion of this flight the 5-loop antenna was replaced with a 4-loop array and all the flight tests were repeated with the exception of the theodolite flight calibration. Figs. 3A, 3B, 3C and 3D show views of the leveled mountain-top site and the 4-loop antenna installation.

FLIGHT TESTS

Radial Flights

Eight radials were flown from the VOR to points 30 miles from the station. The aircraft course on any radial chosen for flight testing was maintained very accurately by verbal directions received from the operator of a theodolite located at the VOR site. Visibility conditions were excellent throughout the flight testing period and theodolite guidance was maintained to a point 30 miles from the station on all radials.

Of the eight radials selected for flight checking, four were airway radials and the remaining four were bisector radials between the airway radials. Three of the eight radials passed over mountains which were higher than the VOR site. All radials were flown at or above the minimum instrument altitude of 11,000 feet msl. The maximum scalloping recorded on each radial was converted to degrees of course displacement, as listed in Table I.

During the radial flight checks the flag alarm current also was recorded. The recordings show that the flag appeared briefly on three of the eight radials; however, it was discovered later during the distance range flight check that the transmitter was not properly adjusted with respect to percentage modulation. The data obtained during the distance range flight test indicated that the variable phase signal modulation at the transmitter was approximately ten per cent low. It was concluded that, had the proper percentage modulation been present at the transmitter, the resulting flag cur-

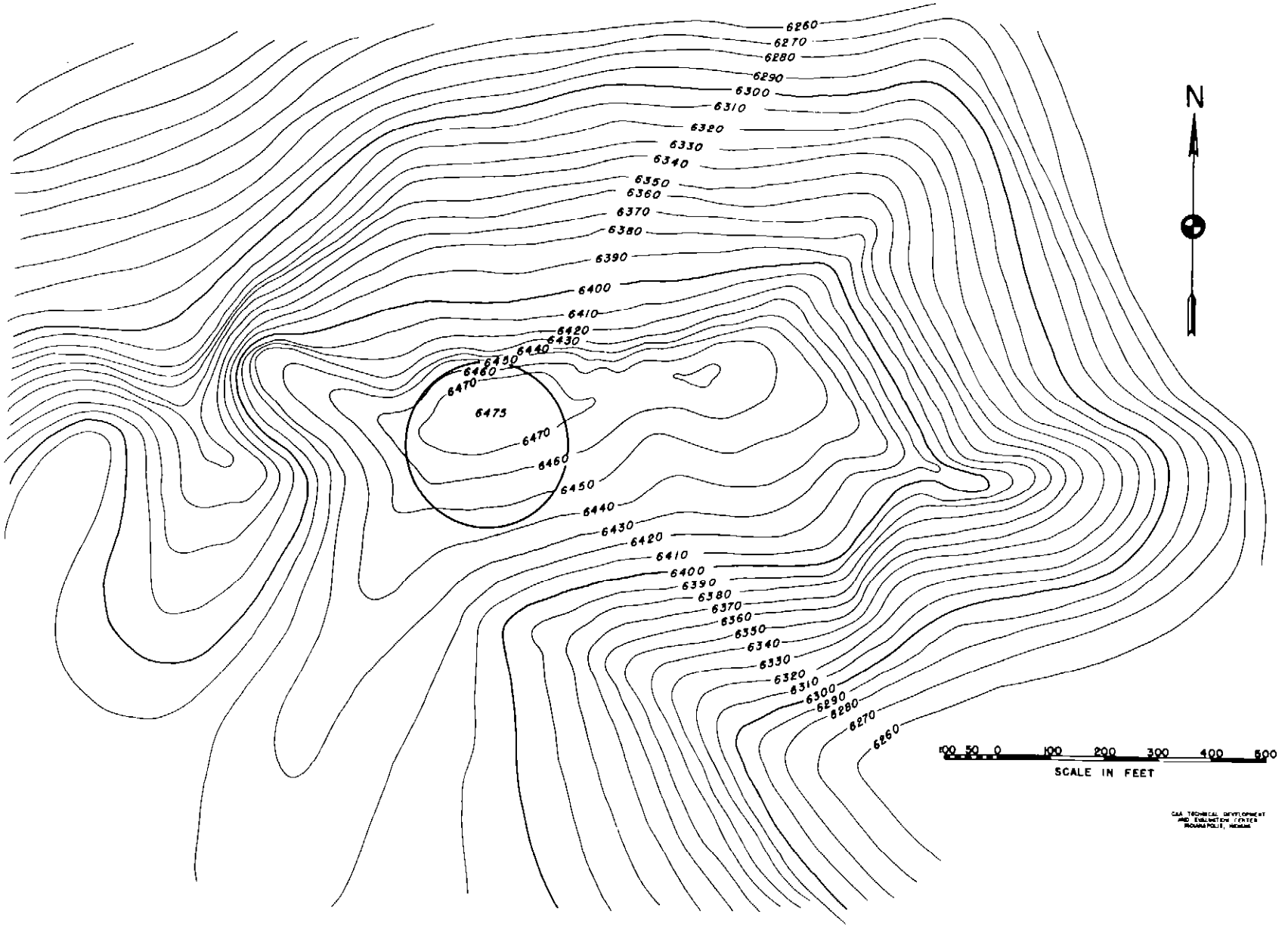
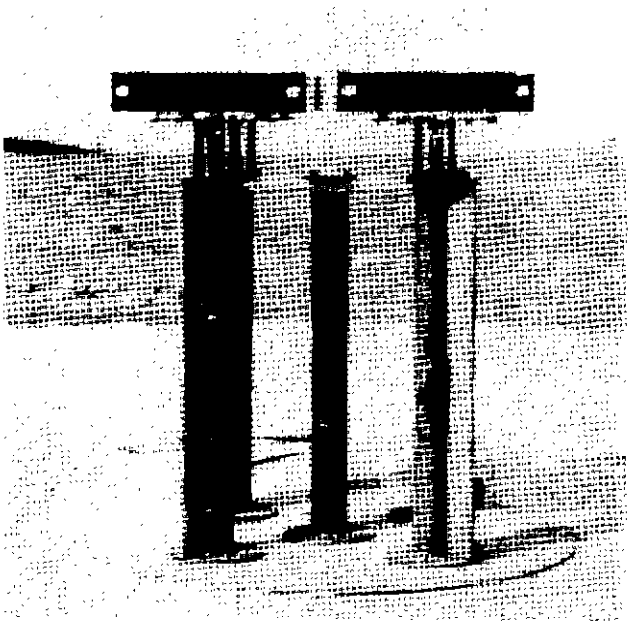


Fig. 2 Malad City, Idaho VHF Radio Facility Topography of Mountain-Top Site



(A) 4-Loop VOR Antenna Array

(B) View of Antenna Array From Southwest Edge of Leveled Area

(C) Looking West From Point Southeast of Prepared Site

(D) View From a Point South of Prepared Site, Showing Portable Transmitter and Approach Road

Fig. 3 Malad City, Idaho Mountain-Top VOR. Prepared Site, 4-Loop Antenna Array.

TABLE I

Radial (degs.)	Maximum Scalloping (Degrees) Original Unprepared Mountain Top 5-Loop Ant.	Leveled Mountain Top Approx. 300' Diameter 5-Loop Ant.	4-Loop Ant.
117	±0.94	±0.5	±0.37
146	±0.47	±0.62	±0.5
87	±0.68	±0.75	±0.5
302	±1.18	±0.4	±0.25
29	±0.53	±0.5	±0.5
272	±0.5	±0.25	±0.25
331	±0.73	±0.25	±0.25
209	±0.56	±0.25	±0.25

rent in the airborne receiver would have been sufficient to prevent the flag alarm from appearing on any of the radial flights. This was verified by the report on the flight conducted by Region Seven, which followed the TDEC evaluation flights approximately two weeks later. The Region Seven report states, "At no time during the entire flight check did the flag show except in the case of the 87° radial, in which case this radial was flown to the end of its usable distance as determined by the flag appearance."

During the radial flight checks conducted August 16 on the unprepared mountain-top VOR installation, it was observed that the most erratic operation of the flag alarm occured on the 117° radial. This radial was much improved by the preparation of the mountain top; however, partial cancellation of the signal still existed and caused small fluctuations in flag alarm and course deviation indicator currents. The recordings of field strength, flag alarm and course deviation indicator currents obtained on the 117° radial (of the prepared site) are reproduced in Fig. 4. Fig. 5 is a contour map of the Malad City, Idaho VOR area showing the 117° radial course.

Theodolite Calibration Flight

The 5-loop antenna on both the unprepared and leveled mountain top was calibrated by theodolite. The actual calibration consisted of recording the current of the course deviation indicator in the airplane as it circled the VOR at a radius of seven miles. The omnibearing selector was advanced in 10° steps to keep the course deviation indicator on scale and to present, at center scale, the indicated magnetic bearing from the station. This indicated bearing was compared with the magnetic bearing from the VOR as measured by a theodolite operator on the ground at the station. The error curves obtained on the two theodolite calibration flights are presented in Fig. 6. These flights were conducted at an altitude of 8,500 feet msl or approximately 2,000 feet above the VOR site.

The direction of flight of an aircraft on a given VOR course affects the course distortion frequency when such distortion is present due to reflected energy. The frequency of distortion is less for a radial flight than for a circular flight. From the recordings obtained during the theodolite calibration flight, wherein a circular track rather than a radial track is flown, it is possible to obtain comparative data with respect to energy reflected from objects in proximity to the station. The maximum over-all scalloping in degrees recorded on each 10° segment of the theodolite error curve recording is plotted as a visual aid in presenting amplitude and azimuth information with respect to scalloping encountered in flying a 7-mile radius circle around the VOR. Fig. 7 is a graph of the over-all scalloping recorded on the theodolite calibration flight on both the unprepared site and the final leveled site.

Cone Measurements

In order to measure the cone of a VOR from a recording of the course deviation indicator current, a definition of the cone must be stated so that the beginning and end of the cone may be positioned on the recording.

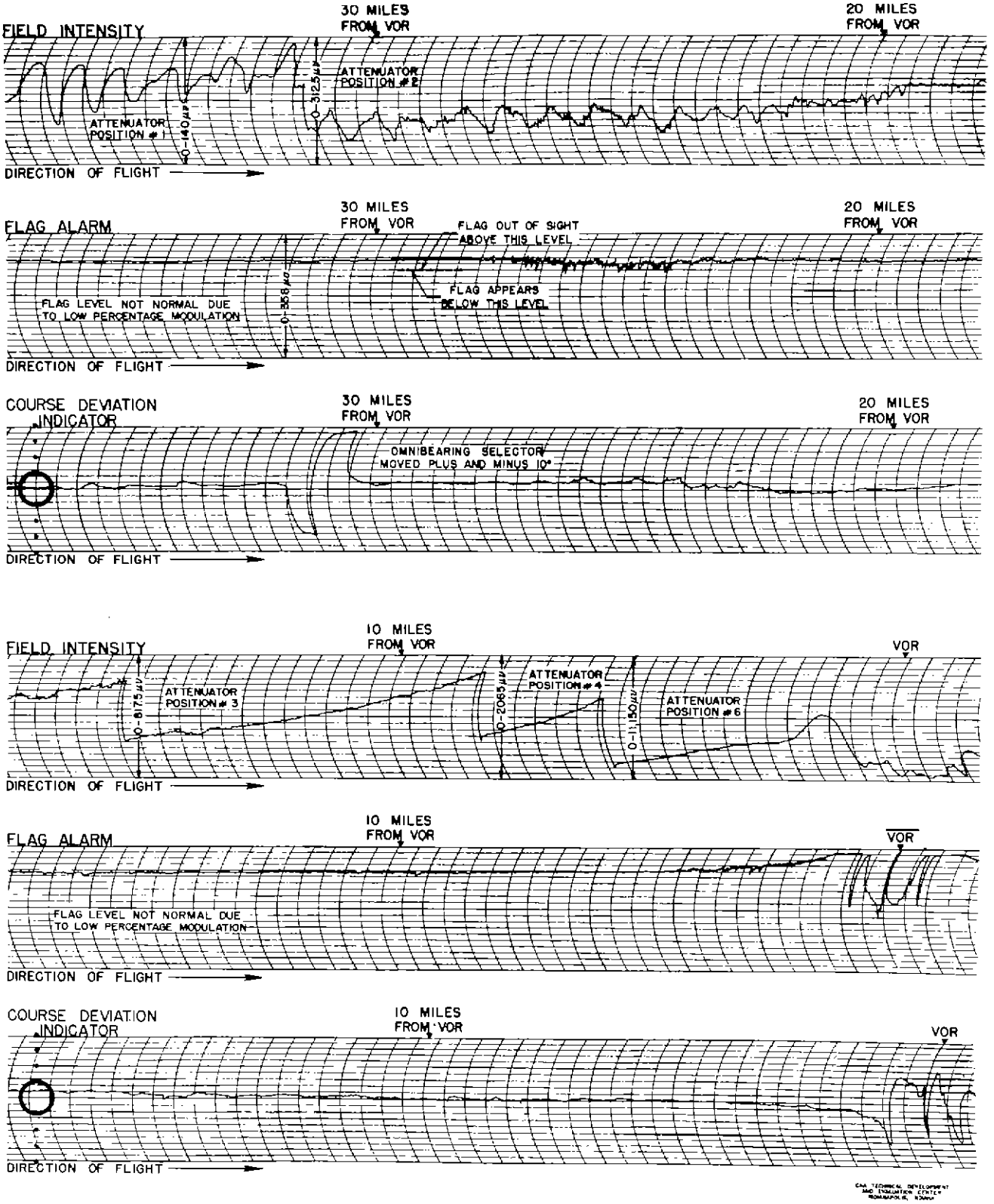


Fig. 4 117° Radial Flight Check Recordings. Malad City, Idaho Prepared Mountain-Top VOR.

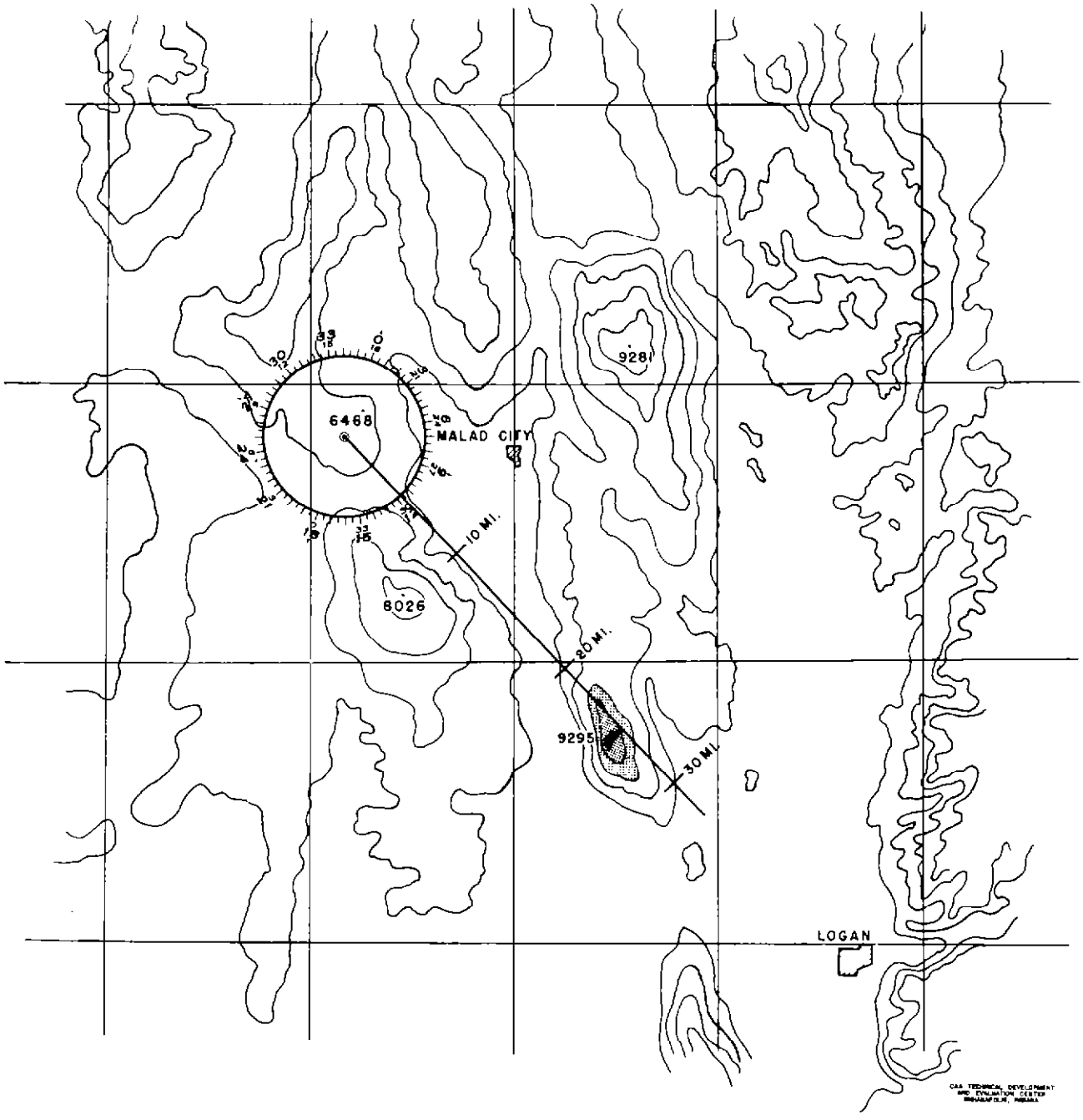


Fig. 5 Contour Map Malad City, Idaho Showing 117° Radial Course

The course deviation indicator is considered to be graduated in ten equally spaced "dots" across the face of the instrument. When the indicator deviates beyond one dot, and this deviation is due to the normal course disturbances encountered above a VOR, the cone is considered to begin at this point. In a similar manner, the cone ends at the one dot deflection point as the straight line course indication is resumed on the other side of the cone.

The cone measurements obtained in the flight testing of the prepared site, on both the 5-loop and the 4-loop antennas, are listed in Table II.

The cone angles measured have a wider range of values than normally encountered in flight testing a standard VOR; however, the

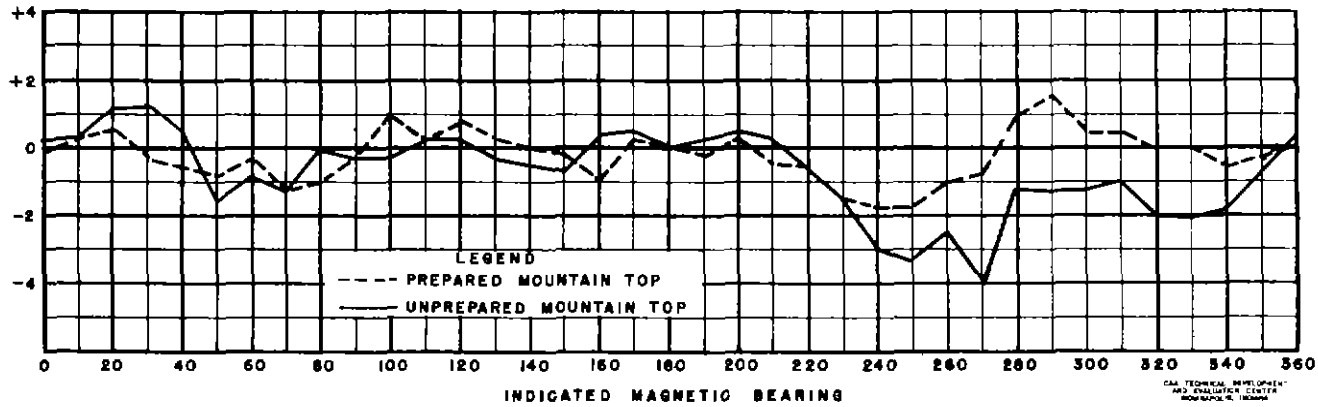


Fig. 6 Theodolite Flight Calibration Error Curves. Malad City, Idaho Mountain-Top VOR, 5-Loop Antenna Array.

TABLE II

Radial (degs.)	Cone Angle Above Ground 5-Loop Ant. (degs.)	4-Loop Ant. (degs.)
209	62.8	75.0
272	48.5	60.6
29	50.0	No record
117	No record	68.6

average value is approximately the same. This would indicate that the mountain-top VOR cone is not as symmetrical as a standard VOR cone.

Vertical Plane Field Patterns

The field intensity recordings obtained on the radial flights provide data for plotting the vertical plane field pattern of the mountain-top site. Figs. 8 and 9 show the relative vertical plane field intensity patterns of the 5-loop antenna and the 4-loop antenna respectively. The vertical plane patterns are plotted from the recordings obtained while the aircraft was flying to the station. The antenna in use on the aircraft was a Type V-109 mounted on the top forward position of the fuselage, and the aircraft antenna pattern directivity is included in the vertical plane field patterns.

Distance Range Check

The distance range of a VOR facility is defined as the distance in statute miles from a VOR at which the course sensitivity in degrees becomes double the course sensitivity measured at approximately ten miles from the station. The distance range flight check was conducted on the 146° radial, which is the enroute airway radial to Salt Lake City, Utah, at the minimum instrument altitude of 11,000 feet msl. The distance range, double course sensitivity point, was measured to be 130 miles from the Malad City station.

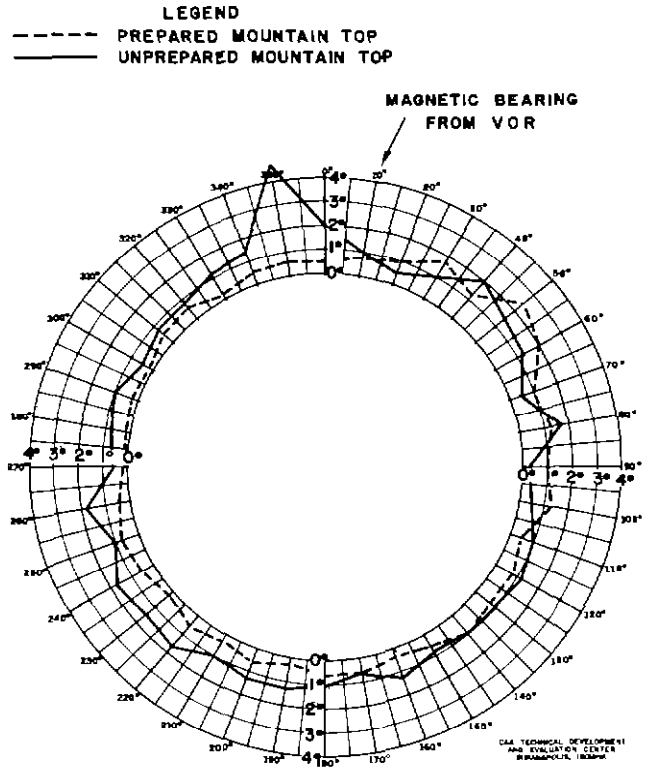


Fig. 7 Scalloping Graph. Malad City, Idaho Mountain-Top VOR, 5-Loop Antenna Array.

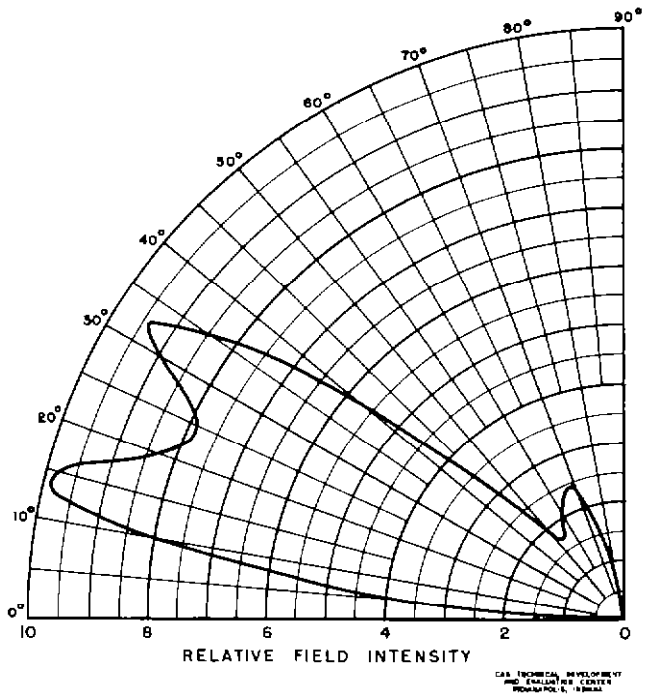


Fig. 8 Vertical Plane Field Pattern. Malad City, Idaho Mountain-Top VOR. 5-Loop Antenna Array on Prepared Mountain-Top Site

30° Wing Rock Polarization Check

One polarization check was made on the Malad City VOR. This check consisted of rocking the wings of the aircraft ±30° while flying toward the VOR. The course displacement of the course deviation indicator was converted to degrees error and was found to equal ±0.12°.

TO-FROM Indicator Recordings

The TO-FROM indicator current was recorded on radial flights directly over the station when the 5-loop antenna was installed and again when the 4-loop antenna was in operation. Fig. 10 is a reproduction of one of the recordings obtained in each case. One of the outstanding features of the 4-loop antenna is the excellent position indication produced by the action of the TO-FROM meter when passing over the station. As shown in Fig. 10, the action of the TO-FROM indicator when passing over a VOR facility employing a 4-loop antenna is one smooth movement of the indicator from the TO position to the FROM position, providing a precise check when the aircraft is directly over the station.

VOR AT UKIAH, CALIFORNIA

At Ukiah a standard VOR employing a 15-foot high counterpoise had previously been installed on a mountain top and the performance was unsatisfactory. The problem was referred to the TDEC for correction. In order to obtain first-hand information on this siting problem, personnel from the Center flew to Ukiah, Calif. on January 25, 1950, to conduct flight tests and make an inspection of the site.

Following these initial flight tests, a detailed theoretical study was conducted at TDEC to determine the most practical and economical means of preparing the site to secure satisfactory VOR performance. As a result of this study, it was recommended that the mountain top be prepared to provide a level circular area 200 feet in diameter. In the center of the area the VOR antenna was to be located on the ground. The transmitting equipment was to be located at a point below the circular leveled area.

Acting on this recommendation, the CAA Sixth Region removed the original installation,

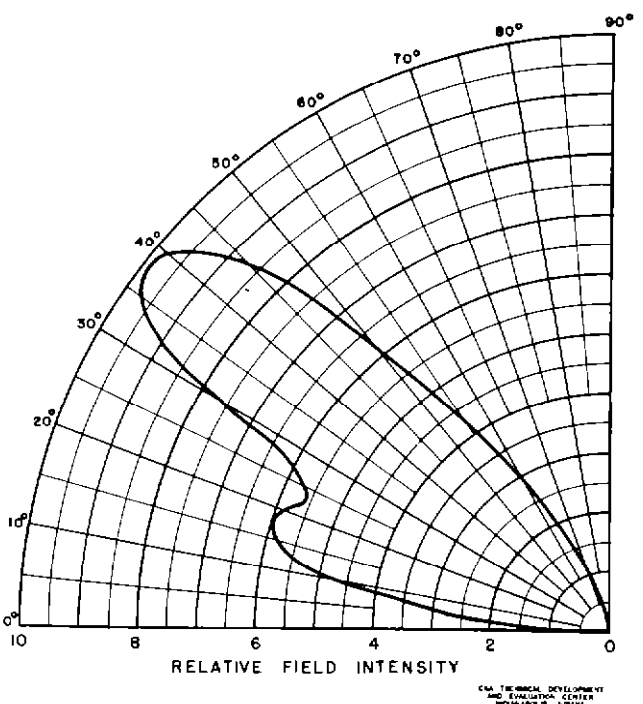


Fig. 9 Vertical Plane Field Pattern. Malad City, Idaho Mountain-Top VOR. 4-Loop Antenna Array on Prepared Mountain-Top Site.

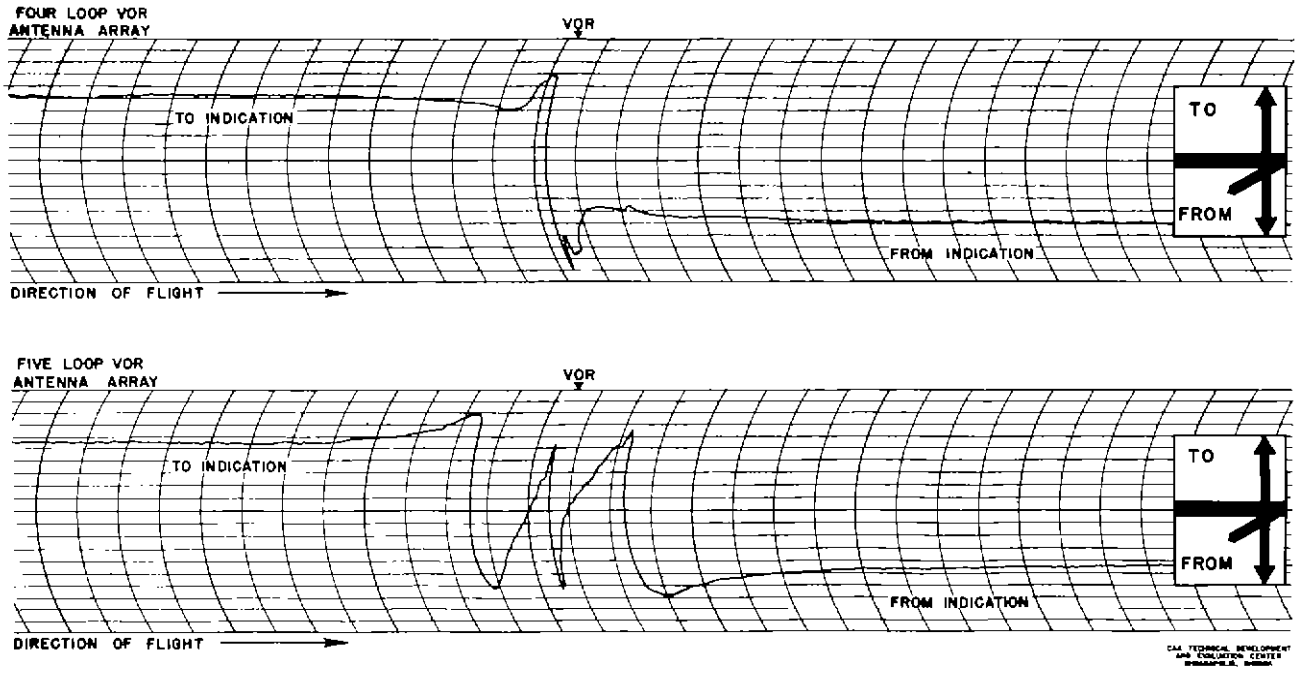


Fig. 10 TO-FROM Indicator Recordings of 4-Loop and 5-Loop Antenna Arrays

and at the same location, leveled the site in accordance with the TDEC recommendations. The location of the Ukiah, Calif. site is 39° 3' 13" Lat., 123° 16' 24" Long. and has an elevation of 3,400 feet msl. Fig. 11 is an aerial view of the site.

FLIGHT TESTS

Flight testing of the Ukiah VOR consisted of a theodolite flight calibration and six radial flights to a distance of 30 miles from the station. During these flight tests the field intensity, flag alarm, TO-FROM indicator and course deviation indicator currents were recorded.

Radial Flights

Six radials were flown from the VOR to points 30 miles from the station at an altitude of 6,000 feet msl. The position of the aircraft was maintained on any course chosen for flight testing by information provided by the operator of a theodolite at the VOR site. The maximum scalloping recorded, on each of the six radials flown, was converted to degrees of course displacement as listed in Table III.

Theodolite Calibration Flight

A standard theodolite calibration flight was conducted on the Ukiah mountain-top installation. During the flight, the air-

TABLE III

Radial (degs.)	Leveled Mountain Top VOR Max. Scalloping (degs.)	Standard 15' High Counterpoise VOR Max. Scalloping (degs.)
14	±1.5	No record
121	±0.5	±1.5
194	±0.5	No record
127	±1.0	No record
249	±0.75	No record
305	±0.5	±2.25

Fig. 11 Ukiah, California Mountain-Top VOR

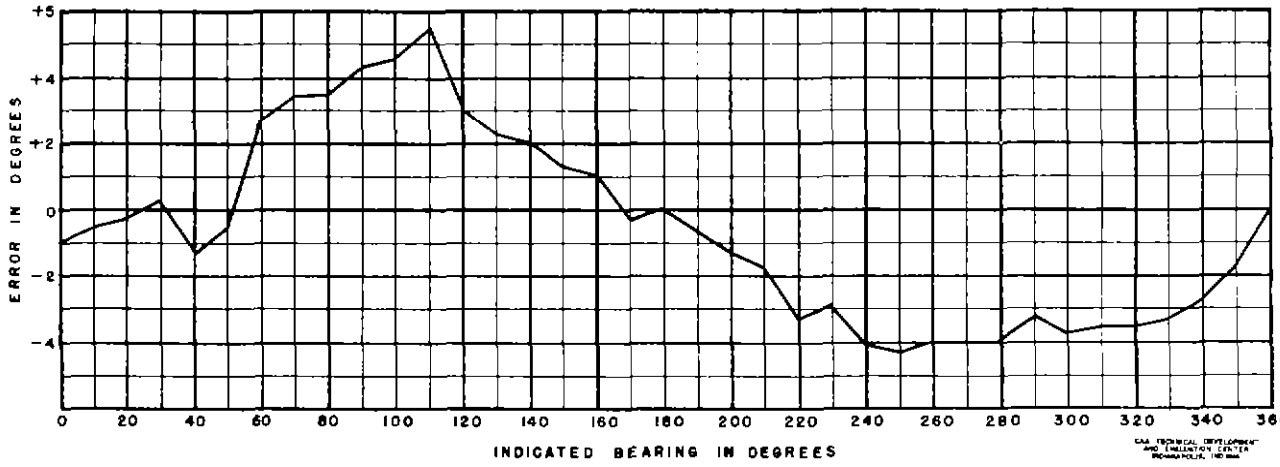


Fig. 12 Theodolite Flight Calibration Error Curve. Ukiah, California Mountain-Top VOR.

craft was flown at an altitude of 5,000 feet msl on a 7-mile radius circle about the station. The error curve obtained revealed an error of ±4.87°, and the error curve is shown in Fig. 12.

From the recordings obtained during the theodolite calibration, the amount of scalloping encountered in a circular flight about the station was measured. The maximum over-all scalloping in degrees, recorded on each 10° segment of the theodolite error curve recording, was plotted and is shown in Fig. 13. Included in Fig. 13 is the scalloping data obtained on the January 25 flight test of the standard installation.

Vertical Plane Field Pattern

The relative vertical plane field intensity pattern of the Ukiah station was plotted from the field intensity recordings obtained on the radial flights and is shown in Fig. 14. This pattern was plotted from the recordings obtained when the aircraft was headed toward the station. The antenna in use on the aircraft was a hatch-mounted Type V-109, and the aircraft antenna pattern directivity is included in the pattern.

Cone Measurements

From the recordings of the course deviation indicator obtained on radial flights, the cone angle above ground was measured. The cone measurements and the corresponding radials being flown are listed in Table IV.

30° Wing Rock Polarization Check

One polarization check was conducted on the Ukiah VOR. For this test the aircraft was banked ±30° at a distance of approximately 15 miles from the station. The nose of the airplane was held "on the point" during this maneuver. The course deviation indicator current was recorded and converted to degrees of course displacement. The course displacement measured was ±2.12°. This is a very high value of polarization error as compared to the ±0.75° error normally measured on a standard VOR facility.

TABLE IV

Radial (degs.)	Cone Angle Above Ground (degs.)
14	47.0
121	51.5
249	50.8

At the time these flight tests were conducted, the Ukiah VOR utilized a portable antenna consisting of a center pedestal 48 inches in height, supporting a plywood sheet on which were mounted four 12-inch pedestals for the sideband loops and a 20-inch pedestal supporting the carrier loop. This particular type of antenna installation has not been utilized before and the results of the polarization tests indicate that the vertically polarized radiation from this array was excessive.

CONCLUSIONS

The results of the flight tests at Malad City, Idaho and Ukiah, Calif. indicate that very satisfactory VOR performance may be

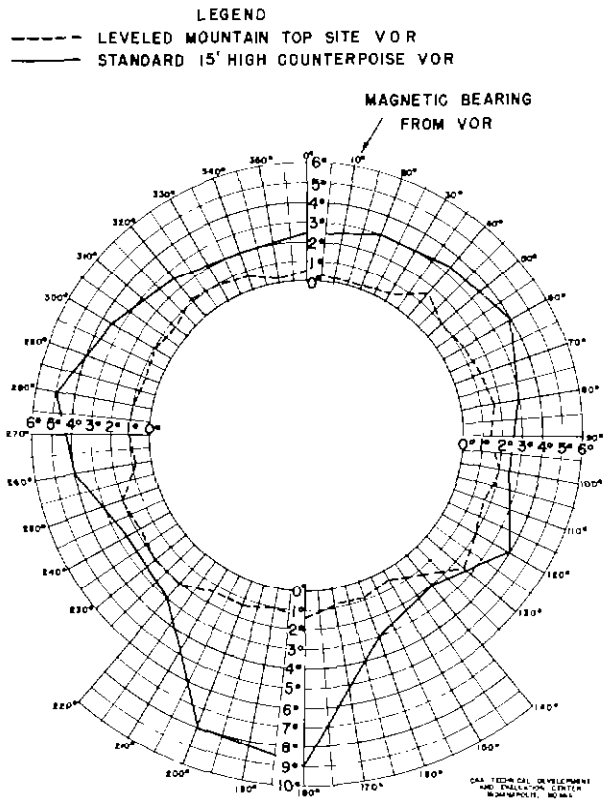


Fig. 13 Scalloping Graph Ukiah, California

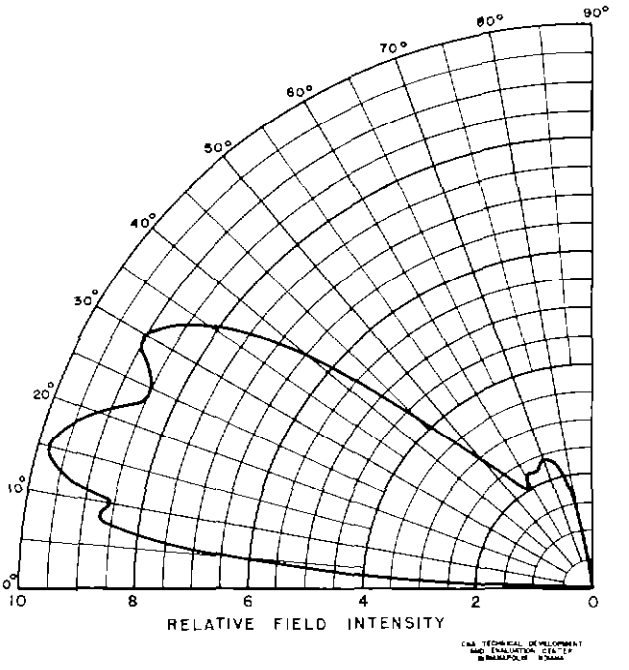


Fig. 14 Vertical Plane Field Pattern. Ukiah, California Mountain-Top VOR.

obtained at mountain-top sites. The results obtained at Ukiah show that a leveled mountain-top site is far superior to a standard VOR installation on a mountain top. It is believed that the error curve and polarization error measured at Ukiah will be greatly improved by the use of a standard antenna array.

All factors considered, the results of these flight tests show that the 300-foot diameter leveled area used at Malad City is superior to the 200-foot diameter flat top used at Ukiah.

In each of the two cases described in this report, portable equipment was used and many of the necessary pieces of test equipment required for final tune-up of a commissioned facility were not available. The flight tests reveal that straight courses with a minimum of scalloping are provided, and the service area of both stations is excellent.

It is recommended that permanent VOR facilities be installed at each of these sites and that mountain-top sites levelled to a 300-foot diameter be adopted where required.

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