U.S. ARMY ELECTRONICS COMMAND

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TECHNICAL REPORT ECOM-0503-P001-G806

MANPACK DF SYSTEM
FINAL REPORT

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DECEMBER 1968

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N.J.

CONTRACT DAAB07-68-A-0503-P001

SYLVANIA
ELECTRONIC SYSTEMS - WESTERN DIVISION
Mountain View, California

Technical Report ECOM-0503-P001-G806

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Approved For Release 2001/09/03 : CIA-RDP76-00451R000200010007-8

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Table of Contents

Table of Contents -- Continued

ABSTRACT

This report summarizes the past two year R&D effort at Sylvania Electronic Systems-Western Division to develop a small transportable high frequency radio direction finding system. This system, the "MANPACK DF System," features "electrically short" antenna elements in an H-Adcock configuration along with frequency isolation of the antenna elements from the horizontal transmission lines to eliminate bearing errors due to downcoming horizontally polarized sky-waves. System description and test results are included in this report.

1.0 SUMMARY AND RECOMMENDATIONS.

There is a need today for a short range portable HF radio direction-finding unit that will work well in the presence of horizontally-polarized sky-wave. As yet, there are no operational portable direction-finding systems which have reliable performance under these conditions. The problem has been studied for some time and several types of portable DF systems proposed to overcome this difficulty but none of the solutions have proven satisfactory. This report describes work performed at Sylvania Electronic Systems - Western Division during the past two years, pertinent to the solution of this problem. This work is the research and development of a particular portable direction-finding system which gives all indications of alleviating the problems associated with horizontally-polarized sky-wave. This DF system has been coined "The MANPACK DF System."

Appendix A describes the problem of horizontally-polarized sky-wave on portable direction-finding systems in general.

Appendix B is a brief history of the MANPACK DF system from the initial conception to the present system design.

The body of the report is a technical description of present MANPACK direction-finding system, and a performance evaluation based on the results of a testing program which was carried out on the latest prototype.

We can summarize the entire MANPACK DF study up to this point as follows:

(1) The objective of the MANPACK study was to reduce or eliminate the errors in bearing estimates which result from horizontally-polarized downcoming sky-waves, for small, short-range, portable direction-finding systems.

(2) The problem was studied and a system was proposed which would alleviate the sky-wave problem. The MANPACK system would incorporate the following design features:

  (a) Small H-Adcock antenna configuration for simple construction and easy transportability.

  (b) Wideband, electrically short antenna elements.

  (c) Frequency isolation of the dipole elements from the horizontal transmission lines.

1.0 -- Continued.

(3) A working model was designed, constructed, and tested, modified, and retested. (The history of this model is discussed in Appendix B.)

Three areas of system performance were measured; sensitivity, sky-wave rejection, and accuracy. The results of the tests were:

(1) Sensitivity. The MANPACK DF system signal sensitivity was slightly better than the sensitivity of a shielded loop type of system which is current operational equipment.

(2) Sky-Wave Rejection. The MANPACK configuration attenuated currents caused by horizontally-polarized downcoming sky-waves by at least 10 db over the shielded loop.

(3) Accuracy. In the absence of sky-wave, the MANPACK and shielded loop both made good estimates, with approximately 3-degree rms error. Under heavy sky-wave conditions the MANPACK system rms error was 4.4 degrees; the shielded loop rms error was 13.5 degrees. In some situations, bearing estimates with errors less than 5 to 6 degrees could be made with the MANPACK when estimates made with the loop resulted in errors greater than 90 degrees.

The MANPACK DF system, therefore, does possess certain advantages over conventional portable DF systems, and can compare favorably with these other systems in most all areas of performance.

The present system is not yet ready to be put into the field as an operational unit. There are several problem areas which must first be studied and improvements made:

(1) The two amplifiers of the Adcock configuration cannot be maintained in a balanced condition. To eliminate horizontal power supply lines, a separate battery supply for each side of the antenna was installed in the end-boxes. The present amplifier design draws considerable current and the supplies drain down rapidly. The operating points of the two amplifiers therefore drift independently of one another, and the different gain of each side of the antenna configuration causes the system to become unbalanced and bearing errors result.

(2) The problem of spurious inter-mod signals has been greatly reduced, but these signals are still occasionally noticed, especially in denser signal environments.

1.0 -- Continued.

(3) Although the system has been repackaged into a much more functional unit, it still would not be acceptable as operational field equipment.

In order to put an operational unit in the field, it is recommended that the following tasks be undertaken:

(1) A detailed system study should be undertaken. The expected operational use of the manpack should be determined, and desired system parameters should be specified. These should include sensitivity, accuracy, dynamic range, frequency band, size and weight.

(2) A detailed analytical study concerning electrically short antennas, should be performed to determine the minimum physical dimensions for the antenna configuration which will meet system requirements. The necessary input characteristics of the high impedance antenna amplifiers must also be determined. Some prefiltering might be considered to eliminate the intermod problem.

(3) Hardware development work must be undertaken to improve the antenna amplifiers and the necessary power supplies. To operate effectively, the amplifiers of the two halves of the Adcock antenna must be stable relative to each other. A common power supply and/or some compensating control between the two sides should be installed.

(4) The present physical packaging should be modified so that it may be easily disassembled and collapsed into a package small enough and light enough to be carried by a person. The fiberglass boom should be made into collapsible sections or telescopic (perhaps adjustable length). The heavy wooden surveyor's transit tripod should be replaced by a lighter fiberglass or magnesium structure which could be collapsed into a small package.

(5) Finally, a detailed testing program should be carried out to evaluate the performance of the final model.

2.0 MANPACK DF SYSTEM DESIGN PHILOSOPHY.

2.1 Adcock Antenna Configuration.

As explained in Appendix A of this report, the Adcock antenna systems have been shown to be superior to loop type of antenna systems for taking bearings on signals in the presence of sky wave. The design philosophy behind the Adcock antenna is the elimination of currents from horizontally-polarized down-coming sky wave.

The cancellation of these sky wave currents requires that the two antenna elements be electrically balanced with respect to ground. The H-Adcock antenna system is usually elevated high enough above the ground to reduce the capacitive coupling of the antenna elements with the earth.

The H-Adcock configuration was chosen for the portable MANPACK system due to the inherent sky wave rejection properties and the simplicity of construction, two vertical dipole elements mounted at the ends of a horizontal boom. This configuration causes problems because the desired size of the system necessitates the use of small elements and the system must be used close to the surface of the earth. This makes it almost impossible to maintain electrical balance with respect to ground. To solve these problems, the currents caused by horizontally polarized down-coming sky waves are further suppressed by other methods as described below, and electrically short antennas are used.

2.2 Electrically Short Antenna Elements.

Recently, extremely short antenna techniques have received much attention.[1] An electrically short antenna is usually considered to be one which has a total physical length less than one-fourth the shortest wavelength for the operating range of the antenna. For small transportable antenna systems, such as MANPACK, these techniques would be extremely useful.

The problem with using electrically short antennas is the small physical size causes the antenna impedance to be almost all reactive, since the resistance is so low. Therefore, the Q of the antenna equivalent circuit is extremely large and a conjugate coupling to the first stage of the receiver would result in very narrowband operation. The technique employed in achieveing wide-band operation is based on coupling the antenna directly into the first stage of a preamplifier whose input impedance is high in comparison to the antenna impedance. This type of coupling provides for an efficient transfer of antenna voltage to the receiver. The preamplifiers usually incorporate the latest developments in semiconductor devices, such as field effect transistors (FET's) which are capable of achieving good noise figures with the high source impedances. Feedback techniques are employed to achieve the high input impedances.

2.2 -- Continued.

The highly reactive impedance of a short antenna is not the optimum source impedance to achieve the minimum noise figure in the first preamplifier stage. At low frequencies, however, when the antenna sizes tend to be quite large, and a reduction in sizes is most advantageous, even a significant deterioration of the receiver noise figure will not impair the overall performance of the receiver. This is due to the fact that at low frequencies, atmospheric noise usually determines the signal-to-noise ratio before the signal is ever received by the antenna.

Thus for a high Q antenna, the ohmic and ground losses contribute only a small additive term to an already high noise figure, i.e., while antenna losses generate noise, the lower Q resulting from the losses improves the noise figure of the receiver itself almost enough to compensate. This is, of course, only true for a highly reactive source such as an "electrically short" antenna.

The optimum source impedance cannot be achieved for high reactance source impedance over wide bandwidths. For electrically short antennas, the impedance of the antenna cannot be changed so the noise figure is optimized by adjusting the first stage of the preamplifier.

The MANPACK system will take advantage of electrically short antenna elements by using high impedance preamplifiers following the dipole elements. For operation up to 30 MHz or a minimum wavelength of 10 meters the overall length of the dipole should be approximately 10/4 = 2.5 meters or about 7 feet. The present model has dipoles of overall length of 70 inches.

2.3 Elimination of Horizontally Polarized Sky Wave Currents.

The small physical size of the antenna makes it difficult to keep the system balanced, and therefore currents which result from horizontally polarized downcoming sky waves have to be suppressed by some other means.

One method by which this could be accomplished would be by the elimination of all the horizontal conductors in the antenna. The vertical dipole elements could be mounted on a dielectric boom and the electrical information at each element could be transmitted via light beams to a central collection box.

In HF radio direction finding, we are usually interested in only one signal at a time and over a limited range of frequencies. Therefore, it is only necessary that the vertical antenna elements be isolated from the horizontal conductors at the frequencies of interest. This could be done by changing the frequency of the signal at each antenna element and passing this signal through a filter which attenuates the original frequency into the horizontal transmission lines which carries the signal at the new frequency to the phase combiner. The amount of attenuation must be very large in order that the vertical dipoles appear isolated from the horizontal transmission lines at the original frequency.

This is the technique that the MANPACK DF system will utilize in order to eliminate the bearing errors due to horizontally polarized sky wave.

3.0 DESCRIPTION OF MANPACK DF SYSTEM.

3.1 General Description.

As explained in the previous section, the MANPACK DF system will take advantage of the following design features:

(1) Small H-Adcock antenna configuration

(2) Wideband, electrically short antennas

(3) Frequency isolation of the dipole elements from the horizontal transmission lines.

A block diagram of the MANPACK DF system is shown in Figure 1.

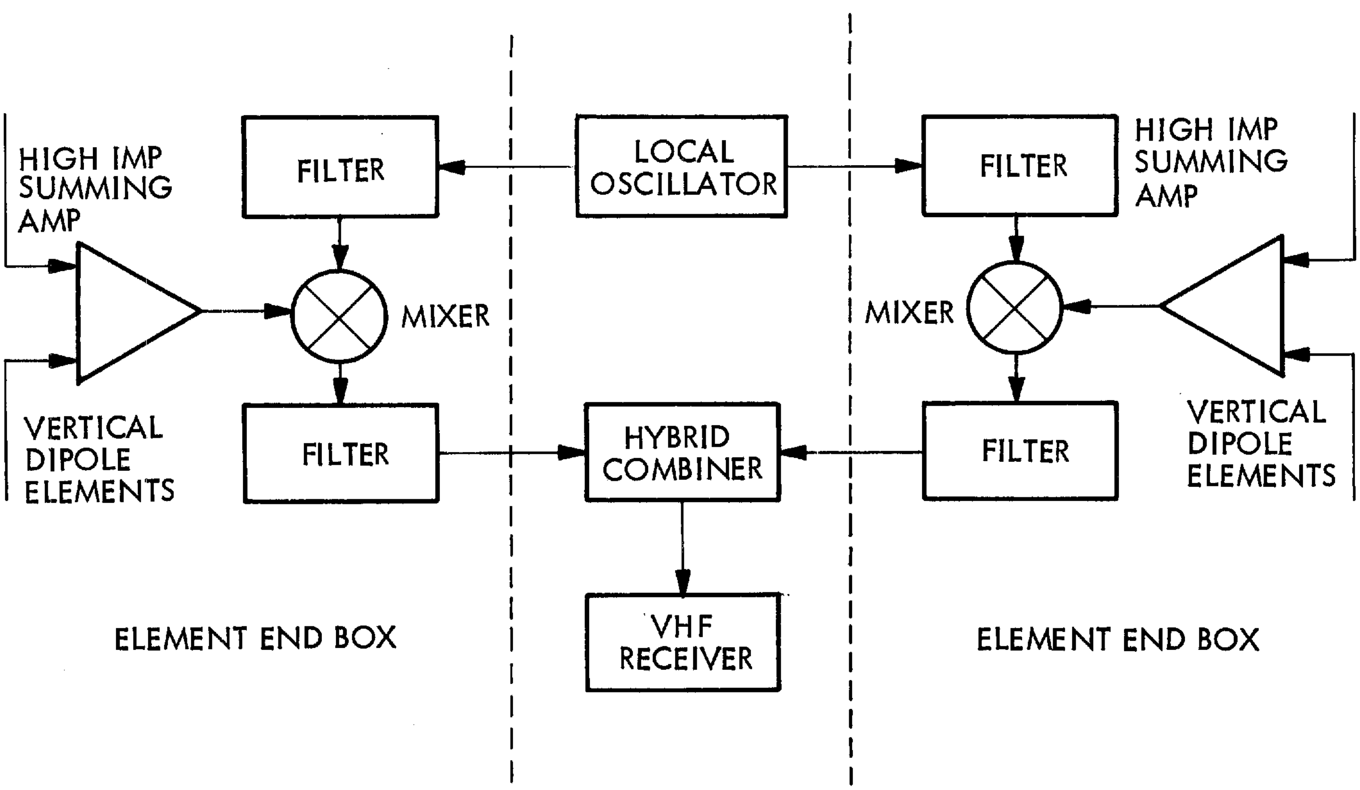

Figure 1. Block Diagram of MANPACK HF DF System.

3.1 -- Continued.

The operation of the system is as follows: the signal is picked up by the "electrically short" vertical dipole antenna elements and passed into extremely high input impedance amplifiers. The output of the amplifiers then enters a mixing stage where the signal is up-converted in frequency. The higher frequency is then passed through a high-pass filter and then down transmission lines to a collection box at the center of the horizontal boom. Here the vector difference of the signals from the two dipoles is obtained with a hybrid combiner, and the difference signal is sent to the input of the DF receiver.

This system is operated just the same as a loop system. A signal of interest is monitored on the DF receiver, and the entire antenna configuration is rotated on a central mast until a minimum or null is obtained at the receiver. In this position, assuming the two halves of the Adcock are balanced, the boom of the antenna will be perpendicular to the direction of arrival of the signal.

3.2 Detailed Description of the Present MANPACK DF System.

The MANPACK system demonstrated at Fort Monmouth in 1968 was redesigned in several areas to improve the performance. The two major items that were deficient in the previous system was the overall sensitivity and the spurious intermod signals generated by the upconversion of signal frequency. To illustrate all of the modifications in a logical order, let us group the changes into three categories: (1) the changes to the antenna and end box circuitry, (2) the changes associated with the center box circuitry, and (3) the physical changes to the packaging of the system.

3.2.1 Modifications to the Antenna Configuration and End-Box Circuitry.

(a) The antenna configuration was changed so that the lower half of both vertical dipole elements was grounded resulting in the elimination of one amplifier at each end-box with negligible change in sensitivity.

(b) The amplifier circuitry at each end-box was modified to increase the sensitivity further.

(c) The original isolation filters in the horizontal transmission lines carrying the local oscillator signals into and the IF signals out of the end-boxes were replaced with bandpass filters of improved design. The insertion loss was approximately 3 db and the isolation was increased from about 40 to 60 db.

3.2.1 -- Continued.

(d) High-pass filters were installed in the amplifier circuits to eliminate intermodulations from signals below 2 MHz.

A schematic diagram illustrating the end box circuitry of the present MANPACK DF system is shown in Figure 2.

3.2.2 Modifications to the Center-Box Circuitry.

The center-box circuitry which includes the 32-MHz local oscillator and the summing amplifier, had several improvements incorporated:

(a) The local oscillator circuitry was left essentially unchanged, but the output voltage was doubled by increasing the power supply levels and running the oscillator at a higher operating point. This reduced the level of intermod signals considerably.

(b) The summing amplifier which originally consisted of a two-channel transistor amplifier, a "magic T" (180-degree hybrid) circuit, and an output isolation amplifier, was changed to a completely passive phase combining circuit. The output of the hybrid combiner is fed directly to the VHF receiver. This resulted in simplified circuitry and improved overall performance.

A schematic diagram of the center-box circuitry is shown in Figure 3.

3.2.3 Modifications to System Package.

The entire antenna configuration was repackaged into a more functional unit. The aluminum boom and mast were replaced with ones made entirely of fiberglass tubing. This not only made the system more lightweight and durable, but the elimination of the horizontal conducting boom enhances the capability for sky-wave rejection. The horizontal transmission lines between the end-boxes and the center-box are contained inside the boom.

The mast is mounted on the tripod from a surveyors transit, and a 360-degree azimuthal direction indicator was added. The system is now easier to transport and operate as well as being a much more durable piece of equipment. A photograph of the present MANPACK DF set is shown in Figure 4.

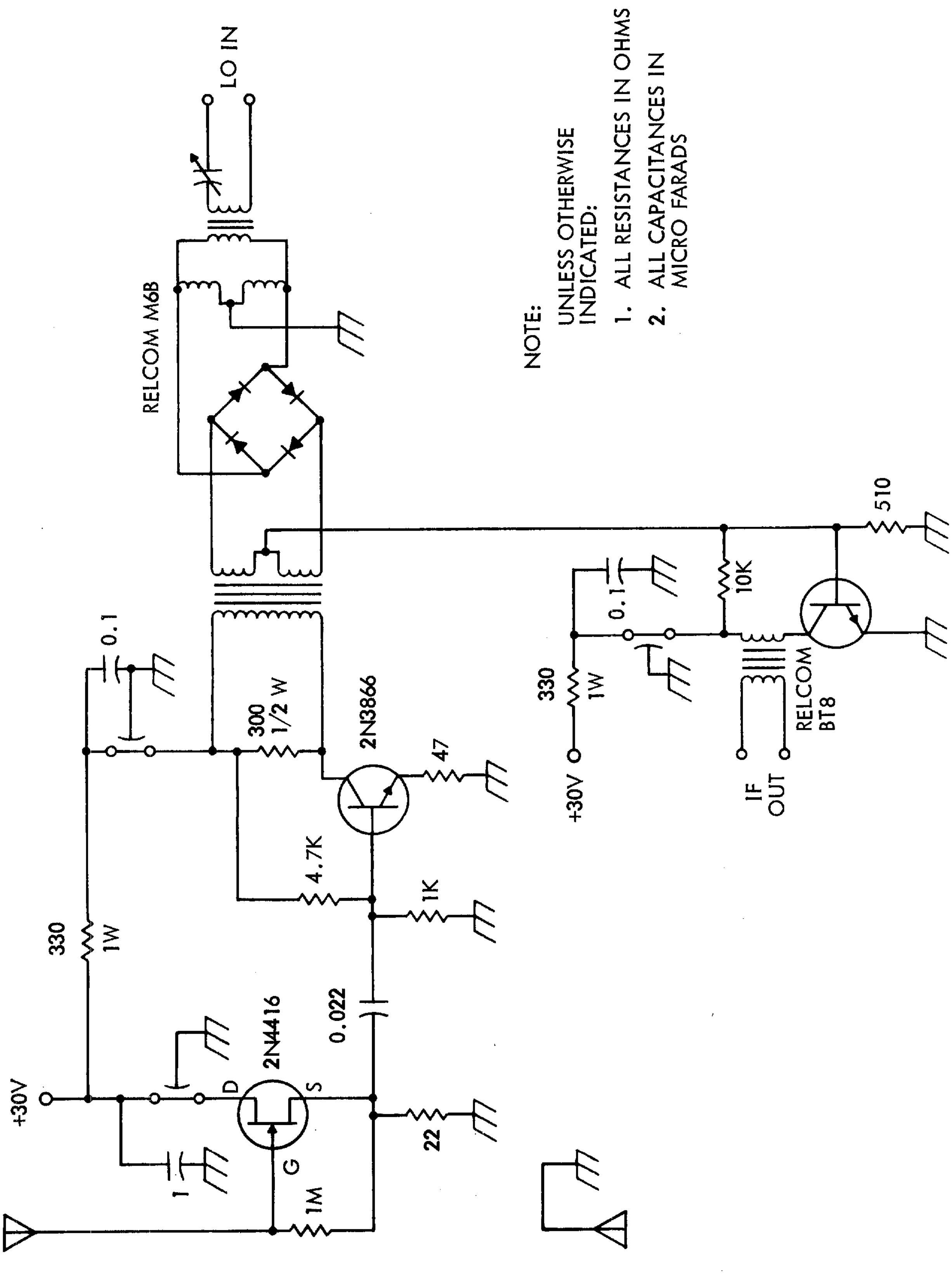

Figure 2. Schematic Diagram of End Box Circuitry.

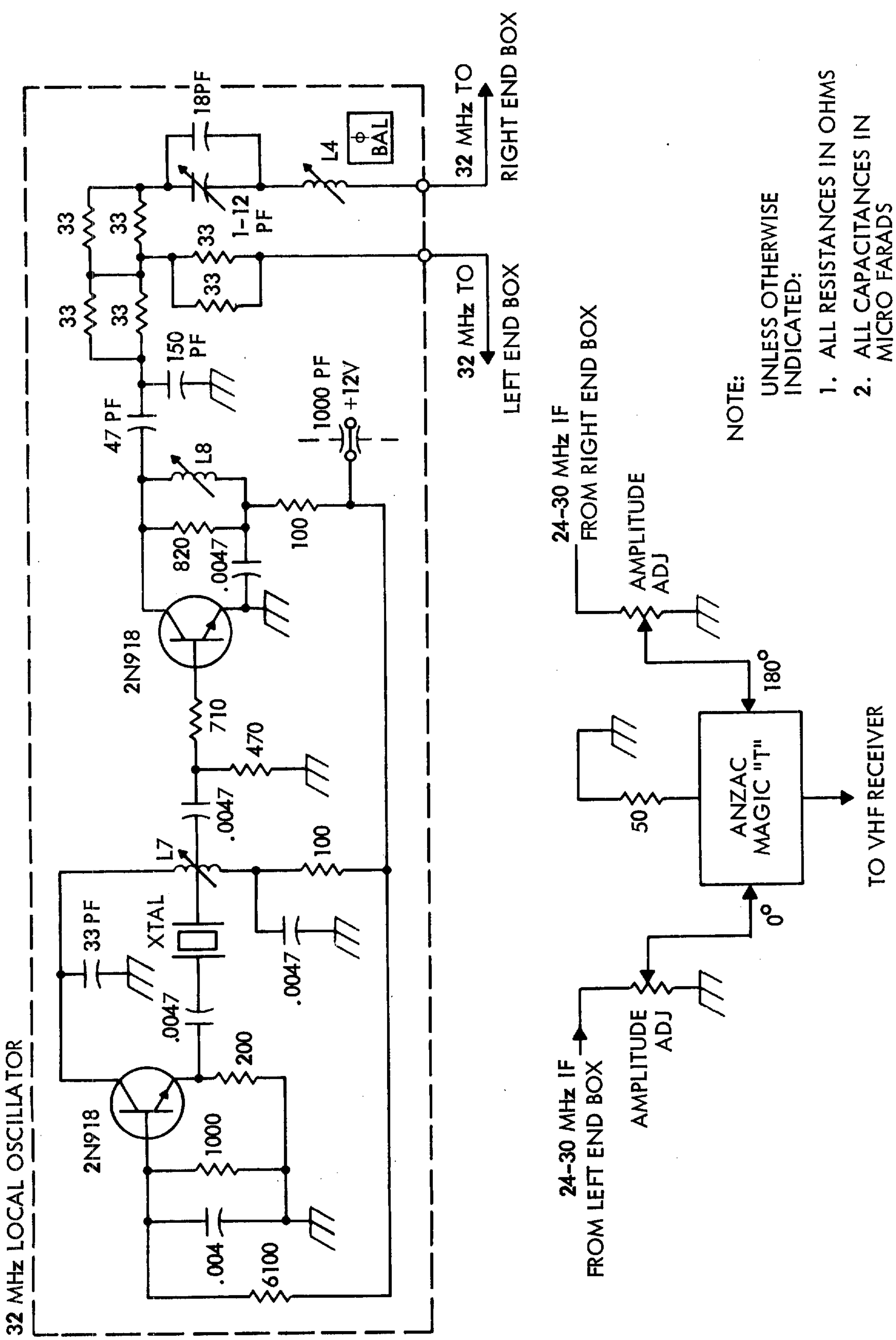

Figure 3. Schematic Diagram of Center Box Circuitry.

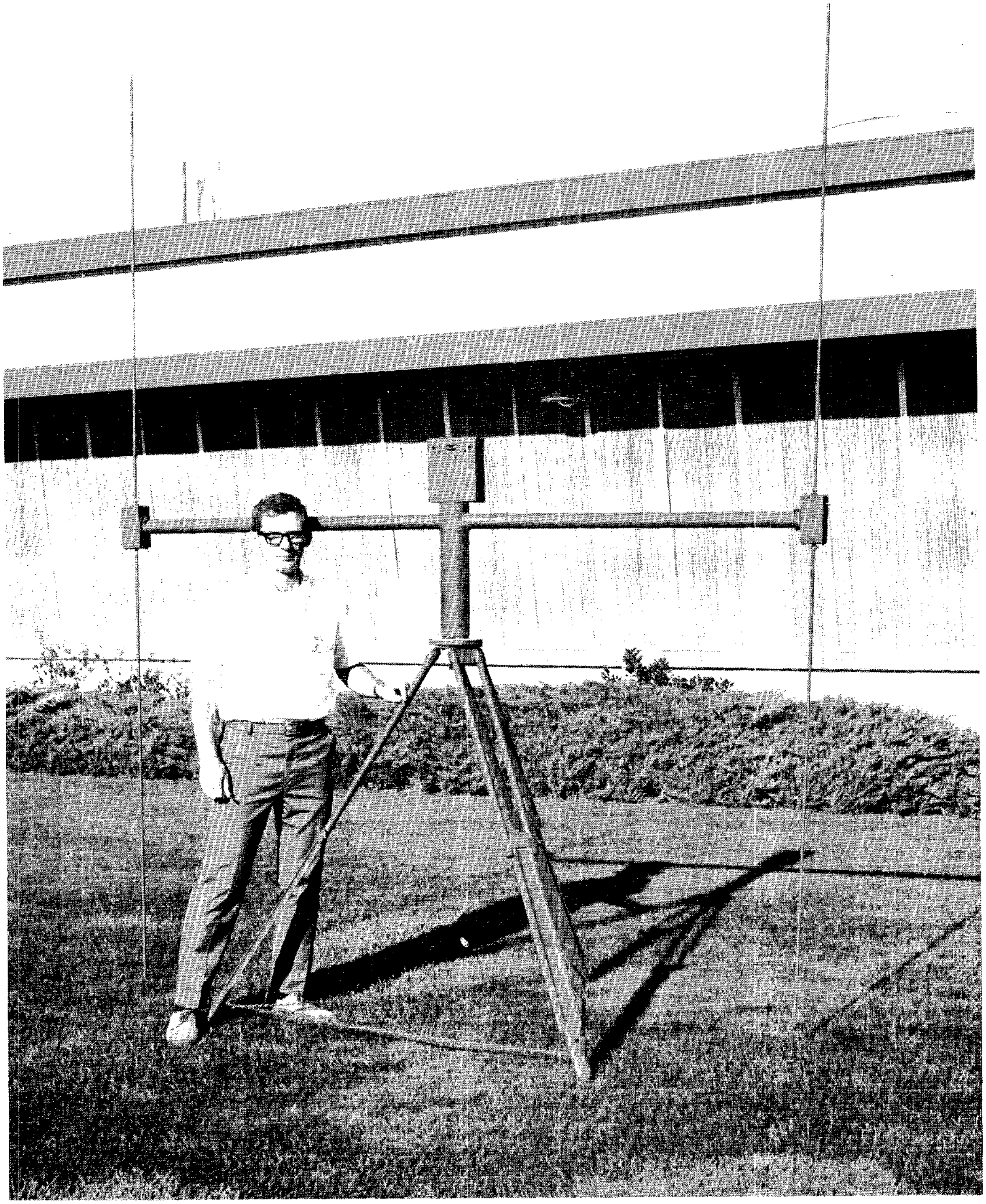

Figure 4. Photograph of Present Manpack Model.

4.0 EXPERIMENTAL TESTS OF PRESENT MANPACK DF SYSTEM.

After all of the modifications that were described in the previous section were implemented, the system was subjected to further testing to determine the level of performance of the present design. There are three characteristics of the DF system which were selected to be measured and compared with other antenna types. These characteristics are: (1) some measure of the sensitivity of the MANPACK system, (2) the amount of sky-wave rejection that could be expected from using the MANPACK design, and (3) the accuracy of actual bearing estimates taken by the MANPACK system. We shall discuss the measurements made of the above three performance specifications.

4.1 Sensitivity Tests.

To gain some insight as to how the MANPACK DF system compares in sensitivity with another antenna system which is now operational equipment, the following experiment was performed.

A ten-inch-diameter shielded loop was selected as a representative portable DF antenna to compare with the MANPACK system. This loop type of antenna was designed for the Army by Sylvania Electronic Systems and currently is operational Army equipment.

The test site was chosen to be a valley just south of Livermore, California. This location is far enough away from industrial areas, and is shielded by high mountains on all sides so that the external noise level is very low.

The MANPACK and shielded loop were set up at one location along with a battery powered National HRO-500 Communications Receiver. The IF output of the receiver was monitored with an HP-403-B rms voltmeter. A TRC-77 battery-powered transmitter was set up one mile away from the receiver site. It was connected to a dipole antenna with a coupling device which allowed the radiated power to be controlled. Another receiver with a signal strength meter was located just out of the near-field of the HF transmitter to measure the changes in radiated RF power. The objective of the experiment is to measure the output signal-to-noise ratio of both the shielded loop and the MANPACK DF systems as the incident signal power or field strength is varied by known amounts. The distance between the receiver and transmitter is such that the sky-wave present at the receiver should be negligible with respect to the ground-wave. Therefore, we shall be measuring the sensitivity of both types of antenna to ground wave signals.

4.1 -- Continued.

The frequency of the CW transmissions was 7.455 MHz. The up-converting process of the MANPACK system with the 32-MHz local oscillator required the receiver to tune in the up-converted signal at 24.545 MHz. Measurements of the HRO-500 receiver sensitivity and the output noise levels using a 2.5-kHz bandwidth at these two frequencies showed:

Frequency	Receiver Sensitivity	Receiver IF Output Noise (1 v = 0 db)
7.455 MHz	-112 dbm	-30 db
24.545 MHz	-121 dbm	-27 db

It was concluded that the receiver was internally noise limited since the receiver output noise remained unchanged with the antenna connected or disconnected. Therefore, 9-db attenuation was put in the MANPACK antenna line to compensate for the receiver's differential in sensitivity as the frequency was changed.

The transmitter was tuned for maximum radiated power and the received signal and noise measured for both the loop and MANPACK antennas. Then the radiated power was decreased in increments of 10 db, and measurements again made. This was continued until the signal was well down in the noise.

The results of this experiment are illustrated in Figure 5. This indicates that there is no loss in sensitivity by using the MANPACK system design. The instrumental accuracies of the experiment were such that one may conclude that the sensitivities of both systems were comparable. The experimental results at the smaller signal-to-noise ratios may not be reliable, since errors can become significant when estimating signal-to-noise ratio at low signal-to-noise ratios.

The output signal-to-noise ratio varies linearly with the input signal-to-noise ratio as would be expected. The noise capture, or small signal suppression effect, of the receiver detector is noticed for the loop antenna at the low signal-to-noise ratios, but again it should be pointed out that experimental accuracies are low in this region.

Since direction-finding applications require an output signal-to-noise ratio of at least 10 db, the conclusion is that the MANPACK design is comparable to operational loop type of antenna systems as far as antenna sensitivity is concerned.

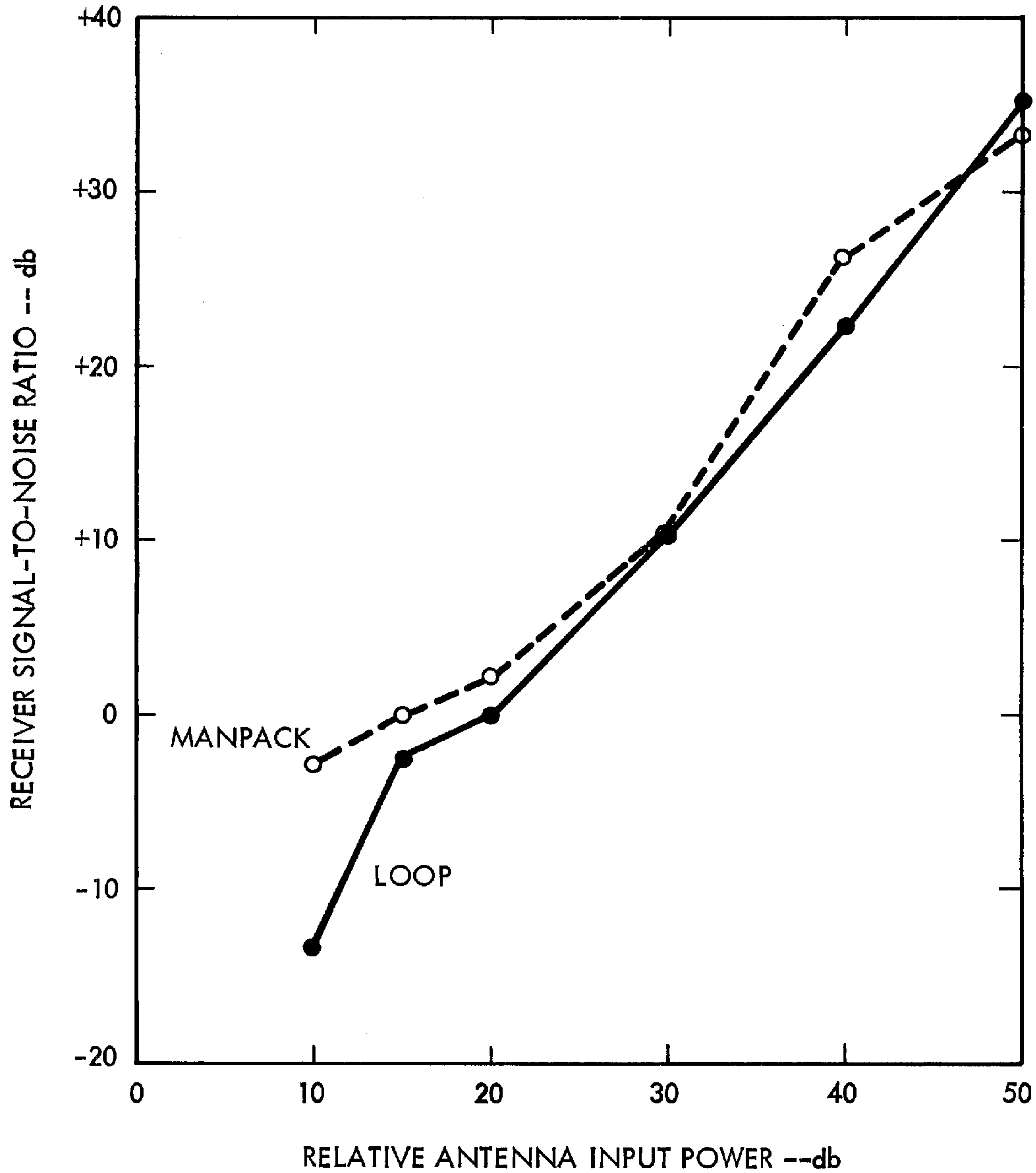

Figure 5. Antenna Output Signal-to-Noise Ratio as a Function of Relative Input Signal Power.

4.2 Sky-Wave Rejection Tests.

The MANPACK system evolved as a result of trying to eliminate the errors in bearing estimates which result from horizontally-polarized sky-wave. The solution was to eliminate currents in the antenna structure resulting from these sky-waves. To measure how much these currents were attenuated by the MANPACK design, the following experiment was performed.

The shielded loop antenna described in the preceding section was selected as a comparison DF system to measure the effects of sky-wave. The test site was the parking lot behind the Sylvania facilities at Mountain View, California. An HF transmitter was located a distance of 6 miles away, and broadcast a CW signal at various frequencies selected by the experimentors. The transmitter antenna was a horizontal windom. Computer propagation predictions were run off so that frequency and time of day could be selected when the sky-wave and ground-wave components of the received signal would have comparable amplitudes. Most transmissions were made at frequencies of about 7 MHz. The MANPACK and shielded loop antennas were set up in the same general area, and both were connected to identical R-390 communications receivers. The receivers were tuned so that both DF systems were monitoring the same controlled signal simultaneously. The IF output of both receivers was monitored by HP-403-B rms voltmeters, and also, in order to have a permanent record, the output of the two voltmeters was recorded on a two-channel visicorder or strip-chart recorder. The test situation is illustrated in Figure 6.

As was pointed out in Appendix A of this treatise, sky-wave signals tend to be time varying in both amplitude and phase due to ionospheric perturbations. This would cause a fading signal to be incident on the DF antennas. The way we propose to measure the amount of sky-wave present at the output of the two DF antennas is to estimate the amount of fading of the signal from the R-390 receivers. This could be obtained by measuring the amount of swing (fading) of the IF being charted by the visicorder.

Recordings were made for both DF systems for several trials and during different hours of the day. As expected during the mid-day, almost no fading was observed from either the MANPACK or the shielded loop, indicating the absence of sky-wave. During the late afternoon hours the fading became noticeable, especially from the shielded loop, showing that the strength of the sky-wave was increasing. From the many recordings made of the fading, it was impossible to determine absolutely how much the MANPACK configuration attenuated currents caused by horizontally-polarized downcoming sky-wave, but from the experimental results, it was concluded that the attenuation was at least 10 db. The fading was measured with both the antennas in the null configuration, which is the orientation where the output of the antenna should be minimum. This was done because the fading due to the sky-wave causes difficulty determining just when the antenna is nulled, and makes the null very indistinct. An

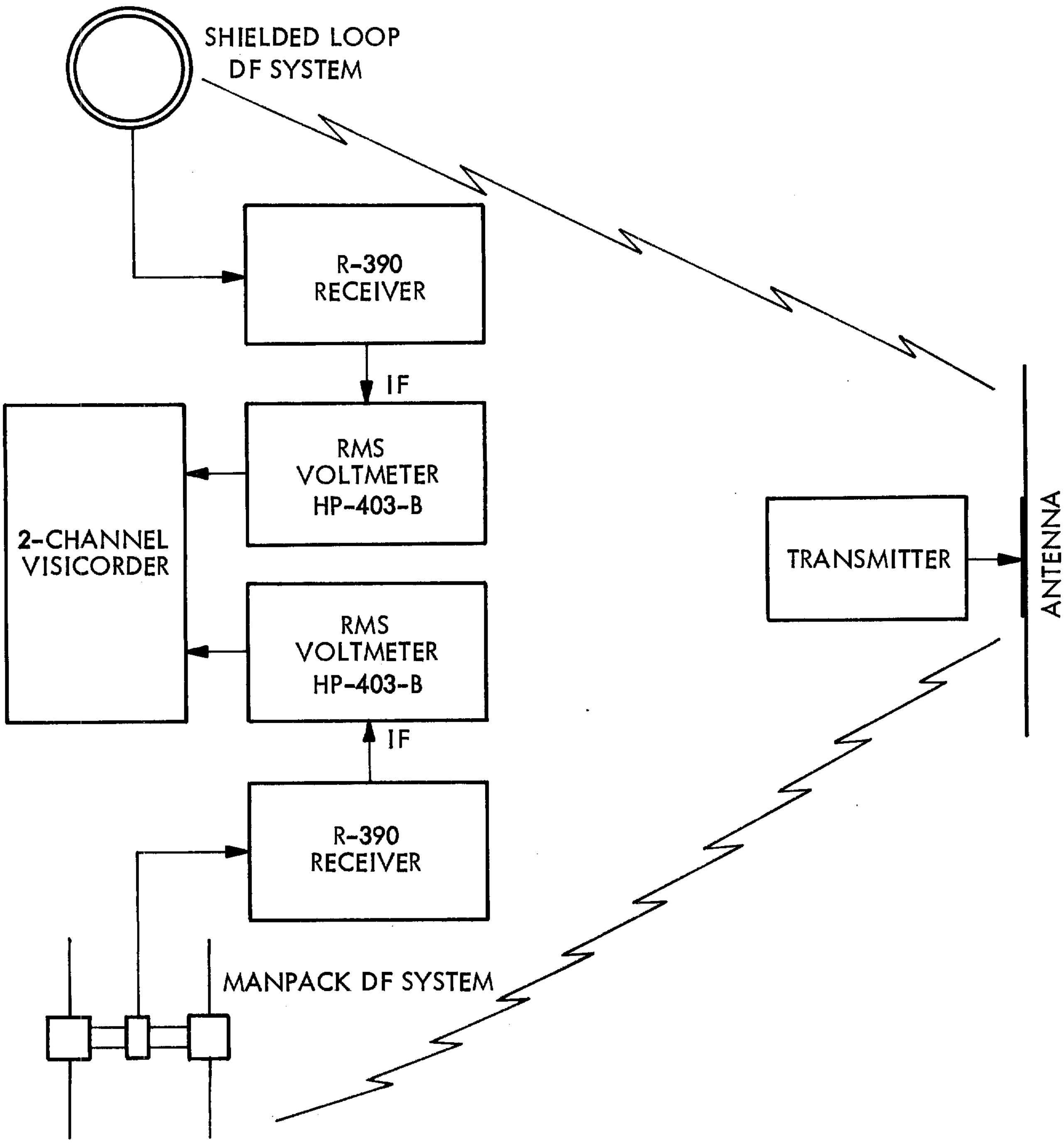

Figure 6. Experimental Setup For Sky-Wave Rejection and Bearing Accuracy Tests.

4.2 -- Continued.

example of the experimental results is shown in Figure 7 which is a photograph of the Visicorder output taken when the sky-wave signal was fairly strong. The photograph shows that the output of the loop antenna is varying in amplitude by amounts of 15 db. This is about the depth of the null of the shielded loop system which was measured in the next series of tests on bearing accuracies. Therefore, the loop antenna is varying completely out of a null configuration under heavy sky-wave conditions. The MANPACK system, on the other hand, remained sharply nulled on the signal with the output variations on the order of only 5 db. This is about 25 percent of the total null depth (20 db).

The gain of the MANPACK amplifiers required different electronics and ranges of operation to be used on the two channels of the Visicorder which is why the scaling is slightly different on the two recordings. Some quantitative measurements may still be made, and the general conclusion reached that the MANPACK DF system attenuates currents from horizontally-polarized sky-wave by at least 10 db and can maintain a null configuration on a signal under heavy sky-wave conditions when the shielded loop cannot.

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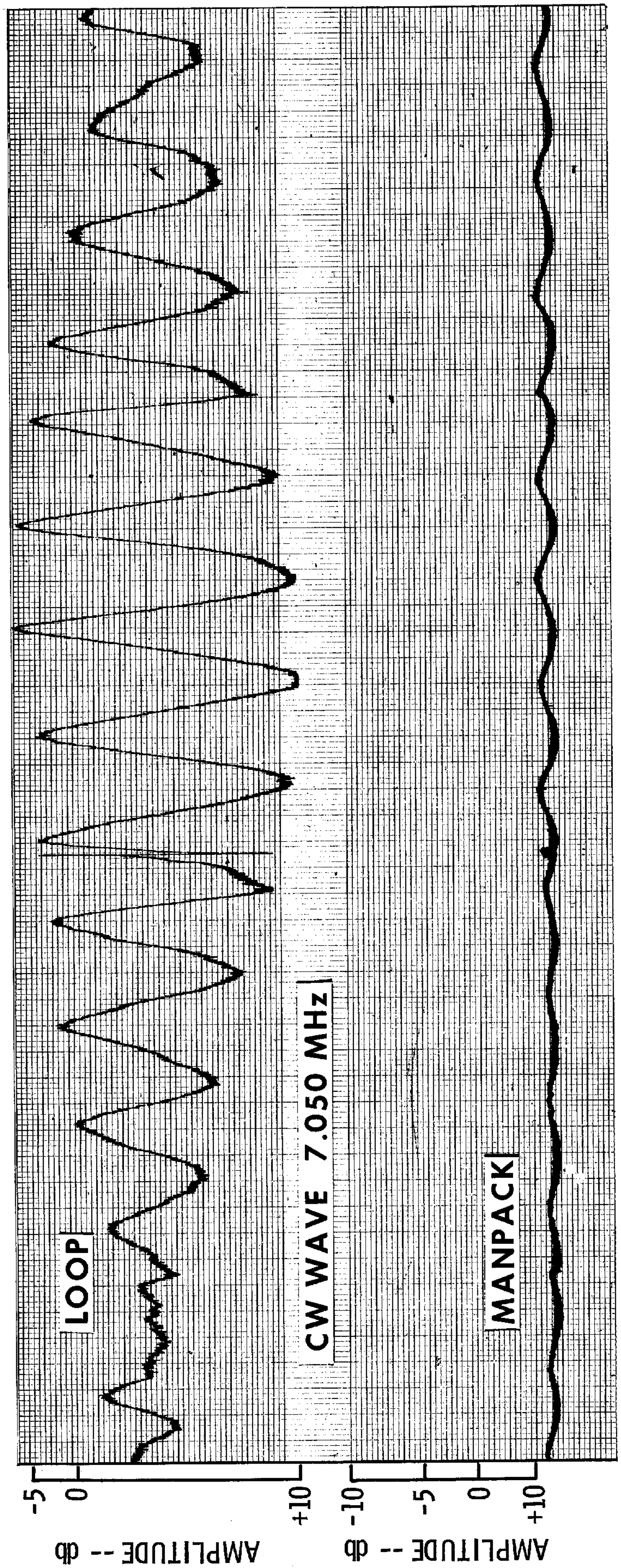

Figure 7. Visicorder Output From Sky-Wave Rejection Tests.

4.3 Bearing Accuracy Tests.

To compare the accuracy of bearing estimates taken with the MANPACK DF system with those taken by the shielded loop system, the same experimental situation described previously which was utilized for testing sky-wave rejection was used. Bearing estimates were taken with both DF systems under varying sky-wave conditions. In the absence of sky-wave, both systems gave comparable bearing estimates, the superiority of the MANPACK was clearly demonstrated for heavy sky-wave condition. The results are summarized below:

		Null Depth	RMS Bearing Error
No sky-wave	Shielded loop	25-30 db	3 deg.
	MANPACK	16-28 db	3 deg.
Heavy sky-wave	Shielded loop	~15 db	13.5 deg.
	MANPACK	16-22 db	4.4 deg.

It should be mentioned that the width of the null (in degrees) was narrower for the MANPACK than the loop. Under heavy sky-wave conditions the null of the loop became very smeared and indistinct, and sometimes completely absent. The null of the MANPACK system remained fairly sharp, but drifted because the amplifiers in each side of the Adcock antenna could not be maintained in a balanced condition. This is due to the large current drain on the battery power supplies. Since each amplifier has its separate power supply, the operating points of the two amplifiers drift independently, causing the Adcock to become unbalanced. This causes the position of the null to drift. To compensate for this, the amplifiers of the two dipoles were tuned to a balanced condition before each bearing attempt on the target transmitter. This condition was also present during each of the previous tests and the system had to be constantly retuned. This should be kept in mind when considering the results of the tests.

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Appendix A

Theoretical Discussion of Portable DF Systems

1.0 GENERAL PORTABLE DF SYSTEMS.

The fact that to a first approximation high-frequency radio waves propagate outward from the transmitting antenna along a great-circle route, enables a person who is picking up the signal with an HF radio receiver to estimate the line-of-bearing from his geographical location to that of the transmitting antenna by measuring the direction of arrival of the HF wave.

Direction-finding (DF) systems are radio receivers which have the capability to make a measurement of the direction of arrival of a radio wave that is being monitored. These systems are useful for determining the actual location of the radio transmitter or for navigation purposes.

This project was concerned with small portable direction-finding systems. We do not refer to the ones which are installed in trucks or mounted on jeeps, but the smaller types which can be transported by one or two men. They must have the capability to be disassembled, transported, and reassembled in a relatively short time for tactical operation. Their primary function is to make line-of-bearing estimates on high-frequency radio emitters in the near vicinity. The range of operation is usually required to be 10 miles or less. The high mobility is the chief requirement.

There are several general types of portable DF systems being used today. We will mention and briefly discuss a few of the principle categories of these DF systems.[2,3]

1.1 Loop-Type DF Systems.

The oldest and most familiar type of direction finder is the loop antenna. The loop antenna is arranged with the plane of the loop vertical and is rotated about a vertical axis. The output of the antenna is connected to an HF radio receiver. The loop is rotated about its vertical axis until a "null" or minimum of the receiver output is obtained (Figure A-1). In this position, the plane of the loop will be perpendicular to the direction of arrival of the HF wave.

1.1 -- Continued.

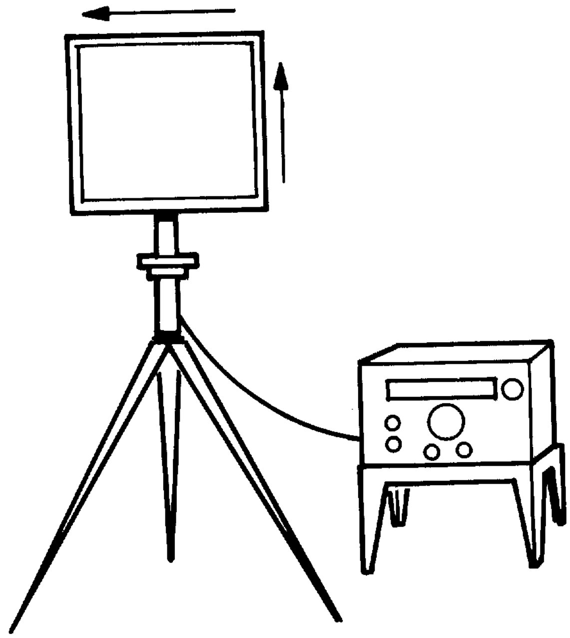

Figure A-1. Drawing of Loop Type DF System.

The propagated wave sets up currents in antenna conductors with amplitude and phase dependent on the amplitude and phase of the electromagnetic wave. If the received signal is ground wave, that is, if the radio wave is propagating horizontally across the surface of the earth, the currents set up in the two horizontal elements of the loop antenna have the same amplitude and phase, since the radio wave incident on each of these elements is the same. These currents tend to travel around the loop in opposite directions, and thus cancel each other out no matter how the loop is oriented. But the currents set up in the spaced vertical elements of the loop may differ in phase due to the relative time delay between incidence of the EM wave. This phase difference causes a resultant current to flow in the loop antenna dependent on the orientation of the loop. Complete cancellation can occur only when the incidence time difference is zero which happens when the plane of the loop is perpendicular to the direction of arrival of the electromagnetic plane wave. The loop antenna, besides being subject to errors due to unknown polarization, will give spurious readings unless it is balanced with respect to ground due to unbalanced reactive currents flowing.

1.1 -- Continued.

These errors can be reduced by using circuit arrangements which are symmetric with respect to ground and by using shielded loops. The operator of this type of system tunes his receiver to the desired signal and rotates the loop antenna until a null is obtained. The direction of arrival is then indicated by the orientation of the loop.

1.2 Adcock DF Systems.

A discussion of the motivations that led to the development of the Adcock systems will be postponed until the problems associated with loop-type antenna systems are reviewed. There are basically two types of Adcock antenna configurations, the U and the H Adcocks. The U-Adcock is illustrated in Figure A-2. The antenna system is basically two vertical antenna elements erected at ground level, and fed with horizontal feeders usually laid under the surface of the ground. This antenna is usually balanced with respect to ground. It would be difficult to physically rotate this type of antenna system, so usually two such antennas are employed at right angles to each other, and the output of the antennas are combined in a goniometer. Rotating the goniometer is equivalent electrically to physically rotating a single Adcock (or loop). Eight-element Adcocks employ four of the single Adcock antenna systems at 45-degree angles to each other, and combine all their outputs in a goniometer.

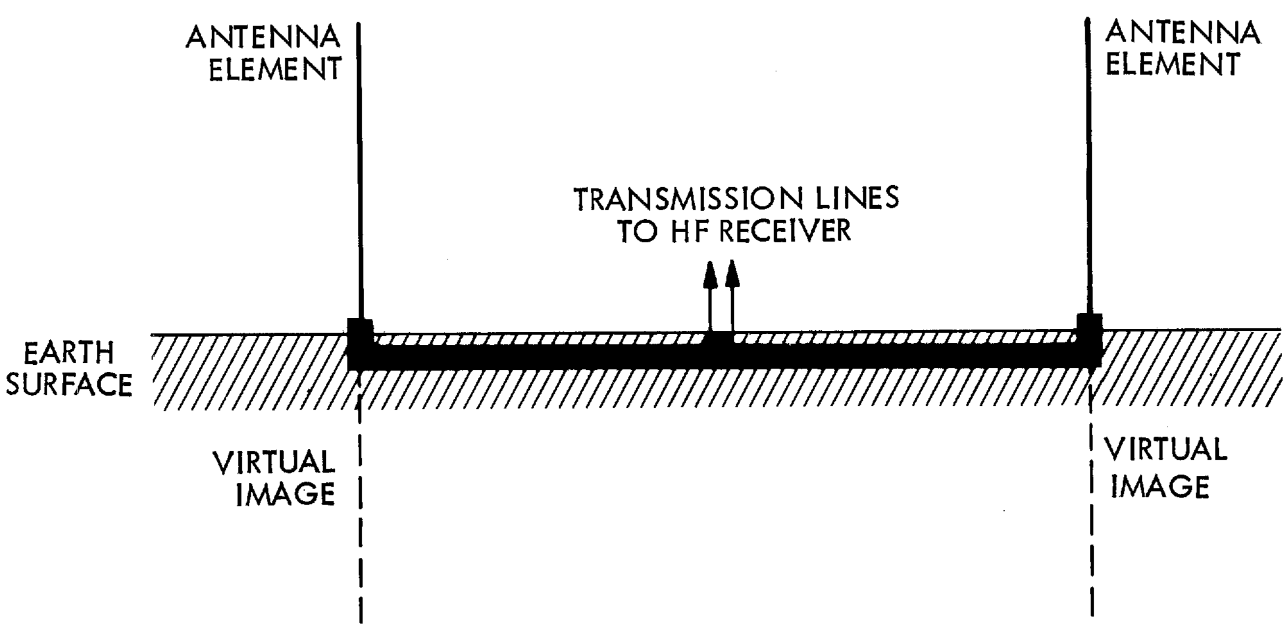

Figure A-2. U-Adcock Antenna Configuration.

1.2 -- Continued.

The H-Adcock antenna is illustrated in Figure A-3. It consists of two vertical dipole elements connected by horizontal feed lines and a supporting boom. This type of configuration can either be rotated physically or several fixed antennas combined with a goniometer. This type of antenna is usually elevated a quarter wavelength or more above the ground so that it can be balanced with respect to ground. The dipole antenna arrangement is difficult to balance when located close to the ground since it is assymetric with respect to ground.

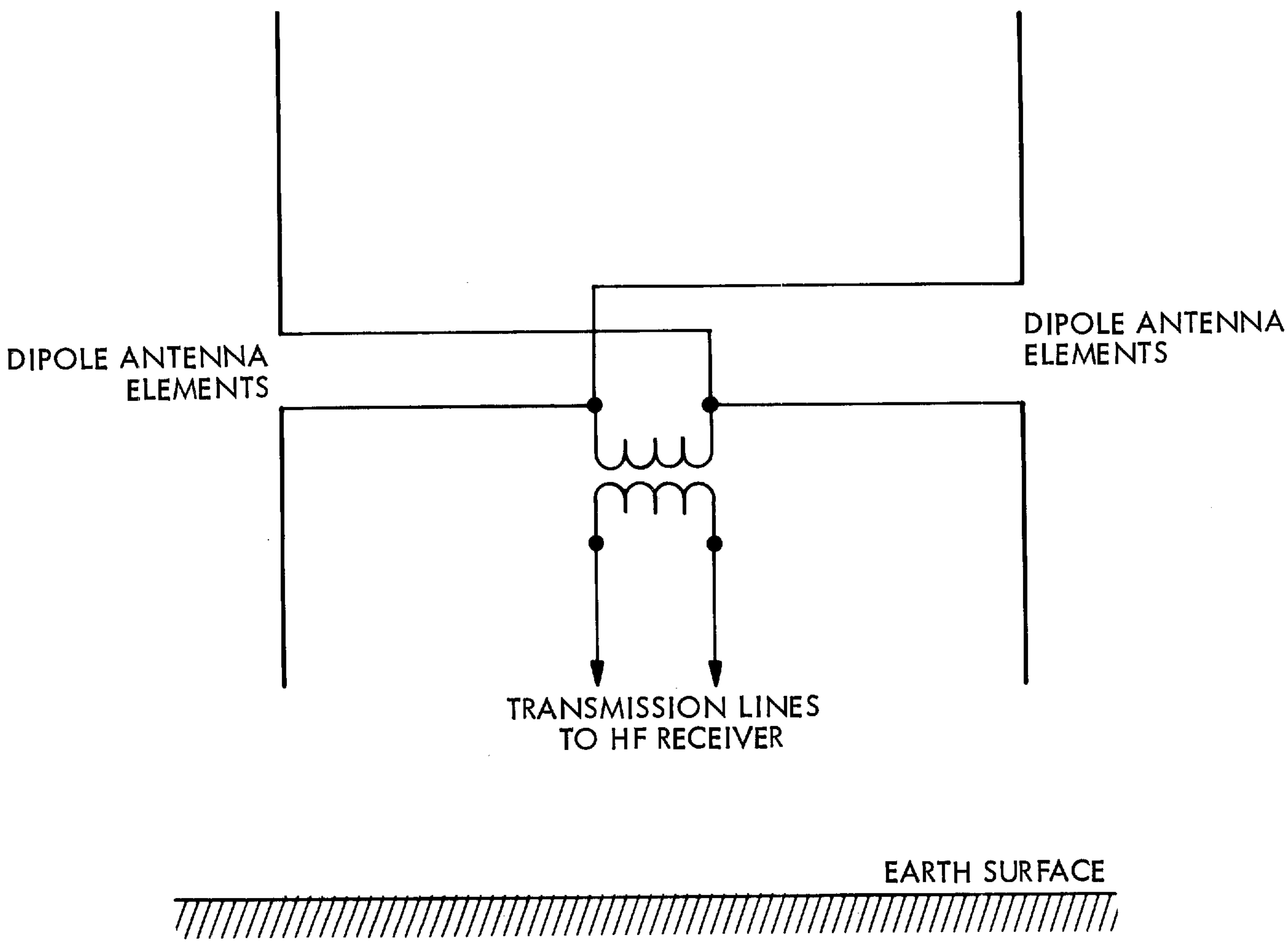

Figure A-3. H-Adcock Antenna Configuration.

1.3 Spaced Loops.

There is currently considerable development work being done on systems of spaced loops.[2] The spaced loop antenna is essentially two standard loop antennas one at each end of a horizontal boom. The output of the two loop antenna elements are usually combined in parallel opposition. There are three common configurations for mounting the two loops: coaxial, vertical coplanar, and horizontal coplanar. Some favorable results from experimental investigations of this type of direction-finding system have been reported, especially concerning sky-wave performance.

1.4 Rotating Systems.

All of the previously described antenna systems, loops, Adcocks, or spaced loops can be continuously rotating, either physically or by means of a goniometer. The output signals of these rotating systems are displayed on a cathode ray tube. Depending upon the particular system, some sort of pattern indicating direction of arrival of incoming signals is obtained. The advantages of rotating systems are that they look in all directions (360 degrees) in a short period of time, depending on the rotation speed of the antenna. Most portable systems have variable speed controls. For example, the AN/PRD-8 DF system has a 30-rpm continuous rotation speed and slow-speed variable operation between 1 and 15 rpm. The display, which is an averaged look in all directions due to the persistence of the scope and the human eye, averages out some of the noise and is convenient to obtain bearing estimates from. Most of the small portable rotating systems have the antenna elements physically whirling. It has been experimentally noticed the rotating systems seem to be more effective when sky-wave is present.

2.0 PROBLEM DESCRIPTION.

The first type of antennas used for direction-finding purposes were the previously described loop antennas. The early experimenters noted a phenomenon that occurred with loop-type direction finders which they termed the "Night Effect" for obvious reasons. It was noticed that during the daylight hours the direction-finding equipment performed very well when taking bearings on HF emitters located several miles away. The bearing measurements made were very accurate and consistent, but during the evening and night the bearing estimates became very erratic and unreliable. Since these irregularities were predominant at night the phenomenon was termed the "night" effect.

2.0 -- Continued.

The reason for the irregularities is the presence of sky wave at the direction-finding receiver site (Figure A-4). During the daylight hours the conditions for HF sky wave are not good since the D-layer of the ionosphere absorbes the electromagnetic energy which is propagated skyward from the antenna of the HF transmitter. Under these conditions the signal received at the direction-finding site is just the ground wave which propagates horizontally across the surface of the earth. This received signal is almost always steady and nonfading and travels directly from the transmitter antenna to the receiver antenna. With this strong steady signal the loop type of direction finders were able to make reliable estimates of the line of bearing.

During the evening hours the D-layer begins to disappear, and the conditions for the sky-wave propagation improves. The energy propagated skyward from the transmitter antenna is reflected back to earth by the higher layers of the ionosphere and received at the DF receiver along with the ground wave. A radio signal propagated via the ionosphere undergoes changes in amplitude and phase due to perturbations of the ionosphere. Also multipath conditions usually exist during ionospheric propagation causing interference at the receiver site. The result is that the received signal has random variations in polarization, amplitude and phase; and the direction of arrival of the reflected wave has random

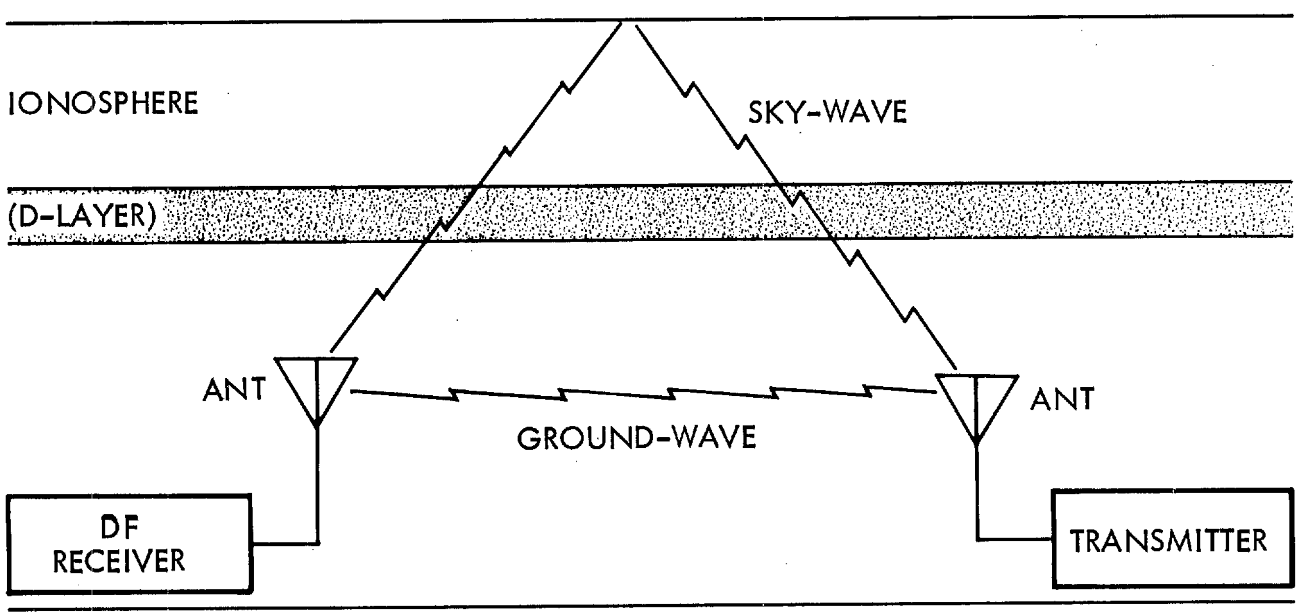

Figure A-4. Illustration of Direction Finding Signal Propagation.

2.0 -- Continued.

variations and errors due to ionospheric tilts and other propagation phenomenon. The results of all this is that as the strength of the sky wave received at the direction-finding site becomes comparable with that of the ground wave, the bearing estimates obtained by trying to null the currents in the loop antenna become very erroneous. There are two major reasons for this. The first reason is that the currents set up in the horizontal elements of the loop antenna due to the downcoming horizontally-polarized sky waves do not cancel each other out as with ground wave. This is because there is a phase differential between the currents caused by the time difference of arrival of the downcoming wavefront at the top and bottom horizontal antenna elements. This causes a resultant current to flow around the loop which cannot be nulled out by orienting the plane of the loop perpendicular to the azimuthal direction of arrival, and the result then is either a false bearing, an indistinct null, or both. The second reason is the random variations in amplitude, phase, and angle of arrival of propagated sky wave; these cause the null to become very smeared and indistinct, and it may be impossible to obtain a null by any orientation of the loop.

As the frequency gets higher and the distance between the HF transmitter and receiver becomes greater, the "night" effect becomes more pronounced, because under these conditions the ratio of sky-wave strength to ground-wave strength is higher.

The errors in bearing caused by downcoming horizontally-polarized sky waves can be eliminated with an Adcock antenna. The action of the previously described Adcock antenna system is the same as the loop for vertically-polarized signals. This is because the output current is proportional to the vector difference of the voltages induced in the vertical elements of the Adcock antenna the same as the loop. Horizontally-polarized downcoming waves induce currents in the horizontal members (feed lines) which are the same in amplitude and phase, and since the feeders are connected in an arrangement to take the vector difference of two sides of the antenna, the horizontal currents tend to cancel each other out.

The Adcock antenna system is effective, however, only if symmetry is maintained with respect to ground. If the antenna elements are not balanced to ground, reactive currents will flow in the antenna when in the null configuration, thus again causing bearing errors.

The U-Adcock antenna system is balanced by the manner of its construction, and the H-Adcock may also be balanced if the entire antenna is elevated at least a quarter wavelength above the earth to reduce capacitive coupling. Small H-Adcock systems which are not sufficiently elevated are usually unbalanced with respect to ground due to the asymmetric arrangement. The problem we are concerned with is the elimination of currents caused by horizontally-polarized sky waves in small unbalanced H-Adcock antenna systems.

Appendix B

History Of MANPACK DF System

1.0 OBJECTIVE OF THE MANPACK DF STUDY.

The objective of the MANPACK DF study was to demonstrate the feasibility of a new type of portable direction-finding antenna system. The motivation for the new design was to eliminate the effects of sky wave which have plagued all small transportable direction finders. The proposed system had several innovations incorporated in order to achieve the objective. Some of these features are:

(1) Small H-Adcock antenna configuration for simple construction and easy transportability

(2) Electrically short, integrated antennas utilized to allow small dipole elements

(3) Frequency conversion at the antenna elements to provide isolation from all horizontal conductors and eliminate sky-wave effects.

2.0 INITIAL DESIGN.

In 1966 the MANPACK DF system was initially conceived and the first working model was designed and built. A technical report, File No. EE-RD-351-4123, was published in January, 1967, which describes in detail the construction, circuit arrangements, and test results of this first model. All of the technical details will not be repeated here, but some of the more pertinent facts are listed.

The unit was designed to operate over the frequency range 2 to 8 MHz.

The preamplifier and up-converter circuitry was contained in two aluminum boxes which also served as a mount for the two halves of the dipole antenna. These boxes were mounted one at each end of a 10-foot aluminum boom. The hybrid combiner and local oscillator were contained in an aluminum box mounted at the center of the boom.

The antenna elements were connected directly to a differential FET amplifier without any preselection or matching networks.

2.0 -- Continued.

A post-selector followed the amplifier with the purpose of narrowing the bandwidth to reduce the number of spurious signals produced in the nonlinear mixing stage. The post-selector had frequency bands of 2 to 3 MHz, 3 to 4 MHz, 4 to 6 MHz, and 6 to 8 MHz.

The local oscillator was crystal controlled and operated at a frequency of 32 MHz.

The hybrid combiner was used in conjunction with a two-channel summing amplifier to obtain the difference signal.

A battery power supply for the entire system was contained in the center box.

The testing program was carried out and the conclusions reached were the following:

(1) The sensitivity of the system was poor and was attributed to matching loss and poor amplifier noise figure

(2) The system suffered from intermodulation problems due to spurious signals being introduced from the nonlinear mixing operation

(3) The amount of isolation of the vertical dipole elements from the horizontal conductors was not sufficient.

3.0 IMPROVED SYSTEM DESIGN.

Late in 1967 some improvements were made on the first model to reduce the previously mentioned deficiencies:

(a) The first stage amplifier was redesigned to increase the sensitivity and reduce the intermodulation problem

(b) The post-selector was removed and replaced with a filter which increased the sensitivity

(c) Finally, dielectric spacers were installed between the aluminum end boxes and the horizontal boom to reduce the coupling between the boom and the vertical dipole elements and thus increase the amount of isolation between the antenna elements and horizontal conductors.

3.0 -- Continued.

(d) The battery power supplies were moved to each end-box eliminating the need for horizontal power supply lines.

In early 1968, this model was demonstrated at Fort Monmouth for the Army. Although the sensitivity of the system was acceptable, the dense signal environment at Fort Monmouth caused the system to suffer badly from spurious intermod signals being introduced into the passband of the receiver.

(This page is Unclassified)

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Manpack		4				
DF		4				
Antenna		4				
Portable		4				
HF		4				
Adcock		4				
Sky-wave		4				
Isolation		1				
Bearing		1				
Electrically-Short		1				
Polarization		1				
Short Range		1				

(This page is Unclassified)

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Sylvania Electronic Systems - Western Division, P. O. Box 205, Mt. View, Calif. 94040	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP N/A

3. REPORT TITLE

MANPACK DF SYSTEM - FINAL REPORT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5. AUTHOR(S) (First name, middle initial, last name)

Richard R. Erickson
Marvin Wahl

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1968	36	4

8a. CONTRACT OR GRANT NO. DAAB07-68-A-0503-P001	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	ECOM-0503-P001-G806

10. DISTRIBUTION STATEMENT

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Electronics Command, Fort Monmouth, New Jersey

13. ABSTRACT

This report summarizes the past two year R&D effort at Sylvania Electronic Systems-Western Division to develop a small transportable high frequency radio direction finding system. This system, the "MANPACK DF System," features "electrically short" antenna elements in an H-Adcock configuration along with frequency isolation of the antenna elements from the horizontal transmission lines to eliminate bearing errors due to downcoming horizontally polarized sky-waves. System description and test results are included in this report.