A TERMINAL VHF OMNIRANGE MARKER

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A TERMINAL VHF OMNIRANGE MARKER*

SUMMARY

This report presents a technical description of a terminal VHF omnirange marker developed at the Technical Development and Evaluation Center of the Civil Aeronautics Administration. The purpose of the marker is to provide an audible position indication to aircraft on designated TVOR approach radials.

The marker incorporates a principle of operation which requires no marker receiver, since the marker signals are received on the VOR navigation receiver simultaneously with the TVOR signals. It is small and inexpensive. Power for the marker is supplied from batteries, and, because of the low-current drain, servicing is required only every six weeks

The data presented in this report are typical of those obtained from the measurements of four units of equipment now operating in conjunction with the TVOR at Weir Cook Airport, Indianapolis, Indiana.

INTRODUCTION

The operational experience gained in the use of the very-high-frequency omnirange (VOR) system resulted in the conviction that there are many advantages to be gained by placing a VOR on an airport. This led to the development of the terminal VHF omnirange, or TVOR[1]. The TVOR offers accurate and reliable guidance for aircraft descending under instrument-flight-rule (IFR) conditions to minima that will place each aircraft in a position to land on a runway when the pilot establishes visual contact with the airport.

Operational experience gained in flying the TVOR as an approach facility immediately revealed the fact that a TVOR marker would greatly facilitate the approach procedure by providing a check point at which the descent to minimums could be safely started.

The use of markers to provide position indication in aerial navigation is not new. For example, the instrument landing systems (ILS) installed throughout the United States are augmented by one or more markers at each installation. These markers operate on a frequency of 75 Mc and require a special airborne receiver and antenna. This type of marker has been in operation for a number of years and has proved to be a reliable and accurate position-indicating device. Such a marker could be used to augment the TVOR and would provide the same service in conjunction with the TVOR as it does with the ILS. However, a new type of marker was developed involving a principle of operation which results in greater economy with respect to the ground-installation and aircraft-equipment requirements.

The TVOR marker consists of a one- or two-tube, crystal-controlled, battery-powered transmitter with an r-f output of one milliwatt and a simple two-V type of antenna array. The marker is located at a suitably located plot of ground approximately 66 feet by 66 feet. The marker transmitter operates on the same frequency as the TVOR, ± 2000 cps approximately, and the transmitter output consists of keyed CW (continuous wave) radio-frequency energy.

In developing the TVOR marker it was assumed that the aircraft would be equipped with a VOR receiver and that no additional equipment would be required in the aircraft. A pilot in an airplane flying a radial over the marker hears a keyed signal of approximately 2000 cps in the headphones of the VOR receiver. The audio output is the result of the beat note derived from the marker carrier signal and from the TVOR carrier signal. This eliminates the necessity for an audio oscillator and a modulator in the marker transmitter. Furthermore, because of its extremely low power, no course distortion of the TVOR is apparent when the aircraft is flying over the marker.

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[1] S. R. Anderson and T. S. Wonnell, "The Development and Testing of the Terminal VHF Omnirange," Technical Development Report No. 225, April 1954.

*Manuscript submitted for publication September 1953

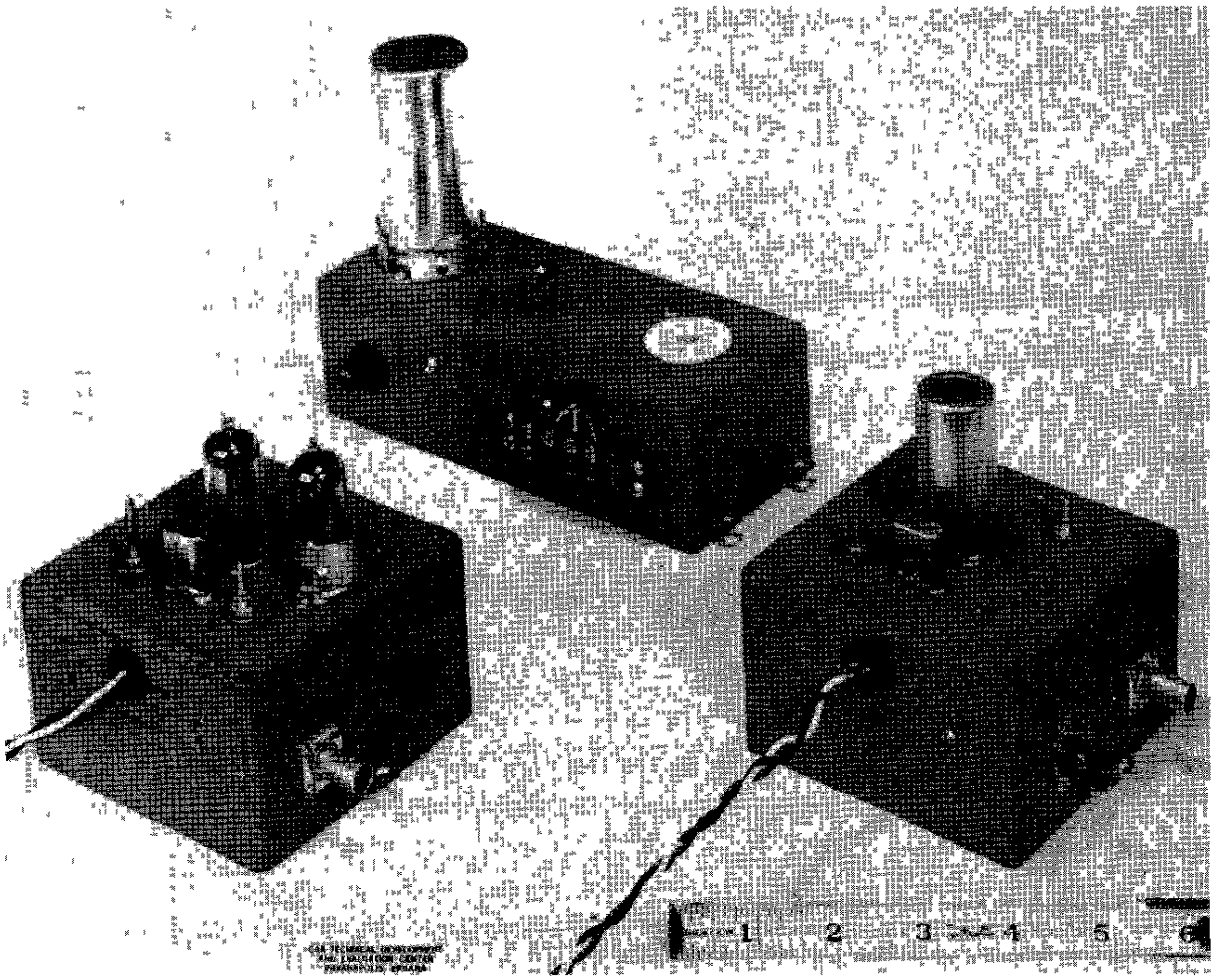

Fig. 1 TVOR Marker Transmitters and Power Supply

TRANSMITTER

R-F Circuits.

The two primary specification requirements for the marker transmitter are that it be crystal-controlled and that it consume a minimum of power. These requirements dictate the use of an overtone-crystal oscillator circuit in order to obviate the use of frequency-multiplication stages.

The TVOR at Indianapolis Weir Cook Airport operates on a frequency of 114.4 Mc. The transmitter, therefore, must transmit on a frequency of 114.4 Mc ± approximately 2000 cps. Three different marker transmitters were developed for this purpose. Two of these employ a fifth-mode overtone oscillator at 57.2 Mc with a doubler output circuit. They are shown in Figs. 1 and 2. The third transmitter consists of a single-triode tube using a ninth-mode overtone crystal oscillating at a frequency of 114.402 Mc.

The schematic diagrams of these three transmitters are shown in Figs. 3, 4, and 5. Of these three, the best transmitter from the standpoints of stability and reliability is the one employing the 12AT7 tube and shown in Fig. 4.

Laboratory tests were conducted on these transmitters to determine the effects of temperature and the variations of battery voltage. The data obtained from the tests conducted

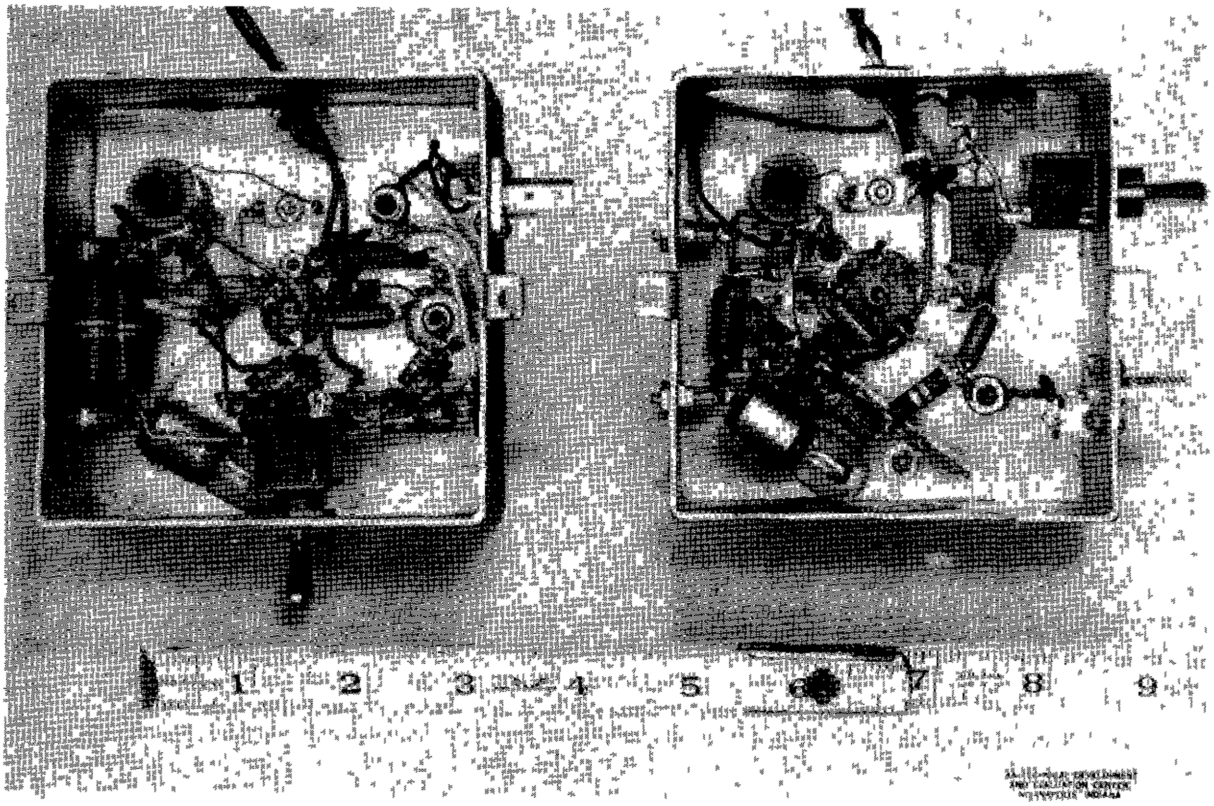

Fig. 2 Bottom View of Types 2 and 1 Transmitters

on a transmitter which used a fifth-mode overtone crystal and a Type 12AT7 tube are presented in Figs. 6, 7, and 8. Figure 6 is a dual graph of output and audio-beat-frequency variations during temperature tests. The temperatures ranged from -25° to +55° C.

The transmitter keying rate was also observed during these temperature tests. It varied from 2.9 to 5 transmissions per second. Figure 7 is a graph of the audio-beat frequency versus the battery voltage. This graph indicates the frequency stability throughout the battery charge-to-discharge cycle. Figure 8 shows the transmitter power-output variation with change in battery voltage.

The development of a keyer for the TVOR marker resulted in the use of a relaxation oscillator which periodically biases the crystal oscillator to the point of cut-off. The keying circuit is shown in Fig. 4.

Power Source.

The specifications for the marker required a battery power source of sufficient capacity to provide 6 volts for tube filaments and approximately 90 volts for the keyer and the plate circuit and to operate the transmitter for a period of not less than six weeks. The high voltages may be produced by the connection of battery cells in series or by the use of a low-voltage source and a vibrator-transformer type of power supply. Several schemes were investigated.

Dry-Cell Batteries.

Effect of Temperature.

In dry-cell batteries, chemical reactions are accelerated by an increase in temperature. In the dry cell, a temperature rise increases both the useful current-producing reaction and the parasitic local reaction during idle periods. The net effect on the total capacity delivered will depend on the balance between these two forces and will be different for various designs of cells. As the temperature decreases, the activity of the cell is lowered until finally the cell

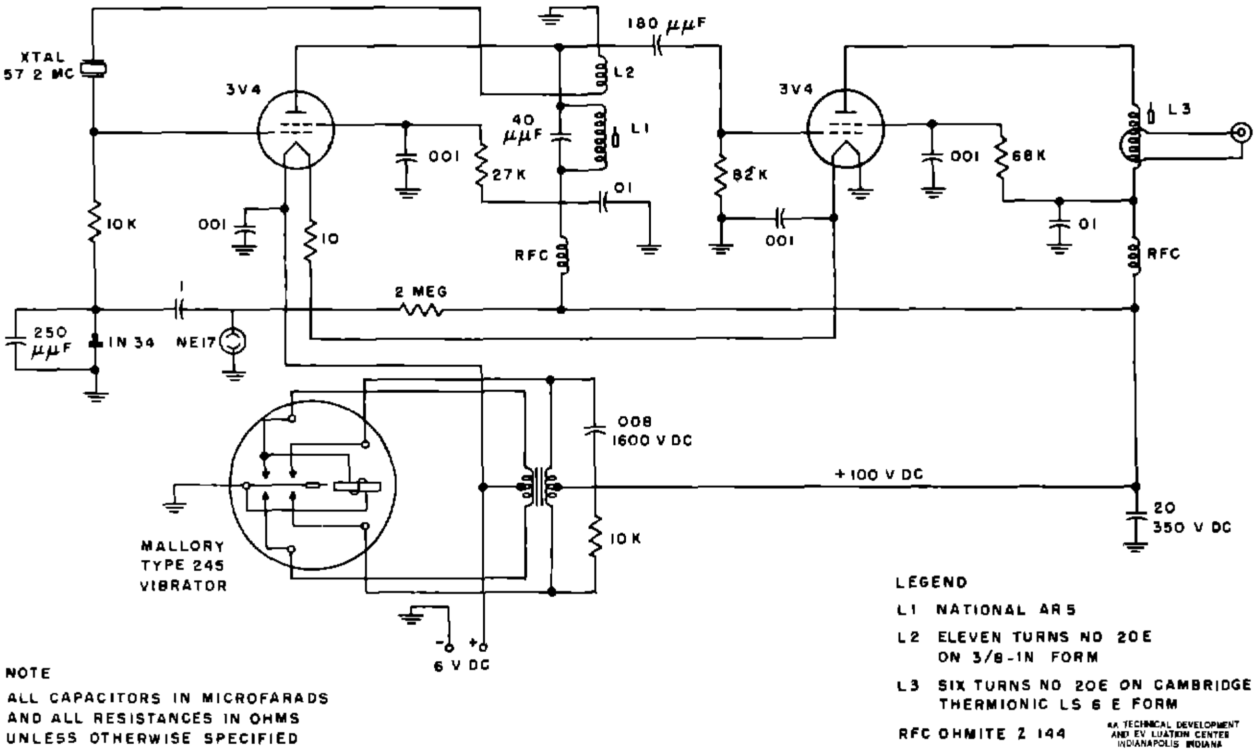

Fig. 3 Type 2 Transmitter (Electrical Schematic)

is unable to maintain a useful voltage while delivering current. The lowest temperature limit of use will depend on the cell formula, the cell size in relation to the drain of current, and the frequency of use. In general, dry cells will not furnish useful current when the actual cell temperature is less than -15° to -20° F. Freezing does not injure a dry cell, and capacity which cannot be realized at low temperature will be available when the cells are returned to normal temperature. Table I summarizes the effect of temperature on dry-cell batteries.

TABLE I

EFFECT OF TEMPERATURE ON DRY-CELL BATTERIES

Temperature (degrees F)	Capacity (Based on value at 70° F taken as 100% capacity) (percentage)
100	140
80	115
70	100
60	90
40	69
20	48
0	27
-20	6

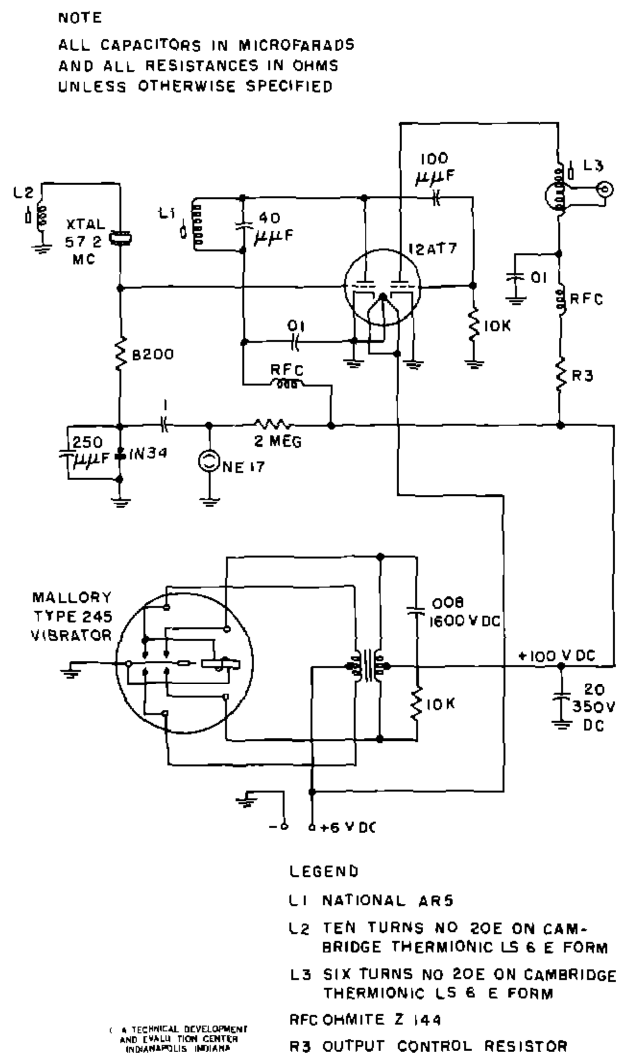

Fig. 4 Type 1 Transmitter (Electrical Schematic)

Battery-Life Factors.

The factors governing battery life are current drain, hours of use per day, and end-point voltage. Of these three items, the hours of use per day becomes the most critical factor when the dry battery is considered as source of power for the TVOR marker. The marker must transmit continuously. Dry-cell batteries are designed for intermittent operation, and all of the data furnished by the different dry-cell manufacturers was based on a maximum of six hours discharge followed by four hours recovery time.

Shelf Life.

Dry-cell batteries have a shelf life which depends on several factors. In operational use a cool dry storage space and a systemized procurement program in operation would be required in order to realize efficient utilization of these batteries.

The possibility of using mercury-cell batteries as a power source was investigated. The mercury cell is unique in that the output voltage is nearly constant throughout its life cycle. These batteries will deliver rated voltage at temperatures up to 212° F, however, they have very poor output characteristics at low temperatures.

It was concluded that the use of nonrechargeable batteries is not operationally and economically practical for this application.

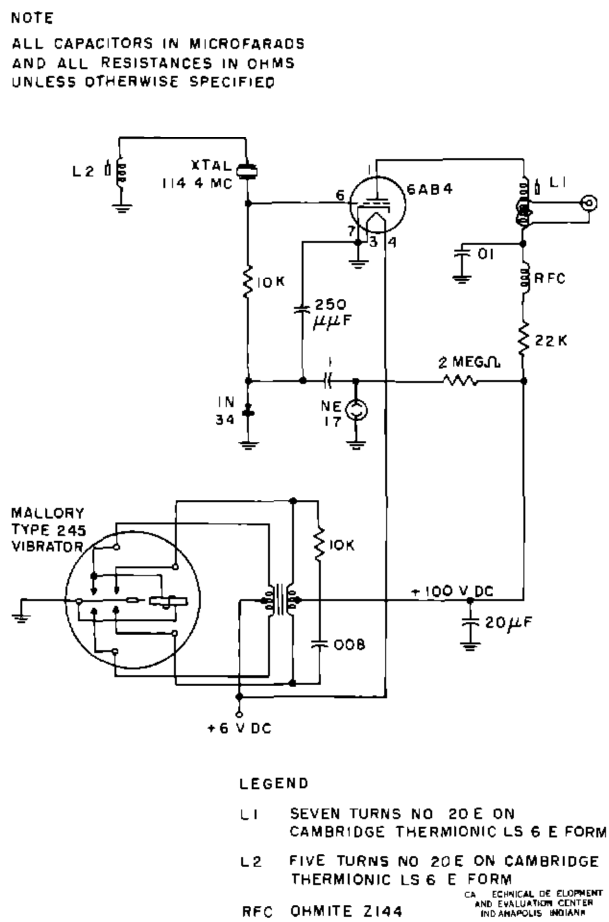

Fig. 5 Type 3 Transmitter (Electrical Schematic)

Wet-Cell Batteries.

The investigation into the characteristics of wet-cell batteries revealed that insofar as this application is concerned there are two major groups

Group 1. The lead-acid cell has a given ampere-hour rating and is capable of high-surge current output.

Group 2. The charge-retaining battery is designed for applications of low current drain.

From available data, it immediately became apparent that there are many advantages to be gained by the use of the Group 2 type of battery as a marker power source. Two distinct advantages of the charge-retaining type of battery are a low self-discharge rate and a voltage which is practically constant throughout the discharge cycle.

Charge-retaining batteries have a self-discharge rate on open circuit of not more than 15 per cent of total capacity per year.

"In a normal lead-acid type battery, the lead grids that hold the active plate material contain from 6 per cent to 12 per cent antimony. During the charging of the battery, a small amount of antimony dissolves from the positive plate grids and deposits on the sponge lead of the negative plates where it sets up a local electro-chemical action.

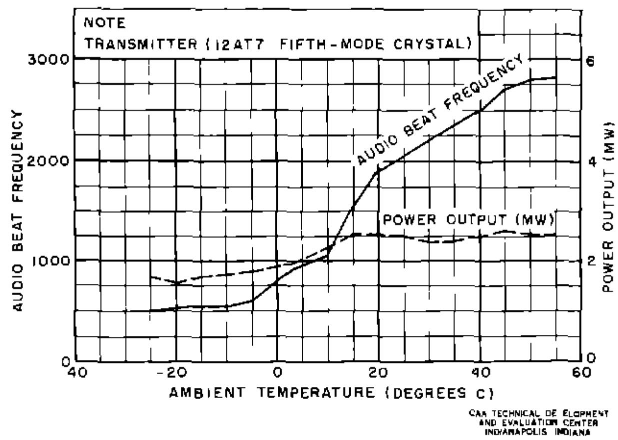

Fig. 6 Frequency-Drift and Power-Output Variation versus Ambient-Temperature Change

This discharges the battery slowly. All batteries with antimony in the grids will therefore slowly discharge on standing and will discharge much faster as the temperature is increased.

The average self-discharge rate at 80° F is 0.001 Sp. Gr. per day."[2]

The charge-retaining type of battery has grids made of 99.996 per cent pure lead in order to eliminate the local electrochemical action. The charge-retaining battery delivers low current over a long period of time at a relatively constant voltage, as shown in Figs. 9 and 10.

For evaluation purposes, two different installations of charge-retaining batteries were put in operation at Indianapolis markers.

No. 1 Installation.

The marker transmitter at this installation used two 3V4 tubes with power requirements of 6 volts at 50 ma for filaments and of 90 volts at 16 ma for the plates. Three Willard 2-volt Type DH-5-1 batteries connected in series supplied the filament power, and 42 Willard 2-volt

[2] "Battery Service Manual," Association of American Battery Manufacturers.

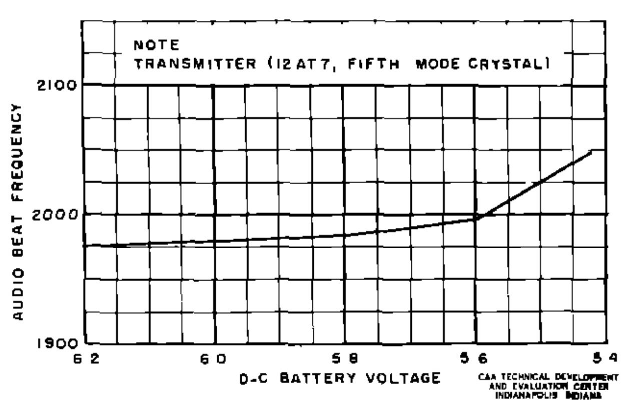

Fig. 7 Audio Beat Frequency versus Battery Voltage

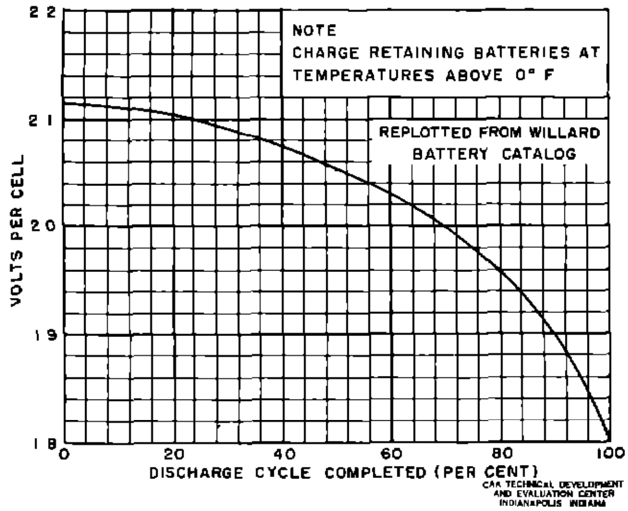

Fig. 8 Power Output versus Battery Voltage

Type DA-2-1 batteries provided the plate supply. Figure 10 indicates an expected life cycle per charge of one year for the filament supply and of ten weeks for the plate supply. This expectation was verified at the No. 1 installation.

No. 2 Installation.

The marker transmitter at this installation used a 12AT7 tube and a vibrator-transformer power supply with a power requirement of 6 volts at 500 ma. Three of the Willard Type DD-5-3 charge-retaining batteries were connected in parallel. These batteries provided power for eight weeks operation, as expected from the curves of Fig. 10.

The operational experience gained from these two installations indicates that

1. The TVOR-marker power source should preferably consist of three or more Willard Type DD-5-3 batteries or their equivalent, connected in parallel and used in conjunction with the vibrator-transformer power supply.

2. The No. 1 installation, consisting of 3 batteries for the filament and of 42 batteries for the plate supply, has the disadvantages of being unwieldy and of presenting the problem of corrosion of the connections between cells. Both of these problems complicate the operational maintenance of the marker.

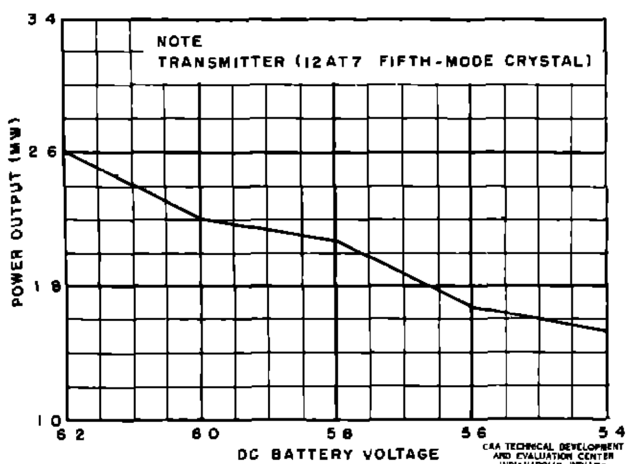

Fig. 9 Average Voltage at Various Stages of the Discharge Cycle

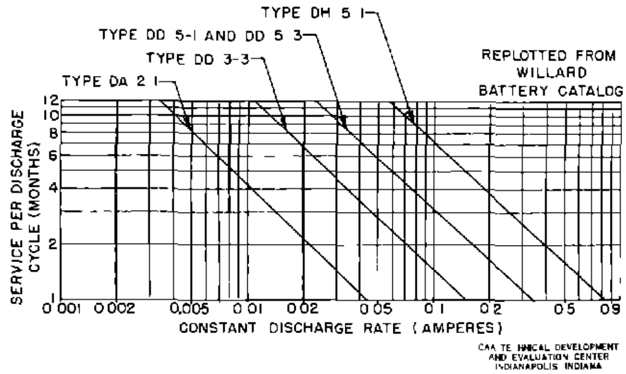

Fig. 10 Battery-Selector Chart, Charge-Retaining Batteries

Battery Vault.

The use of the lead-acid type of storage battery as a power source for the TVOR marker presents the problem of providing protection to the battery during conditions of temperature extremes. The high temperatures encountered during the summer months result in the rapid evaporation of the battery liquid, and the subfreezing temperatures of winter introduce the hazard of battery freezing The solution to this problem consists of housing the batteries in a vault which is placed in the ground and thereby utilizes the temperature-stabilizing effect of the ground.

The battery vaults installed at the four TVOR marker sites at Indianapolis are made of concrete and have inside dimensions of 36 inches long, 24 inches wide, and 36 inches deep. The vault walls are four inches thick and are completely waterproofed. A top for the vault is constructed of wood and is covered with roofing material. The vault is buried to a depth of 30 inches, with the remaining six inches extending above the ground to prevent surface water from entering the vault.

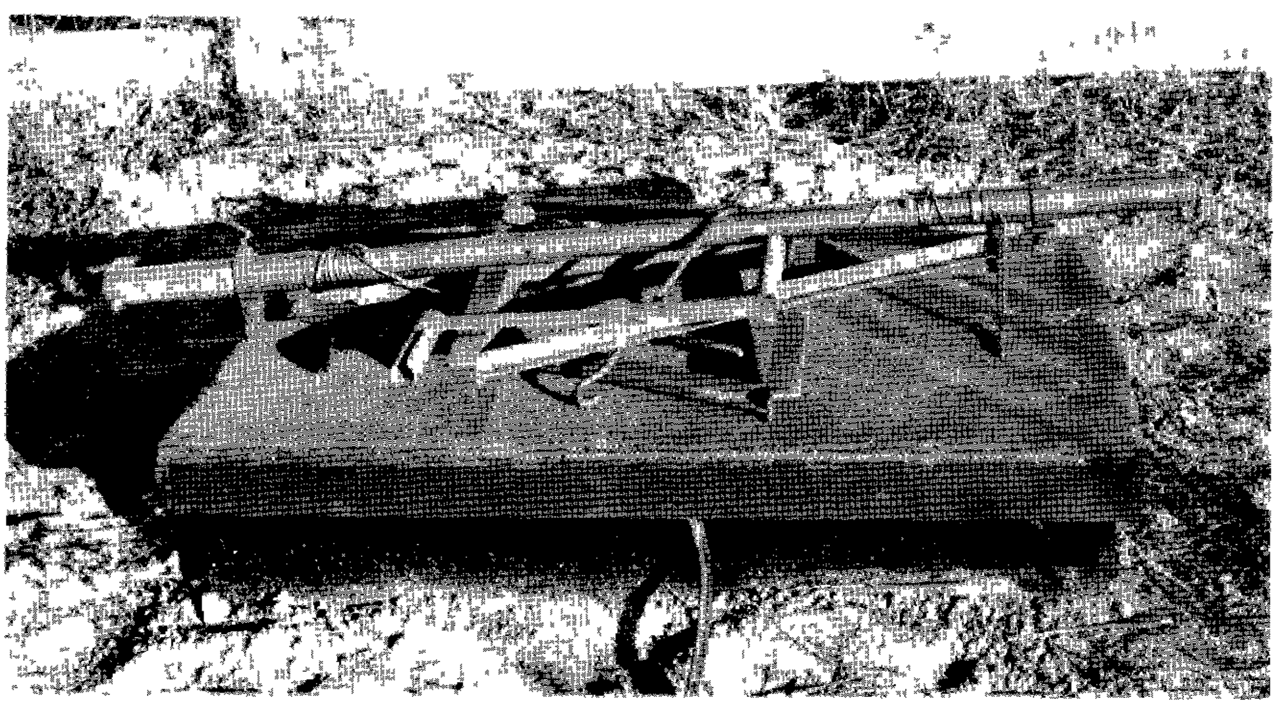

Fig. 11 Winch in Folded Position on Battery Vault

Fig. 12 Battery-Vault Winch Operation

In order to facilitate the periodic battery changes, a portable winch was constructed. This winch can be folded together into a compact form for ease in transportation between the various marker sites. It is shown in Fig. 11 in the folded position on the top of a closed vault. A battery change involves removing the vault top, extending the winch frame and placing it on top of the vault, engaging the hooks in the battery-platform eye bolts, and cranking the winch handle until the batteries reach the level of the vault top, as shown in Fig. 12.

To further insulate the batteries in the vault from surface-temperature variations, a plywood-and-insulation-board separator is lowered into the vault and is allowed to rest on the top of the batteries. This separator, tilted to reveal the position of the batteries, is shown in Fig. 13.

A record of the minimum vault and surface temperatures of the North-East TVOR marker at Indianapolis for the months of December 1953 through March 1954 is shown in Fig. 14. These data were obtained by the use of a minimum-temperature thermometer in the vault and of data provided by the U. S. Weather Bureau Station at the Indianapolis Weir-Cook Airport.

ANTENNA

Two different TVOR-marker antenna arrays were developed and evaluated. The first of these antennas consisted of an array of 8-V type radiating elements designed to produce an

Fig. 13 Battery Vault Opened

r-f pattern of one major lobe directly above the marker. The second antenna array consisted of 2-V type radiating elements designed to produce an r-f pattern of two major lobes with the null between the lobes directly above the marker. Identical V-type radiators were used in each of these arrays, and the r-f pattern differences resulted from the number of elements and the control of phase and power distribution in each array. Figure 15 shows the details of construction of the V-type radiating elements used in both arrays. Type RG 58U transmission line was used with each antenna.

The 8-V Antenna Array.

The 8-V antenna array is a broadside array designed to produce a single lobe which is normal to the axis of the array. A photograph of this array is shown in Fig. 16. In order to produce this single-lobe radiation pattern, r-f power is fed to the antennas through a power-distribution network adjusted to produce a binomial current distribution and based on a 10-element binomial array with the outer pair of antennas omitted. The eight antennas are excited in phase.

Figure 17 shows the power-distribution network. The relative current distribution required in the antennas is as follows center pair, 126, second pair, 84, third pair, 36, and outer pair, 9.

The eight radiators were placed 130° above ground. A 90° height above ground produces maximum energy overhead, however, it was found that the signal lacked range off to the side of the array. The compromise height of 130° was used to increase the signal off to the side of the array at the expense of a minor reduction in overhead signal. A spacing of 254° between antenna elements was chosen to provide the sharpest pattern consistent with negligible minor lobes.

The 2-V Antenna Array.

The 2-V antenna array is designed to produce two major lobes above the array. A drawing and photograph of this array are shown in Figs. 18 and 19. The two radiators are fed

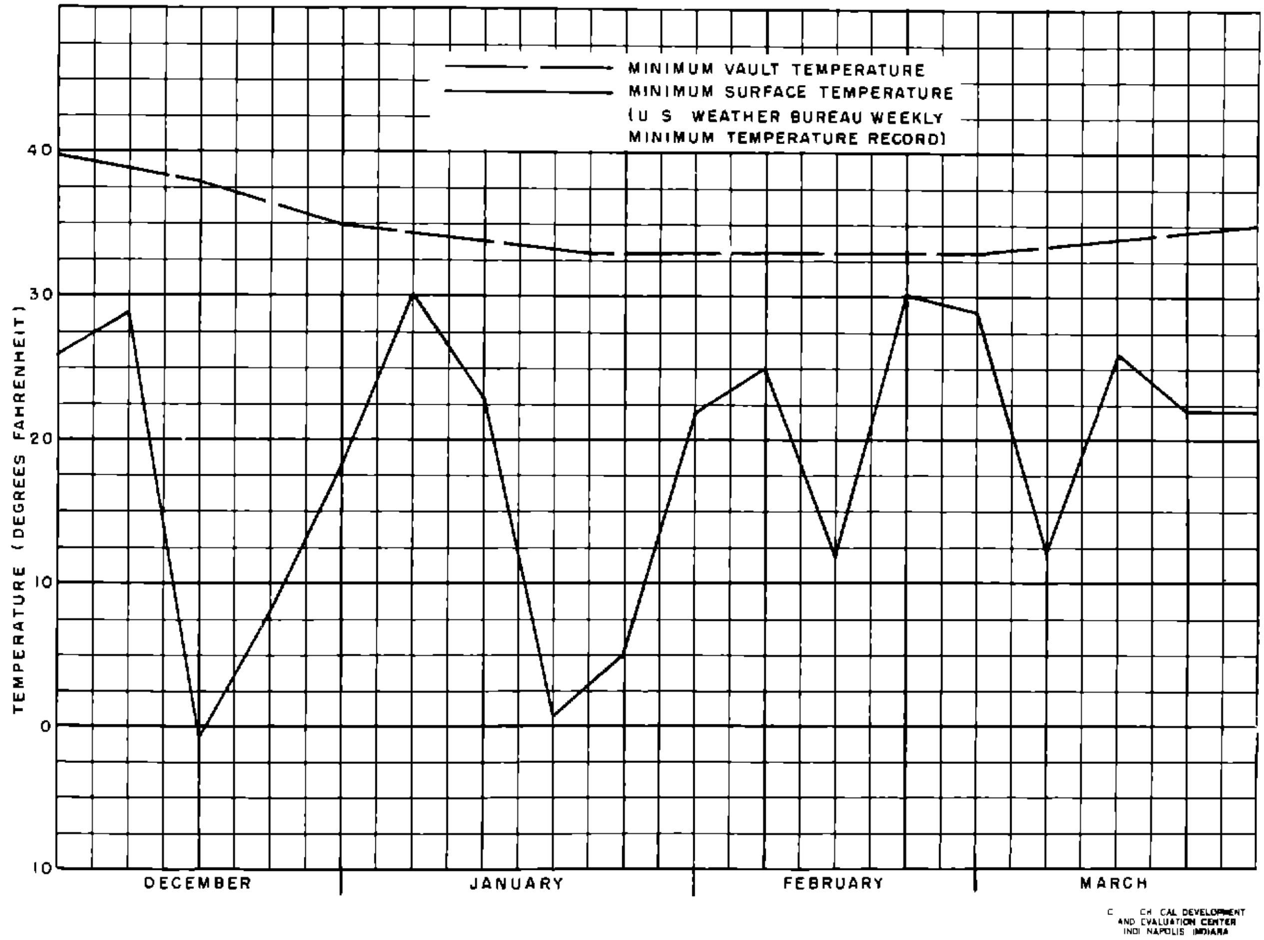

Fig. 14 Ground-Surface Temperature versus Battery-Vault Temperature

180° out of phase, this phasing being controlled by the lengths of the transmission line from the transmitter.

The two antennas are spaced 360° to produce cancellation off the end of the array. The antenna height is 180° above ground, the height required to produce cancellation of the direct and reflected radiation overhead. This height also produces no additional nulls at any vertical angle other than 0°. The resultant horizontal-plane pattern from this antenna array is a "four-leaf-clover" type of pattern with maxima at 30° from the perpendicular. This antenna array is very simple to install, and to date no maintenance problems have been encountered.

SELECTION OF TVOR-MARKER SITES

The TVOR-marker site should be located five miles ±1/2 mile from the TVOR on a line drawn from the TVOR through a point 2500 feet extended from the centerline of the runway to

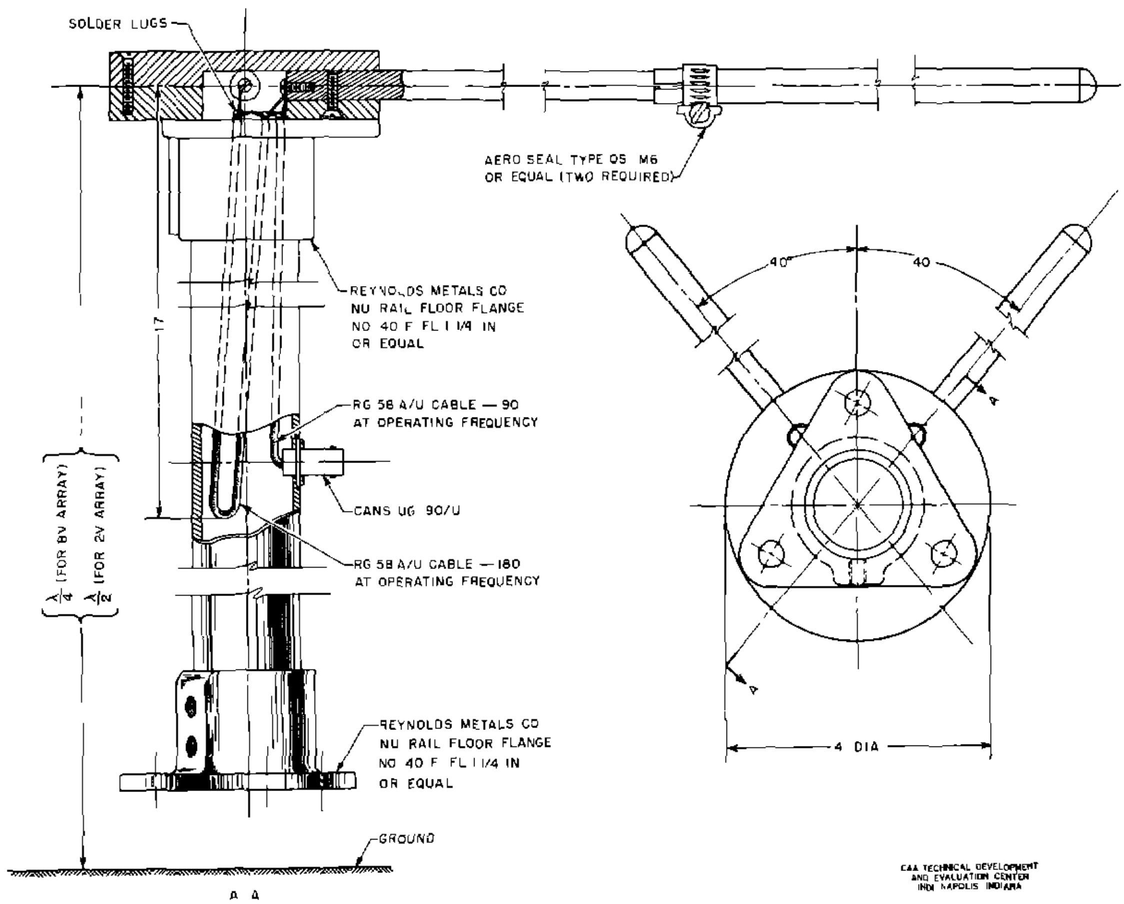

Fig. 15 V-Antenna Assembly

be served. The bearing of this line is to have a tolerance of ±1°. The bearing of the TVOR approach over the marker should not differ from the served runway bearing by more than 7°. This is necessary to limit the change in heading of the aircraft to a maximum of 7° after breaking out of the overcast.

The site should be approximately 66 feet by 66 feet. This provides more than adequate space for the marker installation and represents an area of one-tenth acre which facilitates the leasing of land.

Obstacles such as buildings, trees, and utility lines (30 feet high) in proximity to the marker site should be not less than 250 feet from the antenna. High utility lines will require correspondingly greater clearance.

FLIGHT-TEST DATA

The first series of flight tests were conducted to determine the relative responses of different VOR airborne-antenna locations. For these tests, a single V-antenna situated 1/4 wavelength above ground was excited. The radiation pattern of this ground installation consists of one major lobe directly over the antenna. Passes over this ground installation were made in flight, and field-intensity recordings were made with the use of three different receiving antennas on the aircraft. The recordings obtained for each of the aircraft antennas are shown in Figs. 20a, 20b, and 20c. The bottom V-antenna recording most accurately reproduced the true radiation pattern of the ground antenna, and, when this recording is

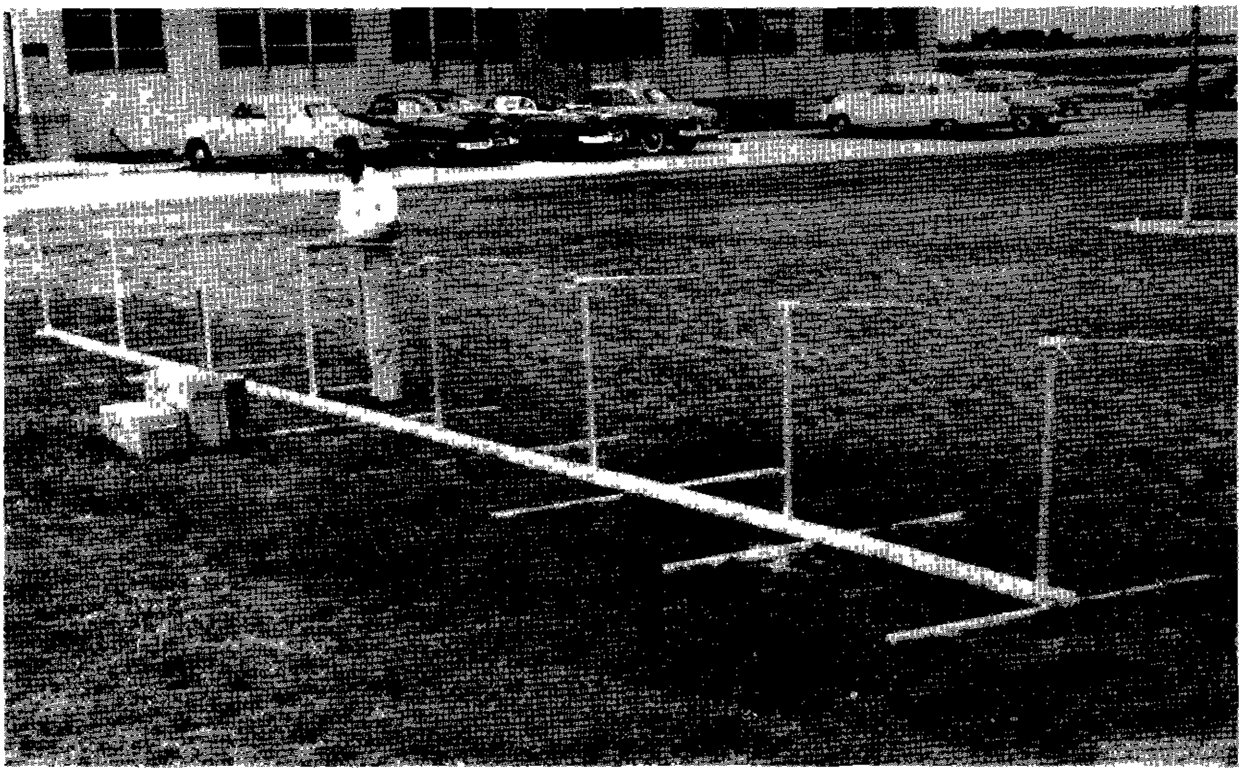

Fig. 16 8-V Antenna Array

compared with those of the tail and hatch antennas, it can be seen that the radiation patterns of airborne VOR antennas are greatly distorted directly below the antenna because of the presence of the aircraft.

8-V Marker.

The first TVOR-marker antenna was designed to place a maximum signal directly above the marker in order to provide position indication in the aircraft similar to that obtained on the 75-Mc markers. Flight tests were conducted in order to record the field-intensity pattern obtained when the three different airborne antennas are used.

The results obtained on this flight test are shown in Figs. 21a, 21b, and 21c. An examination of the recordings reveals that the ground antenna produced the desired radiation space pattern as shown in the recording obtained with the bottom V airborne antenna. However, the recordings obtained with the tail and hatch antennas on the airplane show that for the pilot the marker consisted of a series of maximum and minimum signals with the net result that he was unable to tell exactly which one of the maximum signals was directly over the marker The recordings clearly indicate the position of the marker, because in each case the major-lobe signal had a substantially greater amplitude than the minor-lobe signals, yet, because of the logarithmic response of the human ear, at times there was no discernable difference in level between these lobes. Thus, the 8-V antenna produced a usable TVOR marker, but the actual position of the marker could not be determined to less than ± 0.2 mile.

2-V Marker.

Following the analysis of the 8-V marker flight-test results, it was decided that, because of the distortion of the vertical-plane pattern of the VOR receiving antenna by the presence of the aircraft, a more practical approach to the solution of the marker problem would be to radiate a field pattern consisting of two major lobes with a null directly over the marker. This

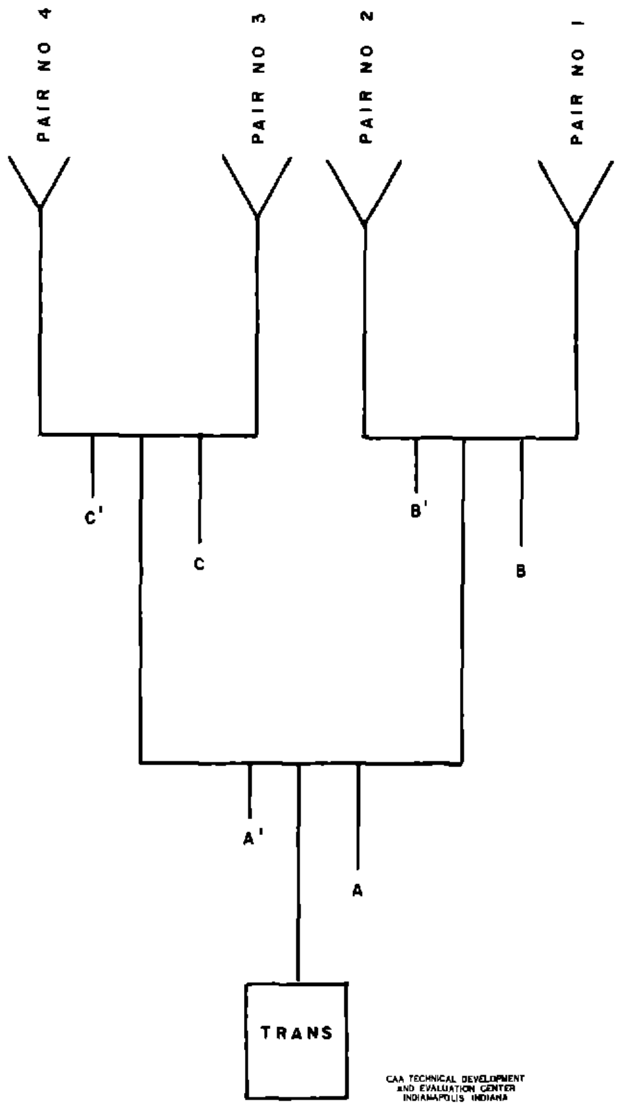

Fig. 17 Power-Distribution Network, 8-V Antenna Array

type of radiation pattern conveys position information by producing a zone of no signal above the marker. The flight-test results, obtained when flights were made over a single V-antenna on the ground, Fig. 16, reveal that there is a seminull below an aircraft VOR receiving antenna in most normal installations. The 2-V marker antenna, therefore, was designed to alleviate the effects of the distorted downward pattern of the airborne VOR receiving antenna.

The tests conducted on the 2-V marker antenna consisted of a number of flights over the TVOR marker to record the field intensity and the audio level obtained with the different VOR airborne antennas. These results are shown in Figs. 22a, 22b, and 22c. Of these three recordings, Fig. 22c, the recording in which the hatch VOR receiving antenna was used probably represents the marker signal that will be received operationally.

Figure 22a illustrates a recording of the field radiated by the TVOR marker, and Fig. 22c illustrates the marker-field recording that will be presented to the pilot. The difference between Figs. 22a and 22c is the result of the VOR receiving-antenna field-pattern distortion due to the placement of the antenna at the hatch location on the aircraft. This difference

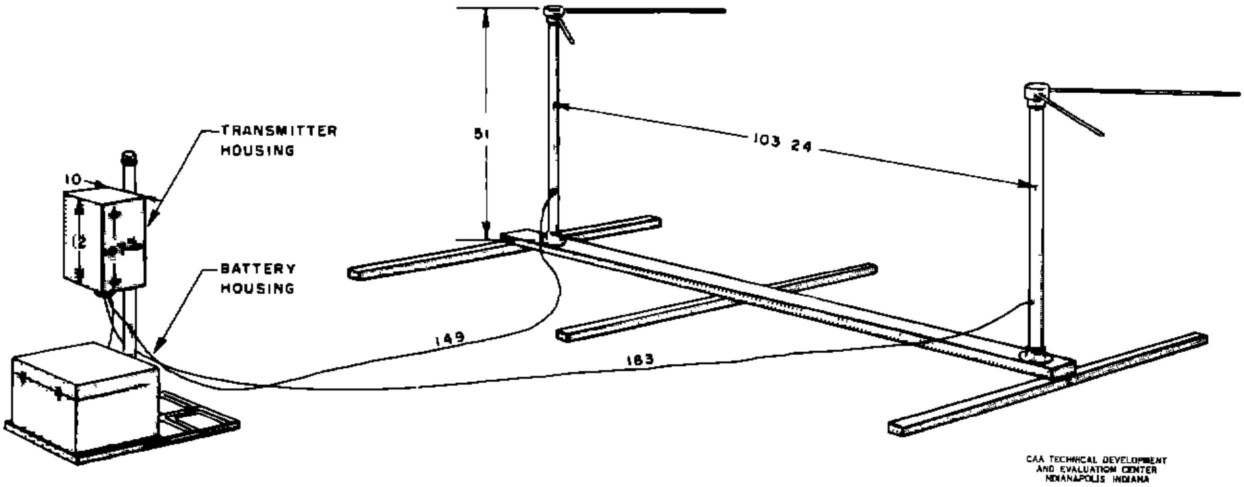

Fig. 18 Dimensioned Drawing of TVOR–Marker Components

between Figs. 22a and 22c may appear to be so great that it leads one to make the observation that an aircraft with a VOR receiving antenna in the hatch position could not receive satisfactory TVOR-marker information. A closer examination of Fig. 22c, however, reveals that as an airplane approaches the TVOR marker the first major lobe is undistorted, then the position directly over the marker is marked by a complete null, and, finally, the second lobe is distorted. This distortion, which appears quite large on the recording, is hardly noticeable operationally. It is reduced by two factors (1) the logarithmic response of the ear does not indicate as much distortion of the second lobe as appears on the recording, and (2) the first lobe is undistorted, giving a strong build-up in audio signal followed by a complete null which indicates the position over the marker. The fact that the second lobe is distorted goes unnoticed by most pilots because their attention leaves the marker signal after the null has been encountered.

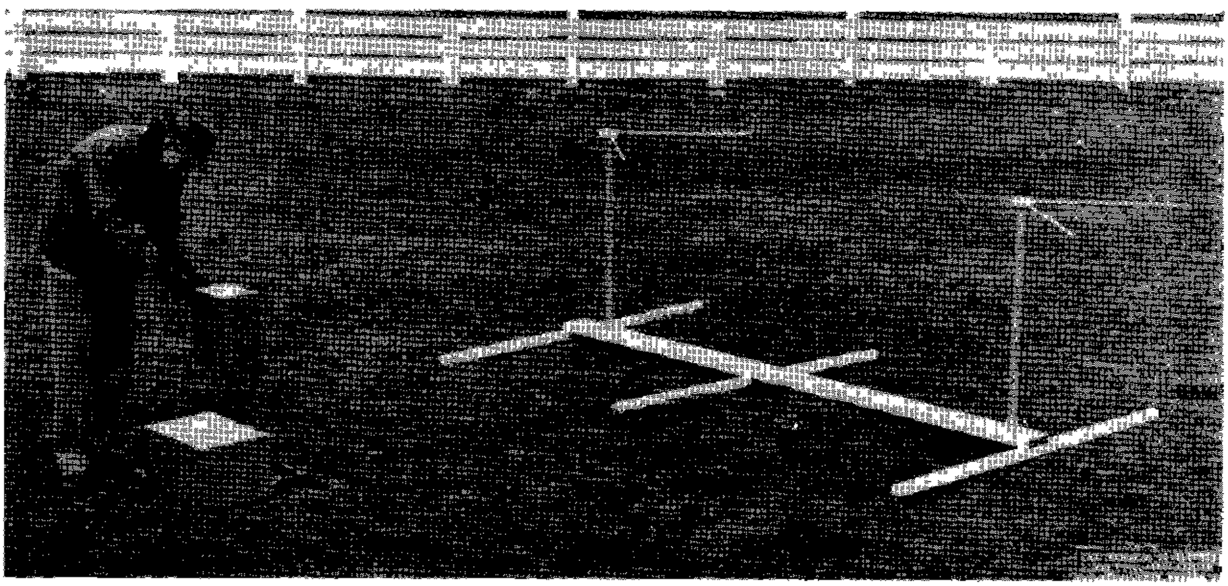

Fig. 19 TVOR-Marker Facility

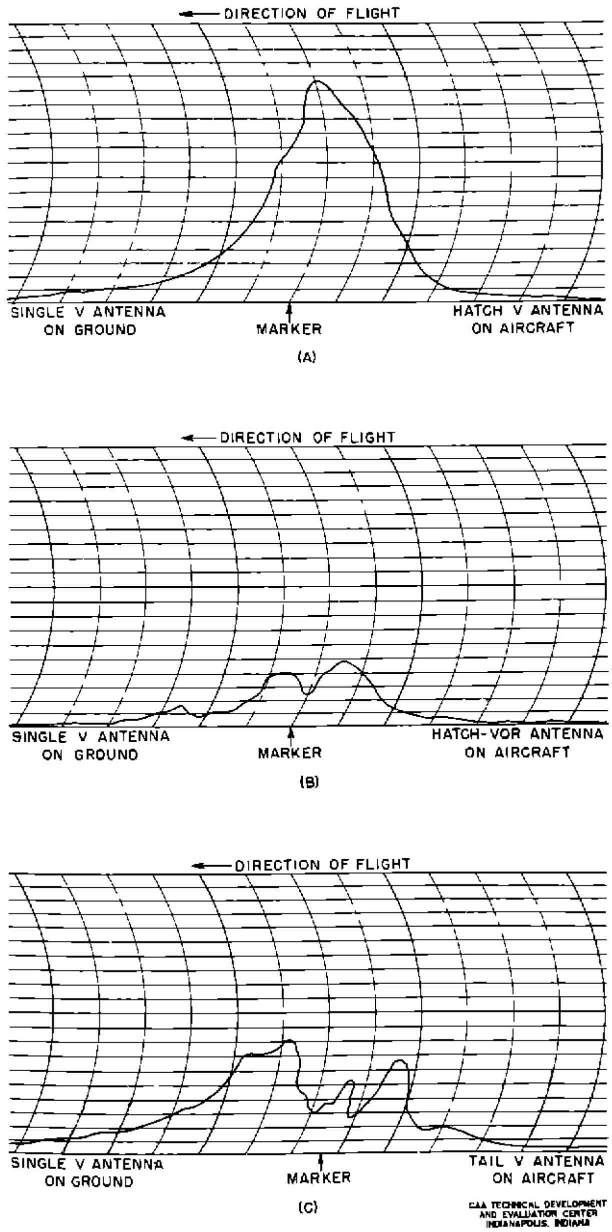

Fig. 20 Field-Strength Recording, Flight Over Marker

Further flight tests consisting of radial flights toward the TVOR but passing to the side of the marker were conducted on the 2-V type marker. Because it was assumed that a pilot might possibly make a mistake in setting his VOR-receiver omnibearing selector when making an approach to a TVOR on an airport or that VOR-receiver bearing errors might exist as in the case of the less expensive VOR receivers, these flight tests were conducted to evaluate the effectiveness of the marker as a position-indication device under such conditions.

Figures 23a, 23b, and 23c and Figures 24a, 24b, and 24c illustrate recordings obtained when radials which were displaced 5° and 10°, respectively, from the radial passing directly over the marker were flown toward the TVOR. These recordings reveal that the distortion of the two radiated marker lobes is practically eliminated. The length of time that the marker audio signal is received is increased, but the null remains as a definite position indication.

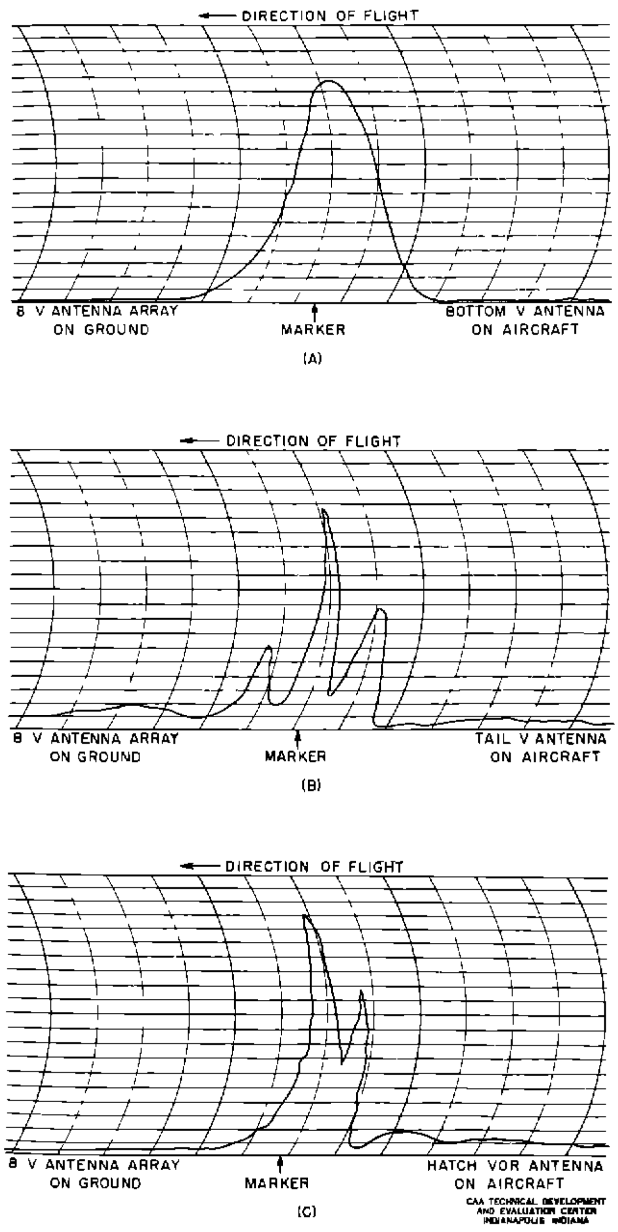

Fig. 21 Field-Strength Recording, Flight Over Marker

This was determined to be another advantage of the 2-V type marker over the 8-V type marker.

The problem of determining the power output required from the marker transmitter for proper modulation of the TVOR r-f carrier by the heterodyne-beat method was determined experimentally. Flight tests were conducted by flights over the marker with recordings of the audio levels of the TVOR voice identification (12.5 per cent peak modulation), the code identification (7.5 per cent peak modulation), the TVOR-tower voice (35 per cent peak modulation), and the marker audio level, as the marker-transmitter power output was adjusted through 1, 2, 5, 10, and 20 milliwatts.

The results of these flight tests indicated that the TVOR-marker power output should not exceed 1 mw. This power produced 30 per cent peak modulation when the aircraft was

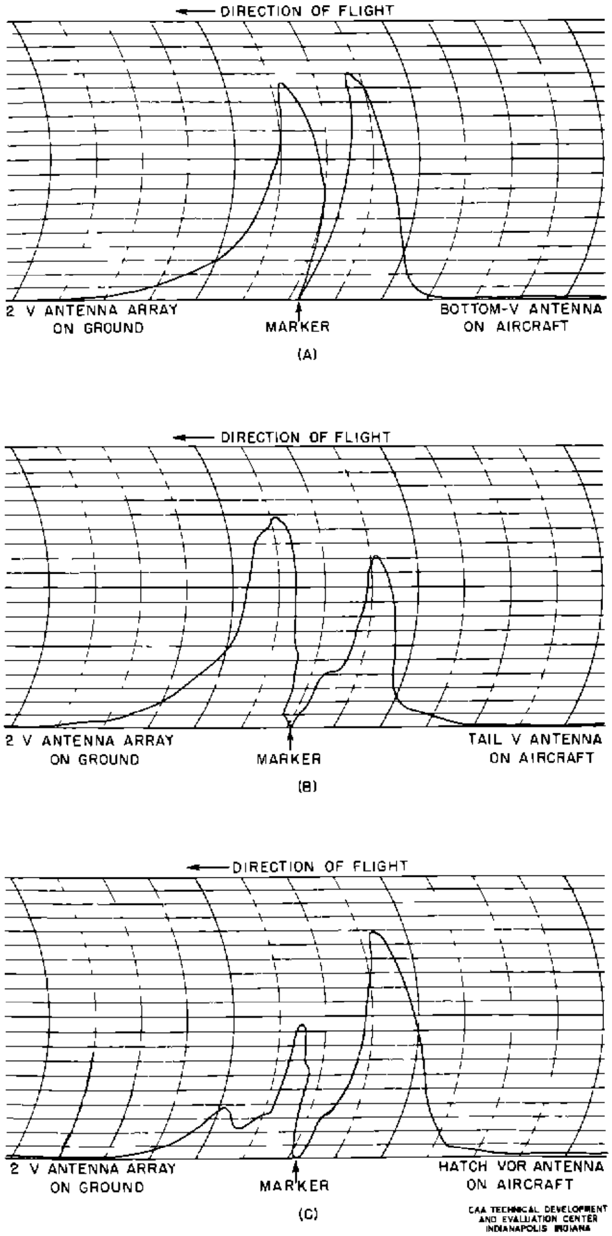

Fig. 22 Field-Strength Recording, Flight Over Marker

flying over the marker at 1000 feet. Greater power output from the marker results in a weak audible signal over a large area around the marker.

ANTENNA-COUNTERPOISE TESTS

Following the flight tests of the 2-V antenna array situated 42 inches above ground, the Office of Federal Airways provided a standard ILS outer-marker counterpoise for installation and evaluation as a TVOR-marker antenna-array counterpoise. The use of the counterpoise was proposed to eliminate the effects of heavy snow encountered in certain parts of the country.

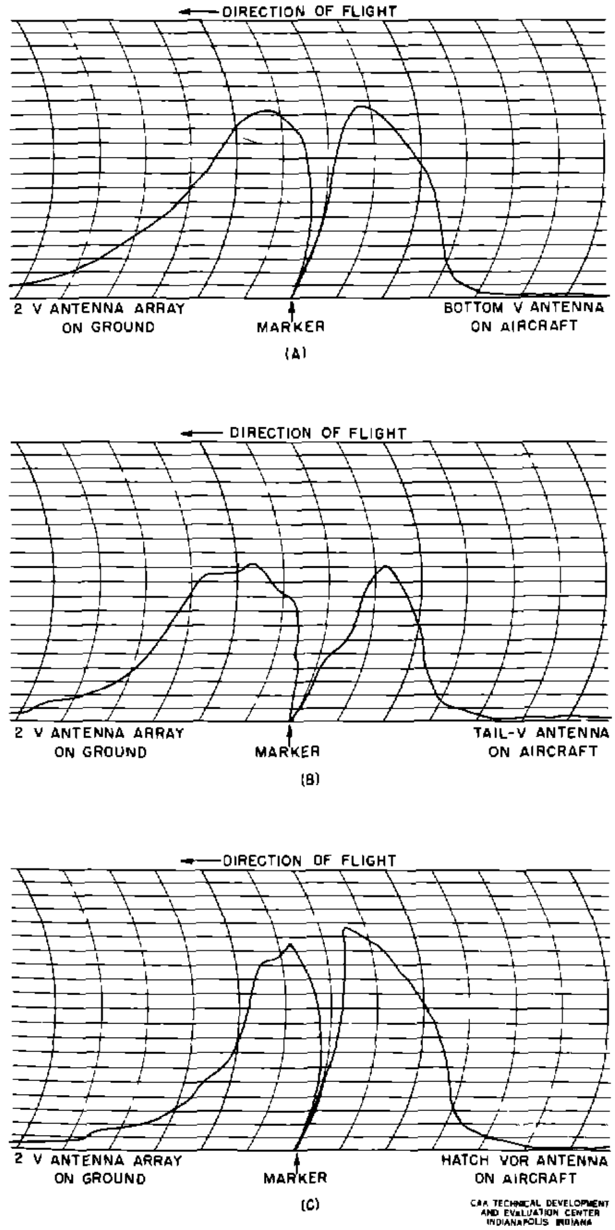

Fig. 23 Field-Strength Recording, Flight to Side of Marker (TVOR Marker Radial +5°)

This standard counterpoise is 20 feet by 20 feet, with the top surface of the counterpoise 6 feet 6 inches above ground. When the counterpoise installation was completed, see Fig. 25, a series of flight tests were conducted which consisted of flights over the marker and on a two-mile-radius circle to obtain field-intensity recordings. These recordings were made on the TVOR-marker 2-V antenna array 42 inches above ground, 42 inches above the counterpoise, and 10 feet above ground. The 10-foot test represents an antenna array of the same height but without a counterpoise as was the array on the counterpoise. Figure 26 is a photograph of the antenna installations at 42 inches and at 10 feet above ground for these comparative tests.

The results of these flight tests are presented in the form of recorder tracings of the vertical- and horizontal-plane patterns. The recorder tracings, Figs. 27a, 27b, and 27c, show that the counterpoise eliminates the nulls which are introduced by the increased antenna height

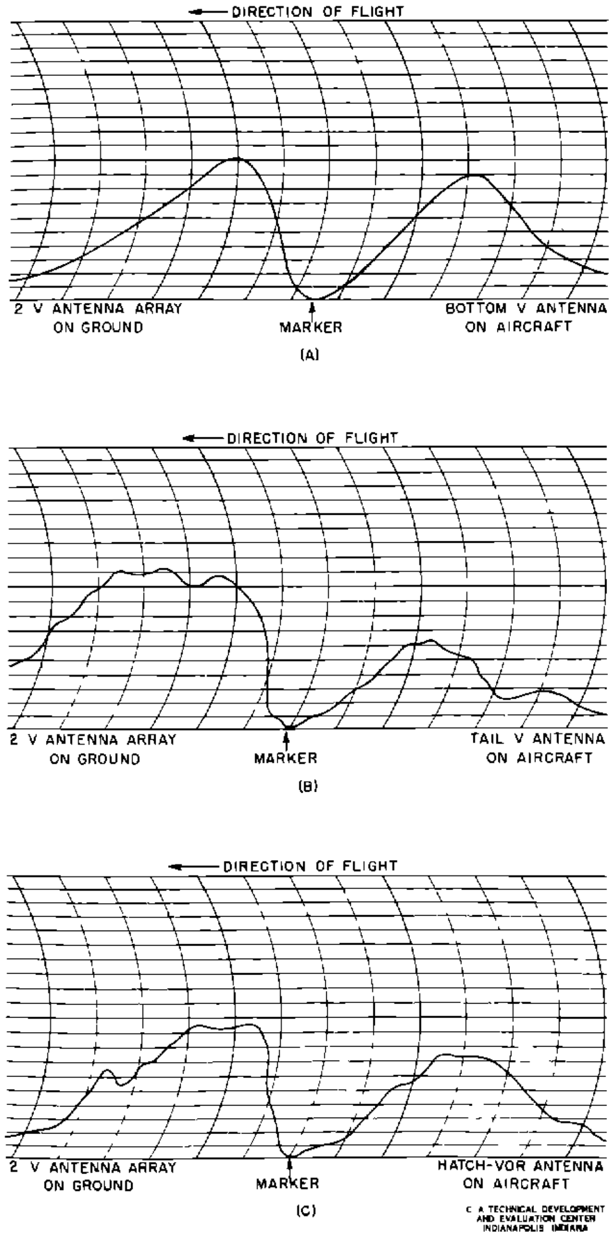

Fig. 24 Field-Strength Recording, Flight to Side of Marker (TVOR Marker Radial +10°)

above ground, however, while the signal strength directly overhead is not changed, the width of the lobe is increased. Figures 28a, 28b, and 28c are vertical-plane patterns plotted from the recordings of Fig. 27a, 27b, and 27c which show no appreciable difference between the array when 42 inches above ground and when on the counterpoise. The vertical-plane pattern of the antenna array 10 feet above ground does not show the first maximum lobe and the first null which theoretically exist because of the low field strength radiated from the 1.0-mw power of the marker transmitter. Figure 29 presents the horizontal-plane patterns of the three antenna arrays and shows that the field strength in the horizontal plane is increased as the antenna array is raised above ground.

The foregoing results of these flight tests and of numerous other flight observations reveal that the use of a standard ILS outer-marker counterpoise would place a definite

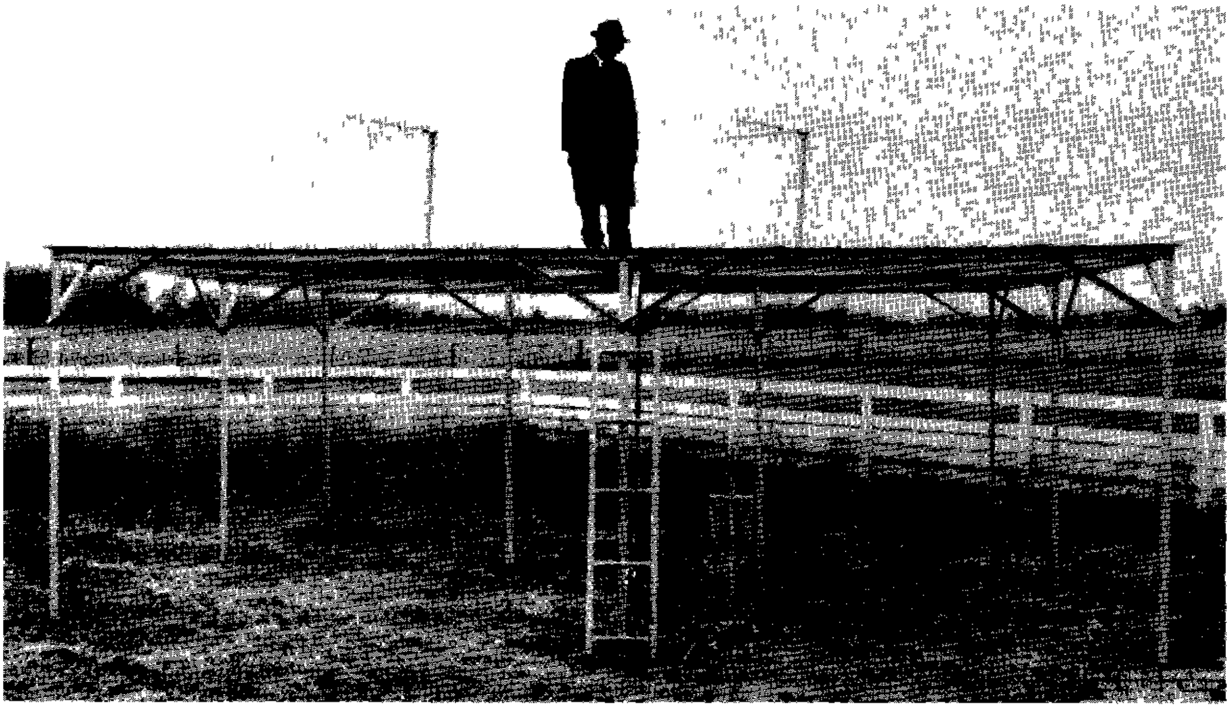

Fig. 25 Antenna Array on Counterpoise

limitation on the use of a TVOR marker. The counterpoise itself is entirely satisfactory, but the increased antenna height above ground causes an increase in the field strength of the main lobes of the horizontal-plane pattern (Fig. 24). In operational use, this results in a weak yet audible signal over a large area around the marker. This would immediately eliminate the use of more than two markers in conjunction with a TVOR and would require that these two be on opposite sides of the TVOR. The use of four markers would result in overlapping lobes and in a certain amount of operational confusion.

From a theoretical viewpoint, the solution to the heavy snow problem with the antenna array one-half wavelength above ground would be to house the antenna array in a shelter having a steep pitched roof and so constructed that a 24-inch clearance is maintained around the antenna elements. An antenna shelter of this type is shown in Fig 30.

SPURIOUS RADIATION

A TVOR-marker transmitter operating on a frequency of 114.4 Mc and employing a harmonic-type oscillator at 57.2 Mc precludes any spurious radiation below this frequency. However, since the oscillator frequency of 57.2 Mc falls in Channel 2 of the Federal Communications Commission Television Frequency Allocation, it was deemed necessary to investigate the field intensity at this frequency and, if possible, to reduce it to a minimum value.

Field-intensity measurements were conducted by using a Measurements Corporation field-intensity meter located 100 feet from the antenna and in the center of one of the major lobes.

The field intensity at 114.4 Mc was 800 microvolts, and at 57.2 Mc it was 83 microvolts. The radiated field at 57.2 Mc was considered excessive, however, by placing a 1/4-wavelength open-ended stub on the transmission line, the radiation at 57.2 Mc was reduced to 9.5 microvolts. The field intensity at 114.4 Mc was unchanged.

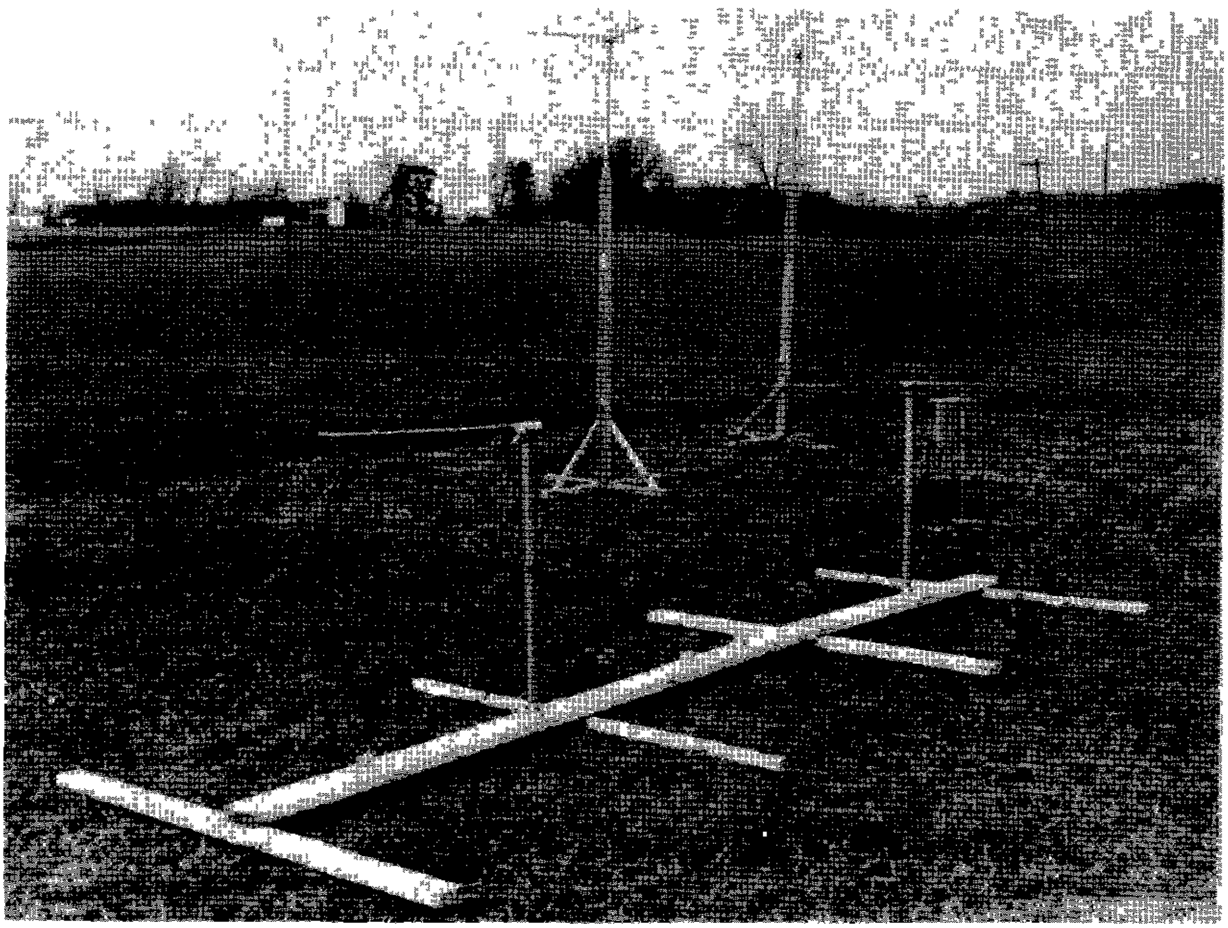

Fig. 26 Test Antenna Arrays

TVOR-FREQUENCY MEASUREMENTS

Because of the interdependence of TVOR and marker frequencies, a series of tests was conducted to measure the magnitude of the frequency shifts which might be encountered in operational maintenance of the TVOR facility. The frequency measurements were conducted by recording the audio-beat frequency between the TVOR r-f signal and a General Radio frequency standard (continuously calibrated against U. S. Bureau of Standards transmission from station WWV) as the following maintenance operations were conducted on the TVOR

Routine Transmitter Tune-Up.

Condition	Frequency deviation from 114.4 Mc(cps)
Transmitter normal	+ 2580
Retune of all stages in transmitter	+ 2550
Repeat of complete tune-up	+ 2600

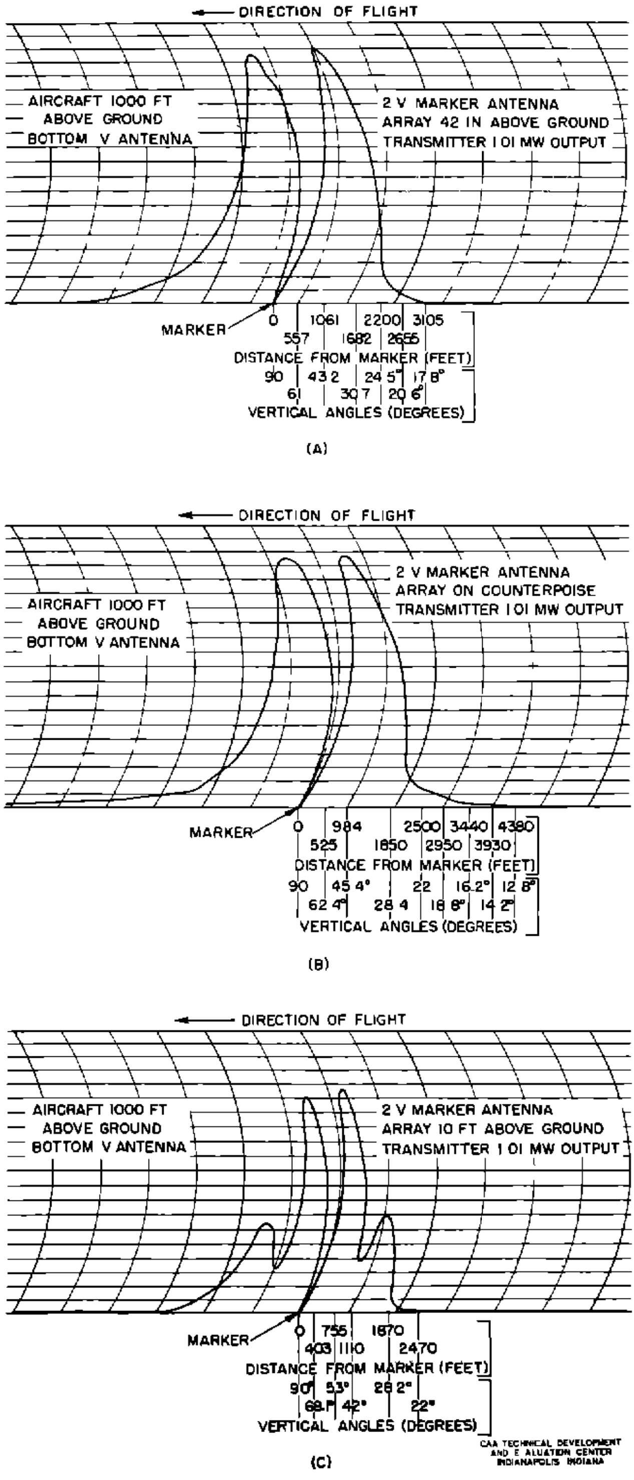

Fig. 27 TVOR-Marker Relative Field-Strength Recording

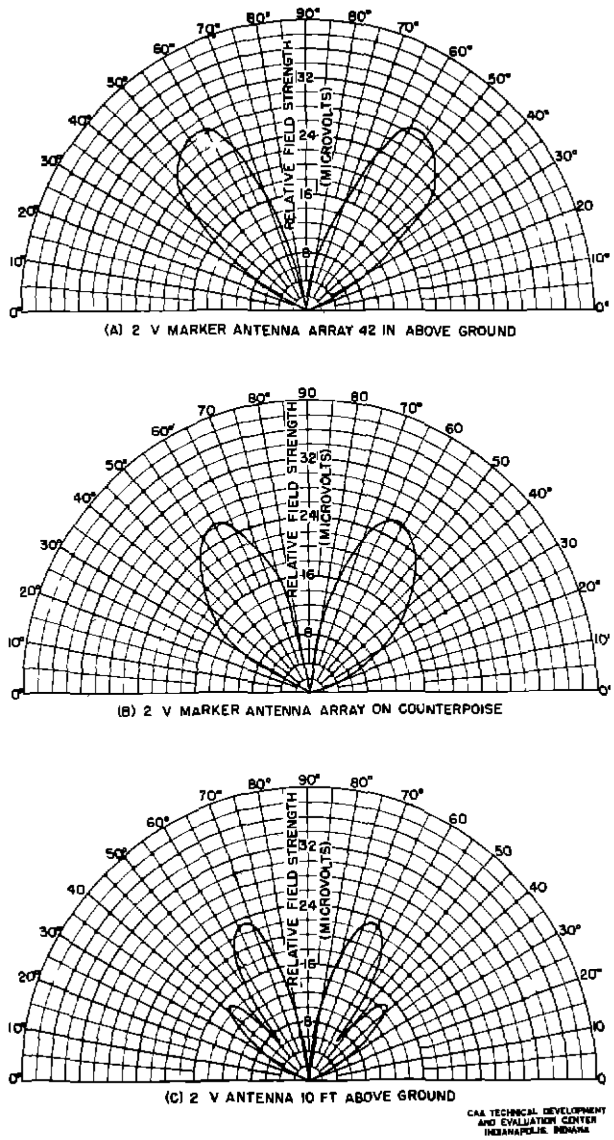

Fig. 28 TVOR-Marker Vertical-Plane Pattern

Effect of Detuning Transmitter Stages.

Condition	Frequency deviation from 114.4 Mc(cps)
Transmitter normal	+ 2585
(1) Crystal-Plate Circuit, slug-tuning full in	+ 2595
Crystal-Plate Circuit, slug-tuning full out	+ 2260
Crystal-Plate Circuit, tuned to resonance	+ 2595
(2) 1st multiplier stages detuned to cause power-amplifier grid to change from 25 ma to 20 ma	
clockwise detuning	+ 2490
counterclockwise detuning	+ 2500
tuned to resonance	+ 2590

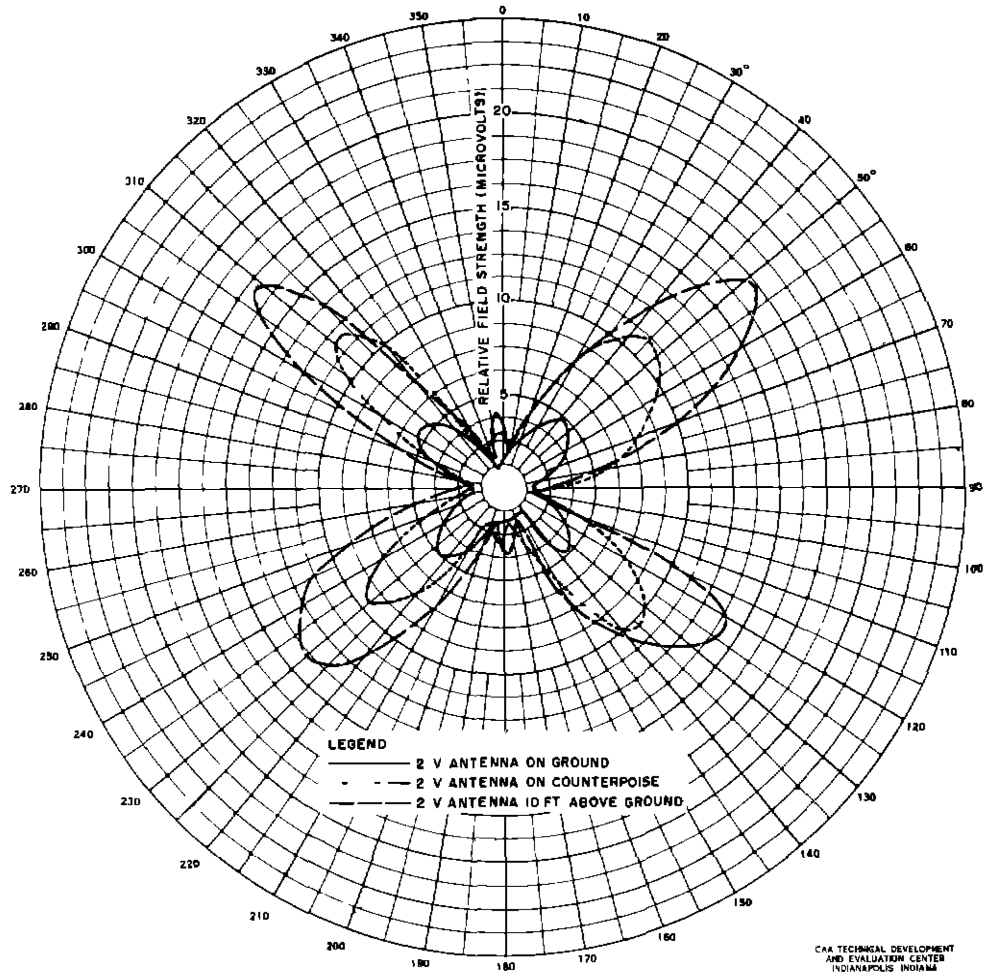

Fig. 29 TVOR-Marker Measured Horizontal-Plane Patterns

Condition	Frequency deviation from 114.4 Mc(cps)
(3) 2nd multiplier stage (test same as 2)	
clockwise detuning	+ 2495
counterclockwise detuning	+ 2505
tuned to resonance	+ 2575
(4) 3d multiplier stage (test same as 2)	
clockwise detuning	+ 2540
counterclockwise detuning	+ 2500
tuned to resonance	+ 2575
(5) Power-amplifier grid (test same as 2)	
clockwise detuning	+ 2540
counterclockwise detuning	+ 2550
tuned to resonance	+ 2575

Condition	Frequency deviation from 114.4 Mc(cps)
(6) Power-amplifier plate (Detuned from 200 ma resonant plate current to 250 ma)	
clockwise detuning	+ 2525
counterclockwise detuning	+ 2550
tuned to resonance	+ 2575

Effect of Changing Oscillator Tubes.
(All oscillator tubes were made by same manufacturer.)

Condition	Frequency deviation from 114.4 Mc(cps)
No. 1 Oscillator tube, transmitter normal	+ 2600
No. 2 Oscillator tube, inserted	+ 2000
No. 2 Oscillator tube, 5-minute warm-up	+ 2050
No. 2 Oscillator tube, 1-hour warm-up	+ 1940
No. 2 Oscillator tube, 3-hour warm-up	+ 1975
No. 1 Oscillator tube, reinserted	+ 2450
No. 1 Oscillator tube, 10-minute warm-up	+ 2585
No. 1 Oscillator tube, 3-hour warm-up	+ 2580
No. 3 Oscillator tube, 5-minute warm-up	+ 1880
No. 4 Oscillator tube, 5-minute warm-up	+ 2210
No. 3 Oscillator tube, 5-minute warm-up	+ 2340
No. 4 Oscillator tube, 5-minute warm-up	+ 1840
No. 5 Oscillator tube, 5-minute warm-up	+ 1810
No. 6 Oscillator tube, 5-minute warm-up	+ 2235
No. 7 Oscillator tube, 5-minute warm-up	+ 1890
No. 1 Oscillator tube, 5-minute warm-up	+ 2580

Effect of Changing Crystals.

Condition	Frequency deviation from 114.4 Mc(cps)
No. 1 Crystal	+ 2580
No. 2 Crystal	+ 1140
No. 2 Crystal, 1-hour warm-up	+ 1000
No. 1 Crystal, 1-hour warm-up	+ 2600

Compensation for Initial or Subsequent TVOR Frequency Deviations.

The grid circuit of the oscillator tube in the Type TUQ TVOR transmitter consists of a grid-return resistor, a 7-mmf condenser, and a crystal all in parallel to the ground.

In order to determine the magnitude of intentional frequency shift that could be accomplished, the 7-mmf condenser was replaced with a 3.6- to 25-mmf variable condenser. Frequency measurements were conducted as the variable condenser was adjusted.

Condition	Frequency deviation from 114.4 Mc(cps)
Transmitter normal	+ 2580
Variable capacitor installed	
Minimum capacity	+ 120
1/8 capacity	+ 1050

Condition	Frequency deviation from 114.4 Mc(cps)
1/3 capacity	+ 8180
1/2 capacity	+10400
3/4 capacity	+14000
Full capacity	+17500

The results of the TVOR frequency-measurement tests reveal that routine TVOR maintenance activities will have a negligible effect on the interdependent marker audio-beat frequency and that initial excursions in frequency due to variations in crystals may be compensated in the crystal-oscillator stage of the transmitter.

CONCLUSIONS

The TVOR-marker development was conducted with two major objectives. First, the marker was to provide reliable and accurate position-indication information. Second, the marker was to be economical with respect to both the ground installation and the airborne equipment required for reception of marker information. Both of these objectives have been attained.

The position information presented to a pilot using the TVOR marker consists of an accurate aural null which provides positive indication over the marker.

An ultimate in the economy of airborne equipment required to receive TVOR-marker information has been attained in that no separate marker receiver or antenna is required for the aircraft. A pilot using a VOR receiver, to make good an approach to a TVOR, hears the marker audio signal from the same VOR receiver as he passes over the marker.

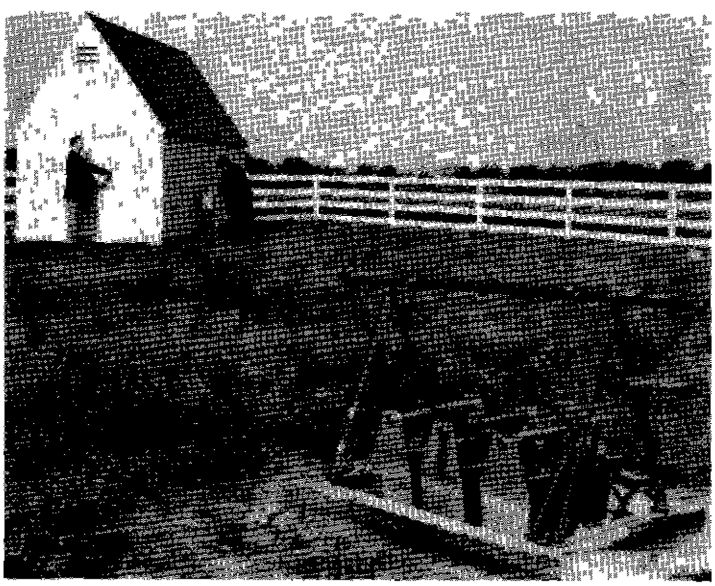

Fig. 30 TVOR-Marker Installation With Antenna Shelter