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A MODERN ARMY MOBILE WEATHER RADAR AN/TPS-41

by

Raymond L. Robbiani

February 1969

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TECHNICAL REPORT ECOM-3102

A MODERN ARMY MOBILE WEATHER RADAR AN/TPS-41

By

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Engineering Development Technical Area
Atmospheric Sciences Laboratory

FEBRUARY 1969

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U. S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

Abstract

The Mobile Weather Radar AN/TPS-41(XE-2) is being developed with a 5-foot parabolic antenna to provide the field Army with a highly mobile, tactical weather radar housed in an S-280 shelter, capable of operation and deployment within 30 minutes and transportable by either helicopter, $2\frac{1}{2}$-ton cargo truck, or cargo aircraft. The radar components are designed for quick removal from the shelter, are operational as outside equipment, and can withstand all environmental and transportation conditions of the field Army. This X-band radar will determine location, dimensions, movement, and rainfall rate of precipitation areas to a range of 150 miles. Iso-Echo contouring will be available to display three levels of rain intensity simultaneously or ten individual levels using the linear/logarithmic receiver.

The radar is entirely solid state, with the exception of the magnetron and display tubes. The low noise receiver (5 db noise figure) uses a tunnel diode preamplifier to provide maximum detectability of light rain areas. A single 7-inch display tube functions as either a Plan Position Indicator (PPI) or a Range Height Indicator (RHI) to minimize size and weight of the console. The display data will be transmitted to remote field locations up to 1 mile from the radar via transmission over a single, twisted pair of standard field wires.

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A MODERN ARMY MOBILE WEATHER RADAR AN/TPS-41

INTRODUCTION

At present, the U. S. Army possesses no ground-based mobile weather radar to support field Army operations. Currently-available weather radars used by other military services are designed primarily for fixed-station operations. Their lack of mobility and large size negate their usefulness for Army operation since they cannot collect suitable data over a specific area of operation at the appropriate time.

An engineering development model of the Mobile Weather Radar AN/TPS-41, designed to satisfy Mobile Weather Radar QMR 1539c(42), will be delivered to the U. S. Army Electronics Command (USAECOM), Fort Monmouth, New Jersey, in June 1969, and is the basis of this report.

Weather radar data are essential and basic in providing an up-to-the-minute three-dimensional picture of precipitation and nuclear detonation activity required for highly mobile, tactical combat operations. Weather radars are the only meteorological equipments capable of collecting precipitation and nuclear cloud data over the entire volume of a friendly Army area and over large portions of an enemy Army area (silent area). The AN/TPS-41 will be capable of collecting required weather and nuclear detonation information, such as precipitation and cloud location, vertical and horizontal dimensions and movement, and also instantaneous rain rates and accumulated rainfall over the areas of interest.

To provide suitable design parameters, consideration must be given to the high mobility and quick-response concepts of the modern field Army, and to special forces for conventional and unconventional tactical combat operations or police actions. Precipitation data are crucial in providing such information as determining friendly or enemy ground trafficability, aircraft (manned or missile) flight conditions, and forecasts. It is also necessary for combat surveillance, such as scheduled friendly reconnaissance ground visibility, enemy visibility of air drop, ground maneuvers or reconnaissance operations, and enemy surveillance limitations. Other available information, such as predicted time of arrival, location and rain rates of severe storms or even light-to-moderate rain areas in friendly or enemy territory, can provide invaluable data to a field commander in making tactical decisions.

In Vietnam, the hazards of using formation helicopter flights through unsuspected shower areas emphasized the need for local weather data. Severe or moderate storm effects on communication reliability also must be considered during extensive or small-scale combat or surveillance operations. In general, any field operation affected by precipitation could be accomplished with greater reliability if current weather radar data were available.

The inherent capability of weather radar to detect, locate, and measure the dimensions of clouds formed by nuclear detonations could also prove invaluable to field commanders in making tactical decisions. They could alert their command of a nuclear detonation and direct troop maneuvers in response to the detonation's yield, cloud movement, and fall-out forecast data.

DISCUSSION

Design Criteria

In considering the high mobility concept of the modern Army and special services, the radar was designed for maximum detection and location accuracy capability within the bounds of practical size and weight. The mobility and quick response aspect of the radar design dictated several design parameters, namely: 1) The antenna must be as large as possible for minimum beam width (maximum location accuracy) and maximum gain (maximum detectability), but must remain within reasonable dimensional limits for easy transport and the quick-erection requirements. 2) The system's power requirements must be kept as small as possible; 400-cycle operation was used to provide minimum size and weight of the radar power supply components and the power-generating unit. 3) The operating frequency must be as high as possible to provide maximum detection capability, a narrow beam width for good angular accuracy and gain, and minimum microwave component size and weight.

The choice of frequency was determined with precipitation attenuation as one of the prime factors. (A discussion of this determination is presented in Technical Report ECOM-2627, "Optimum Frequency Study for Army Weather Radar and Range Tracking System," by Raymond L. Robbiani, dated October 1965.)

Table 1 lists the design characteristics of the Radar Set AN/TPS-41(XE-2) and Figure 1 is an artist's conception of the equipment.

Configuration

During transport, the S-280 shelter houses the entire radar system, including three remote units, power cable and land line, but not the power source (see Fig. 1). This unit is air transportable by helicopter, can operate on or off the truck, on slopes up to 10 degrees, and can be made operational within 30 minutes (including orientation). The total shelter transport weight is designed to be less than 2,800 pounds.

For operation, the entire pedestal-antenna assembly less feed horn is raised manually or by power through the opened roof hatch to the roof of the shelter within 1 minute. In the raised position, the elevator supports occupy a minimum of space and permit the area below the antenna platform to be

TABLE 1

Technical Characteristics
Radar Set AN/TPS-41(XE-2)

Transmitter Modulator	
Peak power	250 kw
Frequency	8500-9600 MHz
Pulse widths	1.0 μsec; 5.0 μsec
Pulse repetition frequency	200, 400, 800 Hz (internal, line, external)
Receiver	
Noise figure	5 db
Sensitivity	109 dbm
Dynamic range; linear	30 db
lin-log	10 + 70 db
log	80 db
IF	60 MHz
STC (range normalization)	56 db
Bandwidth	2 MHz (1.0 μsec) 600 KHz (5.0 μsec)
Antenna	
Diameter	5 feet
Beam width	1.5° at 9300 MHz
Gain	39.5 db
Azimuth, continuous rotation	CW or CCW at 5 RPM
sector scan	Any 10° to 50° sector
Elevation, manual	-5 to +90 degrees
sector scan	Any 10° to 50° sector
A/R Scope	
A scope ranges	10, 40, 80, 160, 240 km
R scope ranges	Any 8 or 32 km
Range marks	1, 10, 40 km
Strobe	0 to 240 km ± 100 meters
RHI/PPI*	
Display	Selectable RHI or PPI
Ranges (azimuth	10, 40, 80, 160, 240 km
(height)	3, 15, 30, 50 km, corrected for earth curvature

*RHI - Range Height Indicator
PPI - Plan Position Indicator

(contd)

Table 1 (contd)

RHI/PPI (contd)

Off-center (PPI)	Variable 2 radii
Azimuth spokes	Every 10 degrees
Iso-Echo*contouring	10 steps, 3 db each (linear) 10 steps, 6 db each (log) light, moderate, heavy
Iso-Echo alarm	Selectable

Remote RHI/PPI

Location	Up to 1 mile from shelter
Display	Same as RHI/PPI

Power Requirements

Power	400 Hz, 3-phase, 120 volts 10 kw shelter configuration 3.5 kw outside configuration

Weight

Radar components and shelter	2800 pounds
Radar components only	650 pounds

Size

S-280 shelter	12 x 7 x 7 feet (588 cubic feet)

*Iso-Echo - IEC

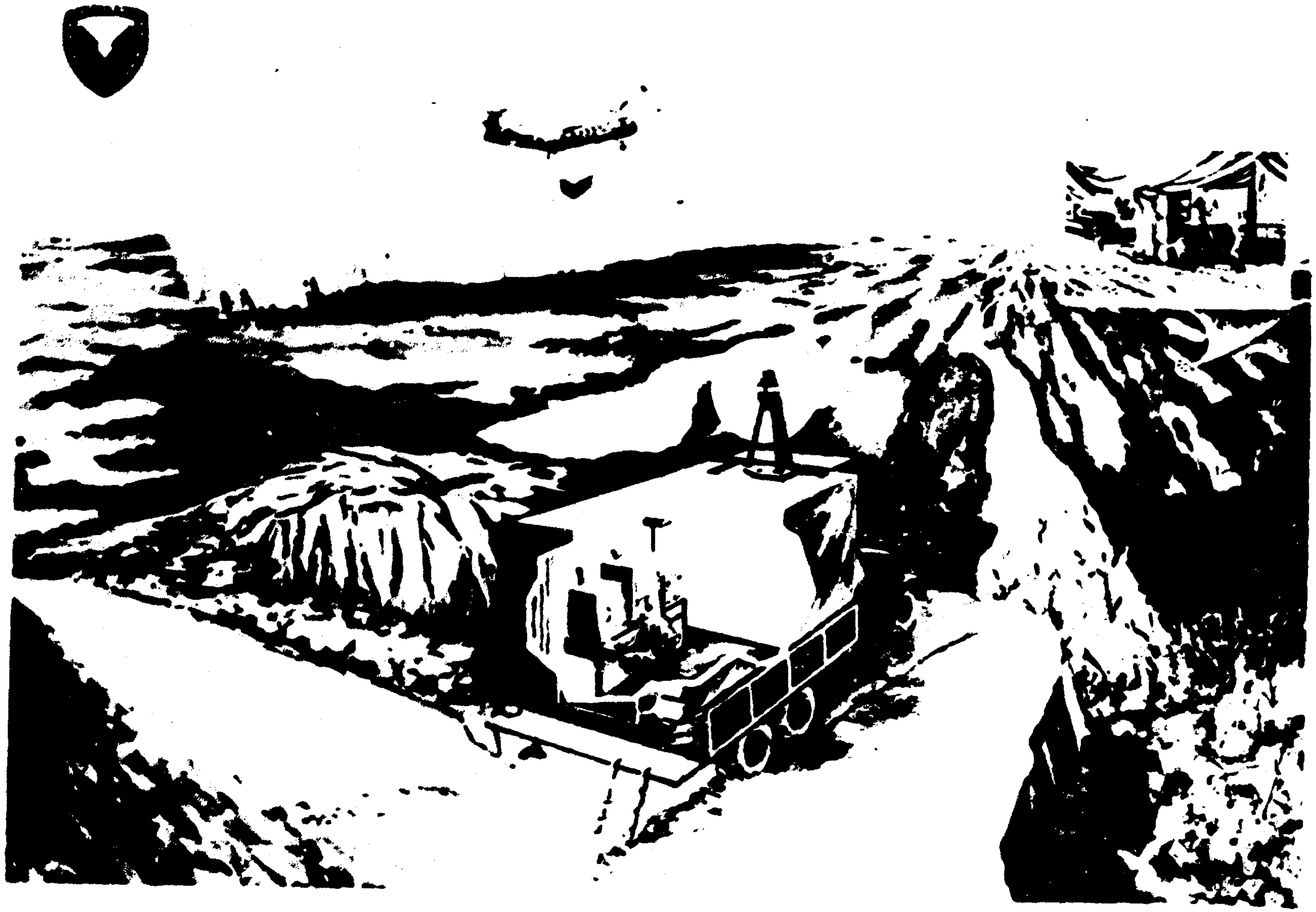


Figure 1. The S-280 Shelter housing the entire Mobile Weather Radar AN/TPS-41(XF-2).

used for storage. The antenna is then 14 feet above ground when operated from the rear of the truck, and the roof hatch cover becomes a maintenance platform over the forward-end of the shelter. To reduce the over-all pedestal antenna height during stowage, the upper and lower portions of the antenna are truncated. The antenna pedestal area is isolated from the operator to reduce the effects of heat and cold transfer through the roof hatch. This isolation results in a minimum of air-conditioning requirements and a considerable savings in air-conditioning weight and power consumption.

Each major radar component of the AN/TPS-41 is designed to: 1) permit its removal from or assembly into the shelter within 10 minutes (this includes the antenna pedestal in stowed or operating position); 2) limit its weight to no more than 150 pounds (and most will be considerably less); 3) operate as outdoor equipment; and 4) to withstand all the required environmental and transport conditions of the field Army and, except for the antenna pedestal, the package test for loose cargo.

This radar design type provides rapid replacement of major components which have malfunctioned, deteriorated, or which have battle damage; provides inherent protection during transport to and from the repair depot; and provides a flexibility in configuration to satisfy many operational requirements. By securing the pedestal antenna on a suitable structure, such as a building, tower, truck bed, or helicopter pallet, and by assembling the components outside the shelter, a lightweight, small-sized radar is available.

The outside configuration of the basic radar will weigh approximately 650 pounds, with an additional 70 pounds for each remote indicator used. This lightweight radar configuration could be transported as open cargo in the rear of a 3/4-ton truck. Elimination of the air-conditioning requirement by this configuration also permits the reduction of the power source from a 10 kw generator for shelter operations to approximately 3 kw for outside operations.

The three remote indicators can be located at any three sites up to 1 mile from the radar, using a single, twisted-pair of standard WD-1 field wires to transmit all necessary control and video data. Experiments at the Atmospheric Sciences Laboratory (ASL), USAECOM, have shown that there is no negligible degradation in system display capability using relatively simple frequency compensating techniques.

Figure 2 shows the degradation experienced at ASL. The first line shows the input pulse, the second line shows the output pulse with no compensation, and the third line shows the output pulse with compensation. The use of this field wire permits concurrent weather data and voice communication to be available between four locations without the use of the local communication media. One mile of WD-1 wire weighs approximately 60 pounds, including the reel. Each remote indicator unit is designed to use whatever AC frequency

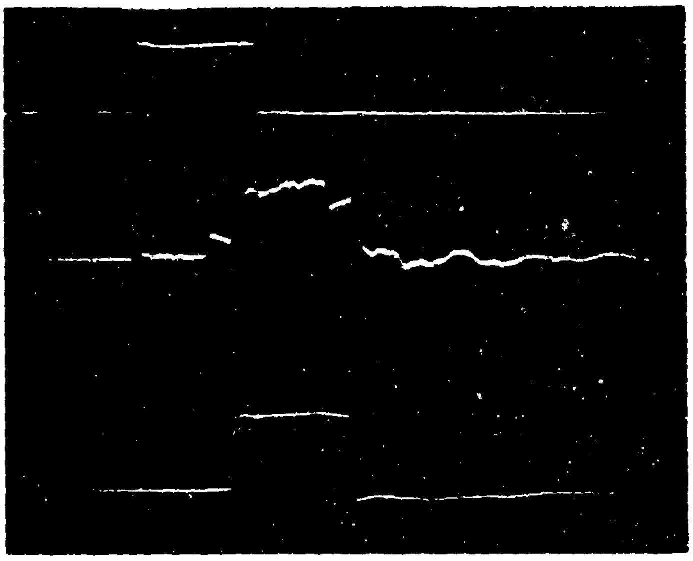


Figure 2. Results of compensation technique.

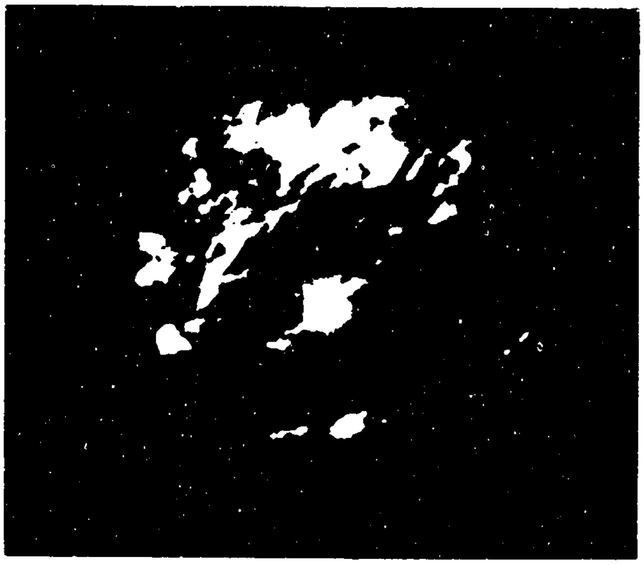
NOTE: Reading from top to bottom: First line - input pulse to telephone line; second line - output pulse uncompensated; third line - output pulse with compensation. 5 usec/cm.

is available at its operating site, and is designed to accept any frequency from 50 to 500 Hz. The transmitter-receiver and modulator units are located in the shelter near the base of the elevator to minimize weight on the pedestal and to permit easy access for component maintenance. These units are designed to occupy a minimum of space.

Console Design

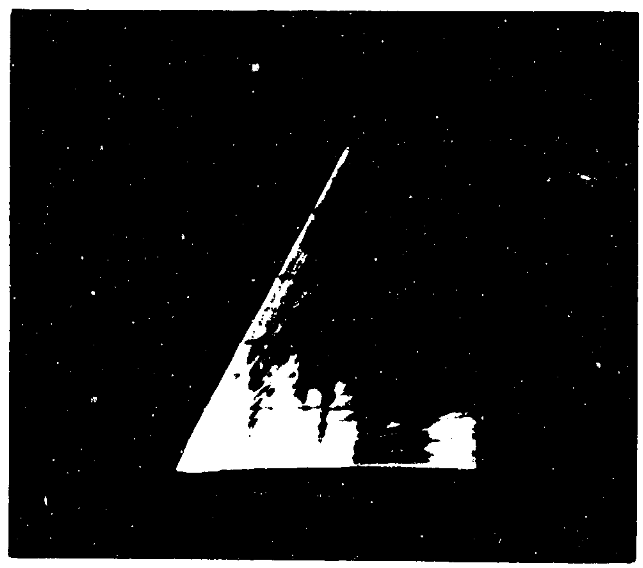
The console is designed to provide flexibility in the mounting position within the shelter or removal from the shelter. It contains the receiver post IF circuitry and controls, the transmitter-modulator controls, the Iso-Echo control and alarm (described later), calibrated attenuator, A scope with inherent controls, a combination RHI/PPI scope with antenna operating mode controls, and the power supplies. Figure 3 is three photographs of the displays available to the operator.

The A/R scope display (Fig. 3) is a flat-faced 3 x 4 inch cathode-ray tube that will indicate the relative intensity of storm areas by the amount of sweep deflection of targets over the entire 240-kilometer (km) range, or to ranges of 160 km, 80 km, or 40 km. Also, this scope will permit the operator to review any 8 or 30 km portion of the storm for detailed scrutiny. Range marks for every 1, 10, or 40 km are available to measure range directly on the scope. A movable range mark (strobe), whose range position is indicated by a calibrated numerical dial, is available for more precise measurement (± 0.1 km).



PPI

On the PPI, the reflected energy produces a brightening of sweeps that are rotated around the center of the scope in synchronism to the antenna rotation. These sweeps appear similar to the spokes of a wheel; the hub being the radar location and the spokes representing the antenna direction and range from the radar. The azimuthal bearing of the antenna is indicated by a lighted, numerical display on the periphery of the PPI. Therefore, the PPI displays the horizontal cross-section of target areas and indicates both range and azimuthal direction. It also possesses an offset capability which permits the displacement of the sweep origin from the center to at least two radii. This, in turn, provides the capability of displaying any target to three times its normal display size for more accurate scrutiny.



RHI

A scope

On the RHI, the same type display is presented as on the PPI, except that the sweeps rotate in a vertical direction in synchronism with the antenna elevation

Figure 3. Types of displays, Radar Set AN/TPS-41(XE-2).

angle and with the lower left-hand corner of the scope acting as the fulcrum. For a particular azimuth direction, the RHI displays the vertical cross-section through a target area.

Since the RHI and PPI (azimuth or elevation) cannot collect usable data at the same time, considerable console size and weight were saved by designing a single scope unit that could be made to operate as either an RHI or PPI by a simple selector switch. The radar provides a single 7-inch cathode-ray tube display system for this purpose that requires no calibration when switched to either RHI or PPI mode.

All three types of indicators are required on the radar to collect necessary meteorological data. The A scope provides a means of estimating precipitation intensity and storm characteristics by the amplitude and characteristics of the deflection through the precipitation area at a particular azimuth. The PPI indicates the location and horizontal area extent of precipitation, which is an indication of the storm characteristics, while the intensity of the echo brightness indicates precipitation reflectivity.

The RHI indicates vertical extent of precipitation, which is also an indication of storm characteristics and which is especially useful in indicating the occurrence of a nuclear detonation. The RHI is compensated for earth curvature for more accurate height measurement at long ranges. All three indicators provide data, pertinent to tactical decisions, which must be available to the operator.

Transmitter and Modulator

The transmitter and modulator are designed in separate packages with the receiver sharing the same package as the transmitter. This design eliminates any interconnecting waveguide sections between packages, except for the required waveguide run to the pedestal. The transmitter and modulator are designed to provide 250 kw peak power at the antenna. In order to provide this power, the standard 250 kw coaxial magnetron, the SFD 304, was redesigned for higher efficiency and then redesignated the SFD-375. Regardless of the redesign, these tubes are interchangeable. The new tube is capable of transmitting up to 475 kw using the same input as the SFD-304.

Receiver Design

The receiver of the radar uses a tunnel diode RF amplifier for minimum receiver noise (5 db, 109 dbm system sensitivity). The tunnel diode is a broad-band, low-noise device that requires sufficient protection against large or extraneous signals that might damage the diode. Special solid-state,

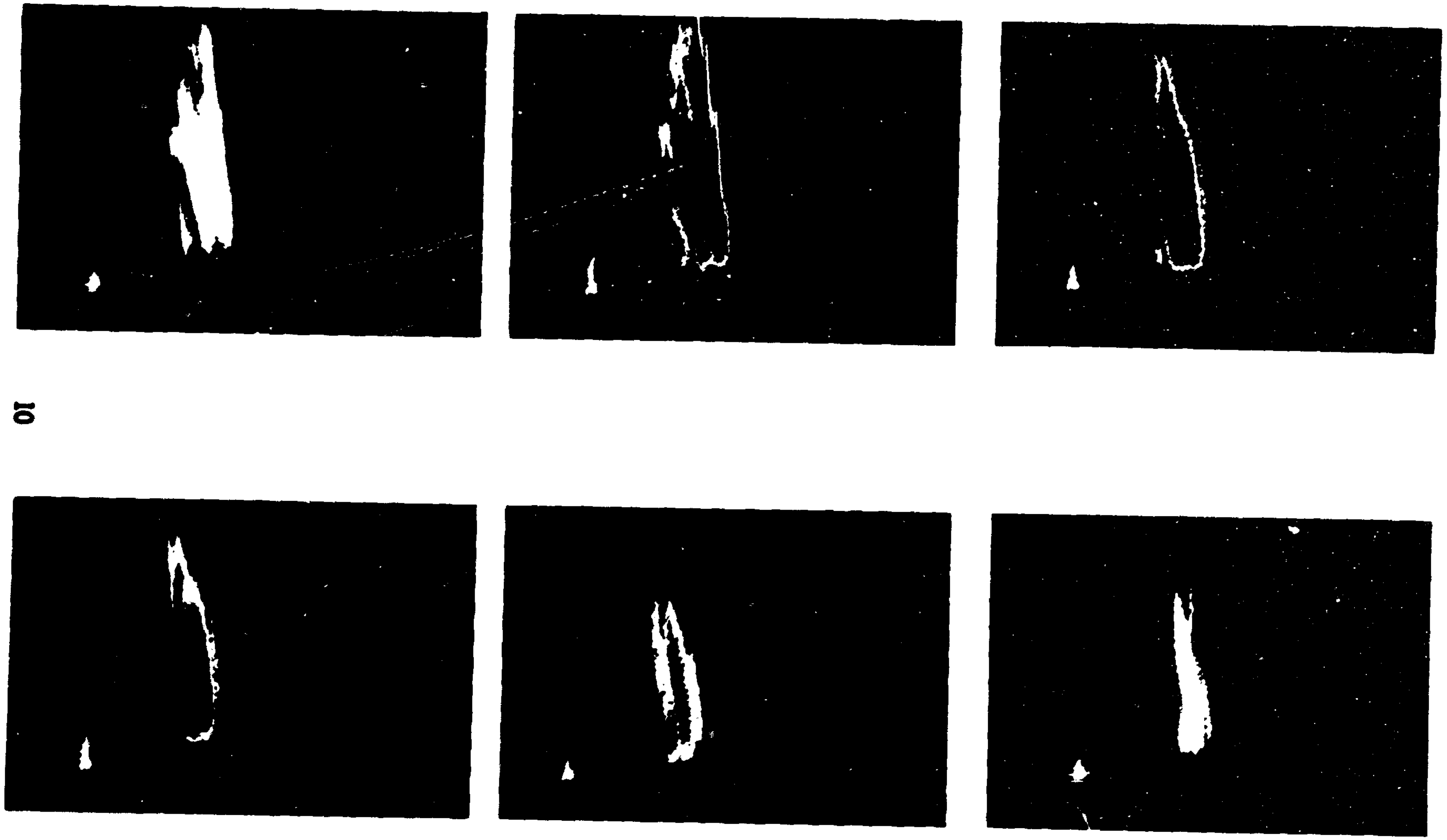


Figure 4. Iso-Echo contour display of RHI.

passive, limiting devices are included that prevent excessive damaging signals from reaching the tunnel diodes.

The receiver has three modes of operation: linear, lin-logarithmic (lin-log) and logarithmic (log). In linear operation, the dynamic range of the receiver is 30 db. In other words, any echo signal greater than 1000 times the noise will saturate the receiver and, therefore, will not be capable of distinguishing any signal power greater than that level. Many rain areas provide reflections of sufficient strength to saturate linear receivers. Linear operation is used primarily for general surveillance and measurement of lower rain intensities.

By designing the receiver so that the larger the receiver signal power the lower the receiver gain, signals as high as 10^8 times the noise (80 db) can be displayed on the radar. This design is called logarithmic mode because the correlation of gain and signal follows a logarithmic function. Since weather radar uses the relative reflection from precipitation areas as a measure of rain intensity, the greater the dynamic range, the greater the measurement capability of the radar. Lin-log operation (10 db lin, 70 db log) is used at the discretion of the operator for intermediate rain intensities.

Iso-Echo Contour Design

The Iso-Echo contouring (IEC) method used by most current weather radars depicts intensities above a particular value by blanking those echoes that exceed a particular value. The fallacy of this system is that it is not always certain that dark areas imbedded in extended storm echoes are heavy rain areas. In fact, they may be very light rain pockets. This method does not provide any calibration except when rain above or below a particular value is present.

One available Iso-Echo contouring display of the radar selects a particular level of echo intensity to be displayed for each antenna sweep and, indirectly, three relative rain rates. Figure 4 depicts this type display and shows Iso-Echo levels on the advanced development model RHI in discrete steps of 7 db each. The engineering development model will have IEC circuitry which will greatly improve the display of discrete levels by reducing overlap between levels due to noise. The upper left picture is a normal presentation of a thunderstorm, and each photograph progressing to the right is discrete steps in 7 db levels.

When using single IEC displays, the echoes of lower intensity target echoes are blanked, but noise spikes are displayed. Echoes with higher level intensities than those of the chosen display level are also blanked, but the video is driven negative so that very dark (black) areas result with no noise background at all. High reflective areas, therefore, will be emphasized

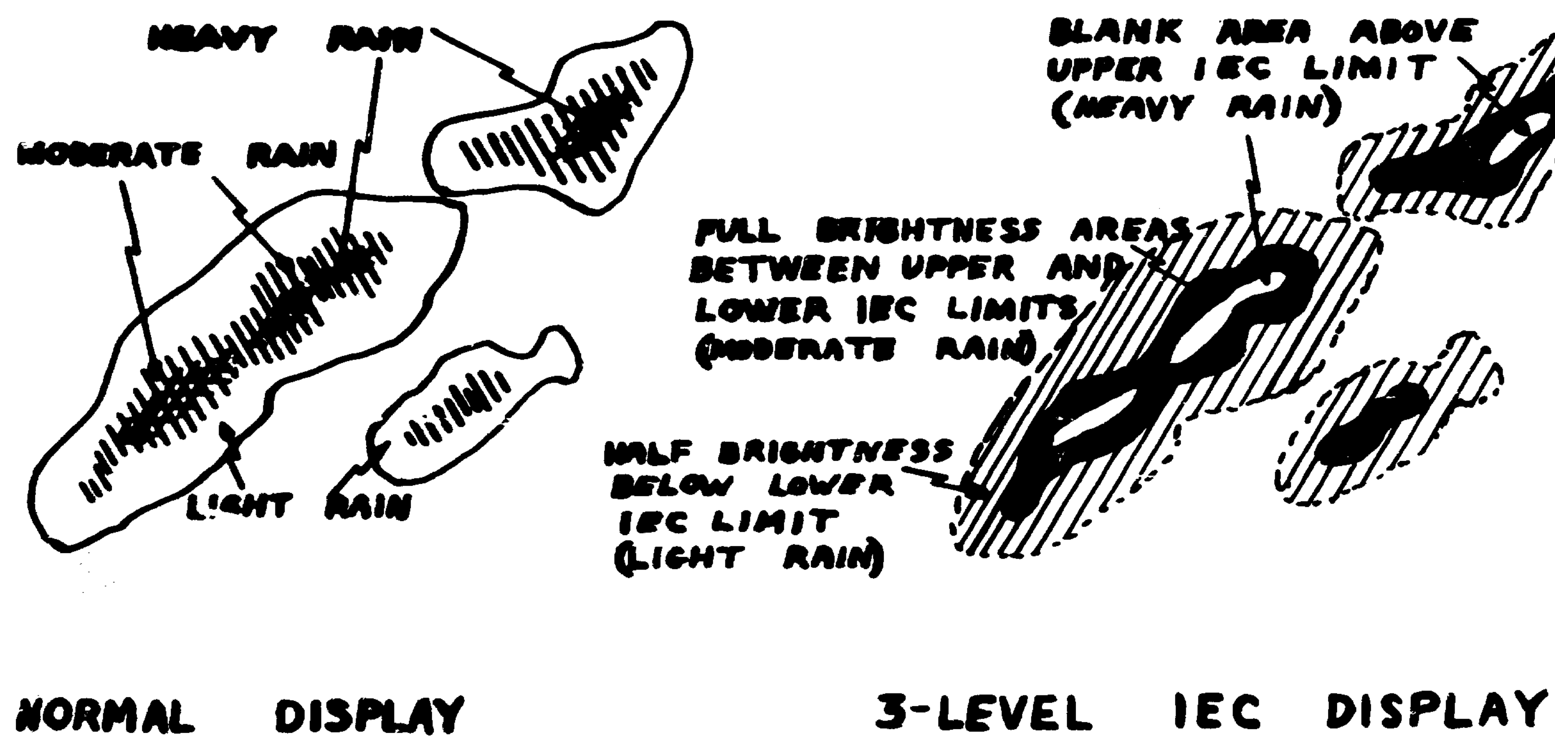


Figure 5. Three-level IEC comparison.

by the bright area of the calibrated level. The single bright level indicates echo signals within a 3-db intensity pass band on linear receiver operation and 6-db pass band on logarithmic receiver operation. The 3- and 6-db pass bands correspond to the 30-db dynamic range of the linear and 80-db dynamic range of the logarithmic receiver operations.

The Iso-Echo contour feature will permit the operator to plot echo intensities over the entire storm area using a calibrated tool rather than ambiguous and highly individualistic personal judgment. At the discretion of the operator, any one of ten calibrated levels of echo intensity can be displayed as brightened areas on the PPI or RHI, or the operator may choose to display light, moderate, and heavy rainfall areas simultaneously. When displaying simultaneous IEC rainfall, light rain is displayed at half brightness, moderate rain at full brightness, and heavy rain as blanked areas. The cross-over between rainfall levels is controlled by the linear IEC level selector (see Figure 5).

Sensitive Time Control (STC)

Range normalization STC is also included in the radar display system. Range normalization, in accordance with the range squared (R^2) law for filled radar beams, compensates for signal loss due to target range. The displayed echo intensity then represents a true relationship between near or far targets. In weather analysis where relative target reflection is used as a measure of rain, range normalization is indispensable.

Severe Storm - Nuclear Detonation Alarm

An alarm system (ringing bell) is included in the radar to alert the operator whenever a target intensity exceeds a chosen intensity level. The purpose of this alarm is to insure that severe storm characteristics or nuclear detonations are detected at the earliest possible time. A step attenuator, calibrated in 1-db steps, is included to aid in equipment maintenance and to permit the operator to analyze storm areas rapidly by determining the echo intensity comparison with a known storm area or with the receiver noise level.

Remote Indicators

Remote indicatores are available to display all RHI, PPI, and IEC data over standard field wire up to 1 mile from the radar shelter. This permits real-time data to be available to Tactical Operations Centers (TOC) or Army aircraft control centers from radars located on adjacent high terrain. Figure 1 shows radar used to provide data to the TOC and to an airfield threatened by heavy rainfall. This unit eliminates the need for sharing transmission time with other meteorological data sensors, and removes a radiating source up to 1 mile from the data acceptance center. The same choice of

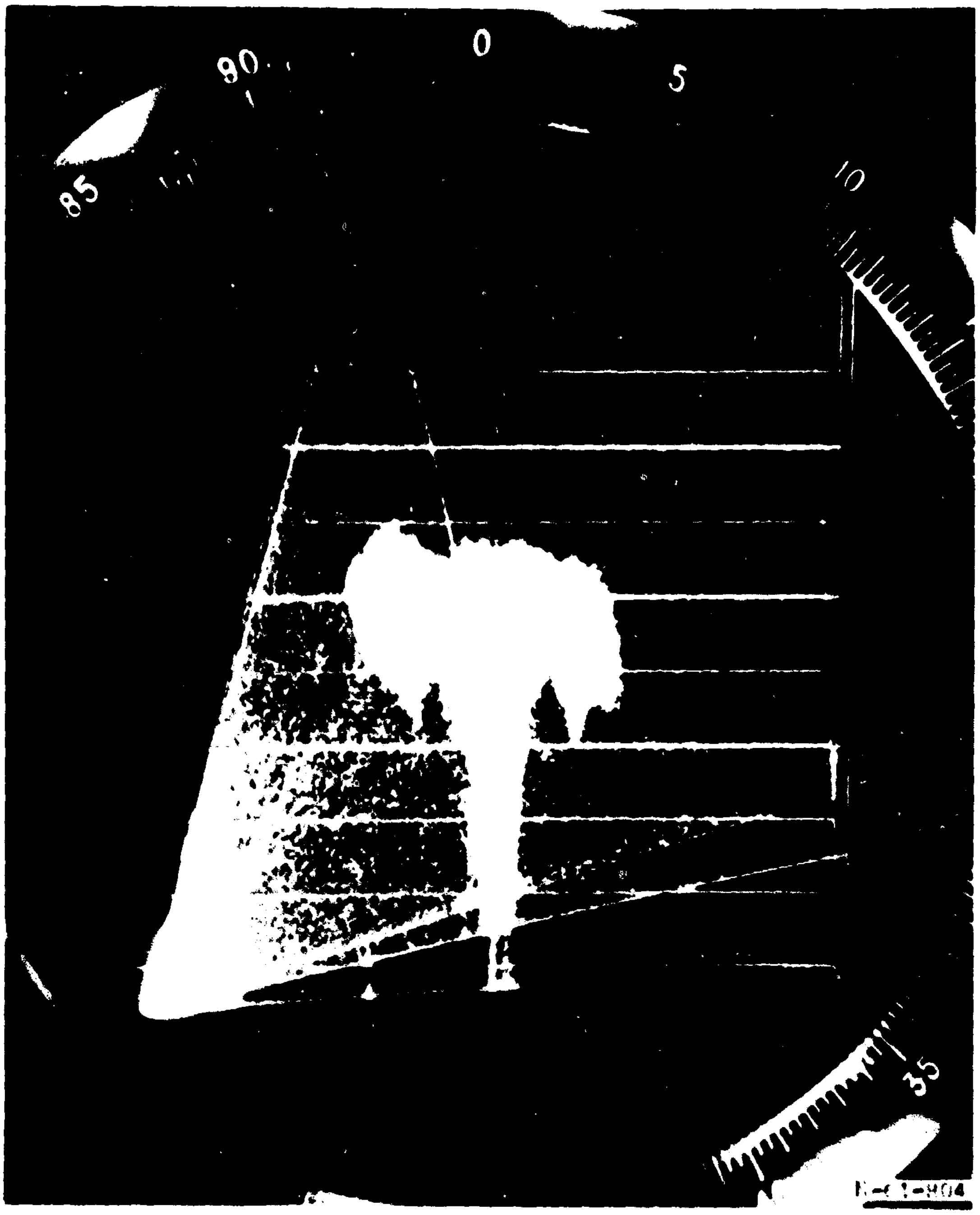


Figure 6. Nuclear detection by Weather Radar AN/CPS-9 (Pacific Test) - Radar Set AN/TPS-41(XE-2).

range display and antenna orientation data is available, but antenna control is retained at the radar.

Performance Characteristics

The AN/TPS-41 radar will be capable of detecting light rain (1 mm/hr) to a range of approximately 240 km with a range accuracy of approximately ± 200 meters and azimuthal accuracy dependent on the range of the target. A target at 45 km will have an azimuthal accuracy of approximately 0.5 km, using the 5-foot diameter antenna. Area surveillance mode of operation includes automatic clockwise or counter-clockwise 360-degree azimuth scan, -5 to 90 degrees elevation, manual scan, and an automatic sector scan of any 60-degree sector of azimuth or elevation direction.

Figure 6 is a photograph of a nuclear detonation cloud as detected by another radar. From this type of data, the detonation yield and direction of movement can be indicated.

CONCLUSIONS

The design of the AN/TPS-41(XE-2) radar provides not only a flexible configuration for either fixed station, mobile, or lightweight operations, but also offers a building block design capability. By simply replacing the transmitter, modulator, and receiver RF section, this radar can be changed to any radar frequency operation.

The pedestal drive is capable of handling antennas up to 8 feet in diameter in 60-mph winds. All the other components, such as the console, remotes, servo systems, shelter, etc., need no changes.

It is therefore concluded that this radar may be the basic model of a building block type weather radar series that could be tailored to the specific requirements of the user.

APPENDIX I

Pictures Taken During Development and Fabrication Stages of Radar Set AN/TPS-41

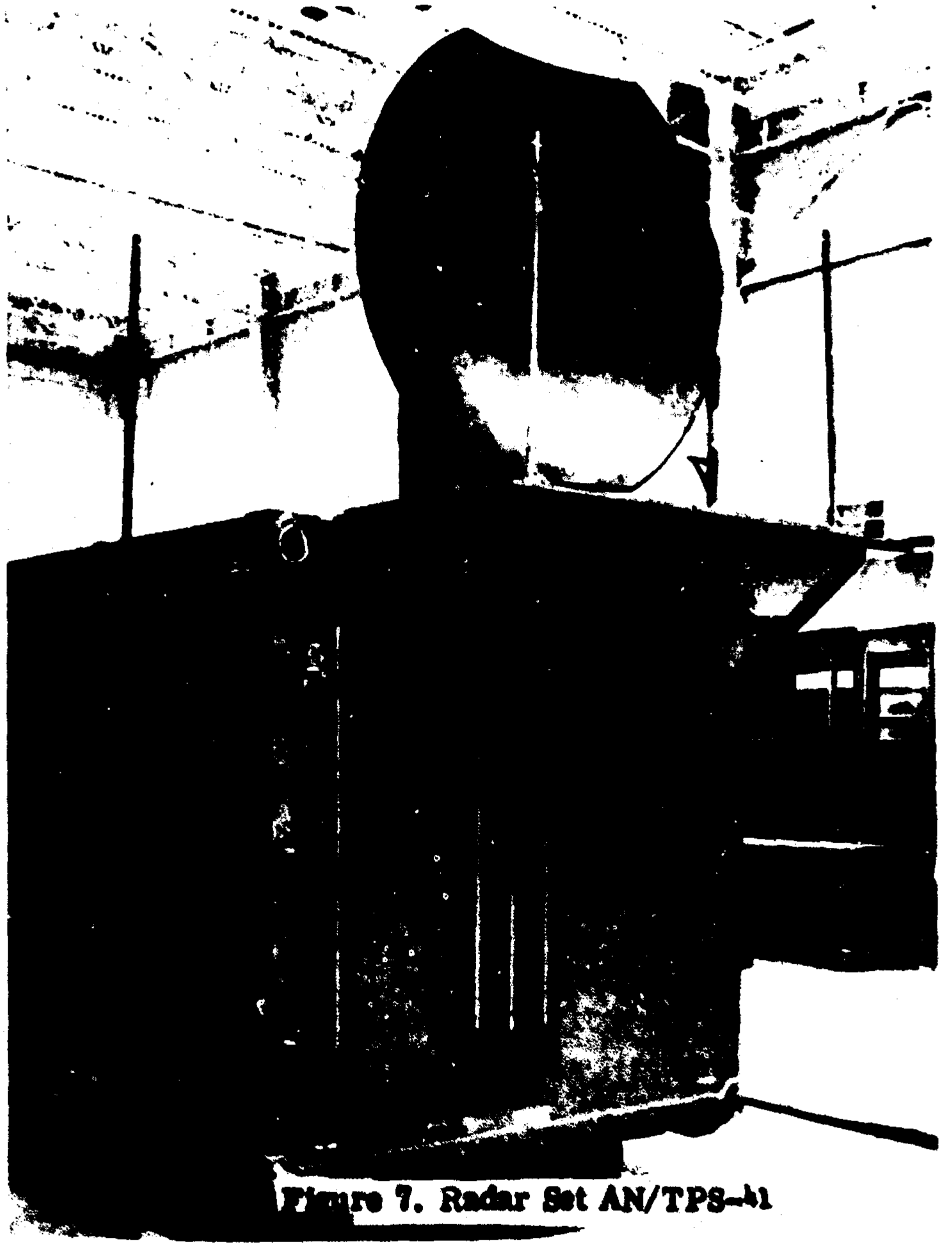


Figure 7. Radar Set AN/TPS-41

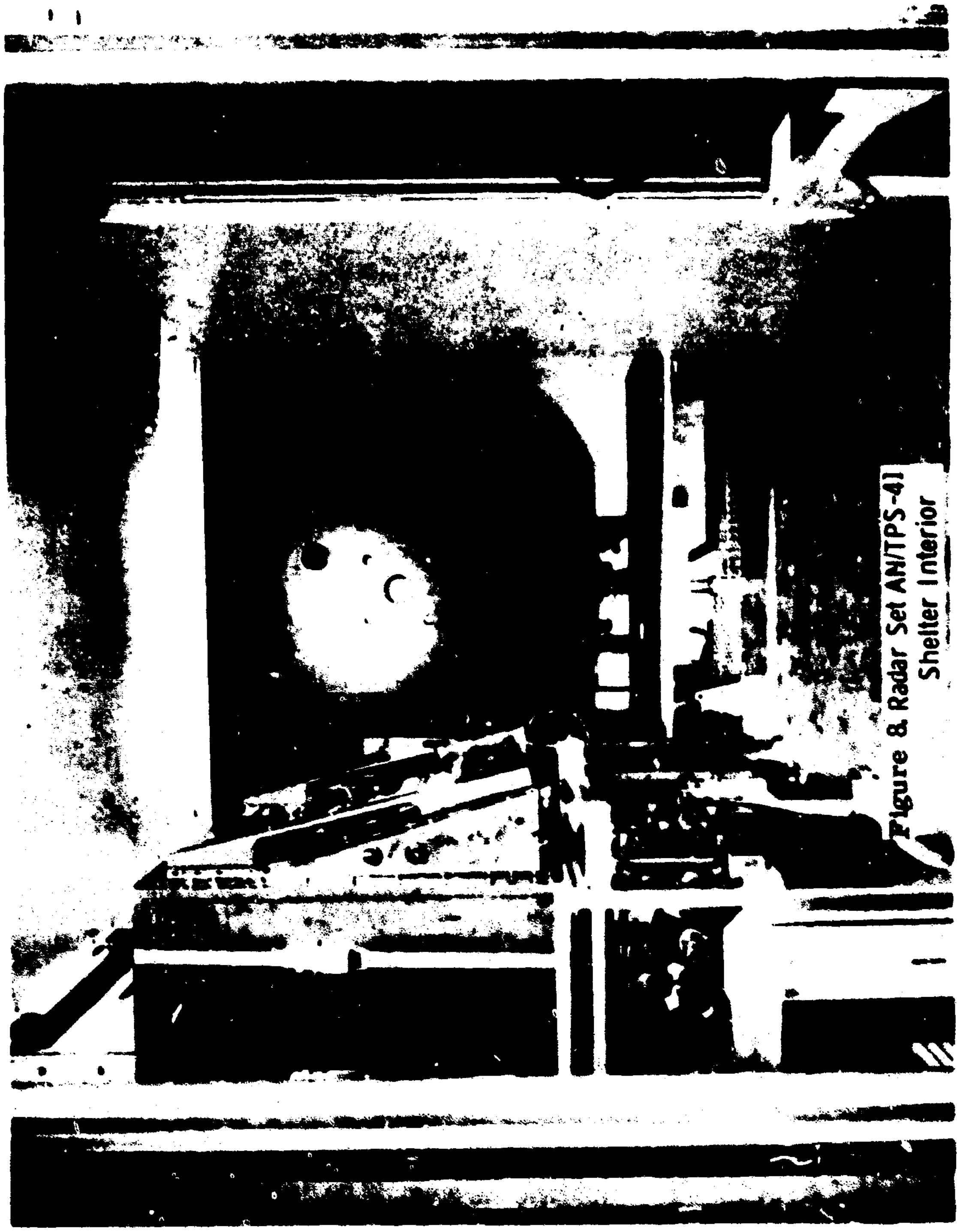


Figure 8. Radar Set AN/TPS-41 Shelter Interior

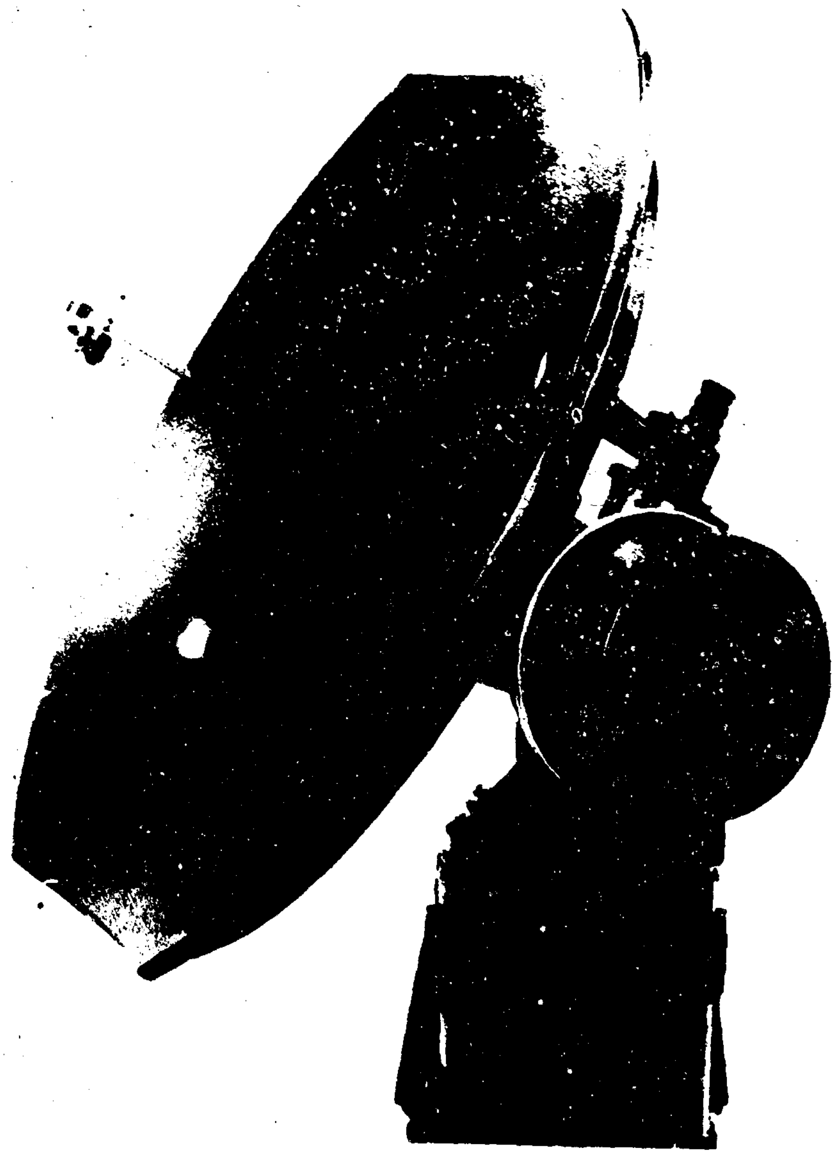


Figure 9. Radar Set AN/TPS-41, antenna pedestal.

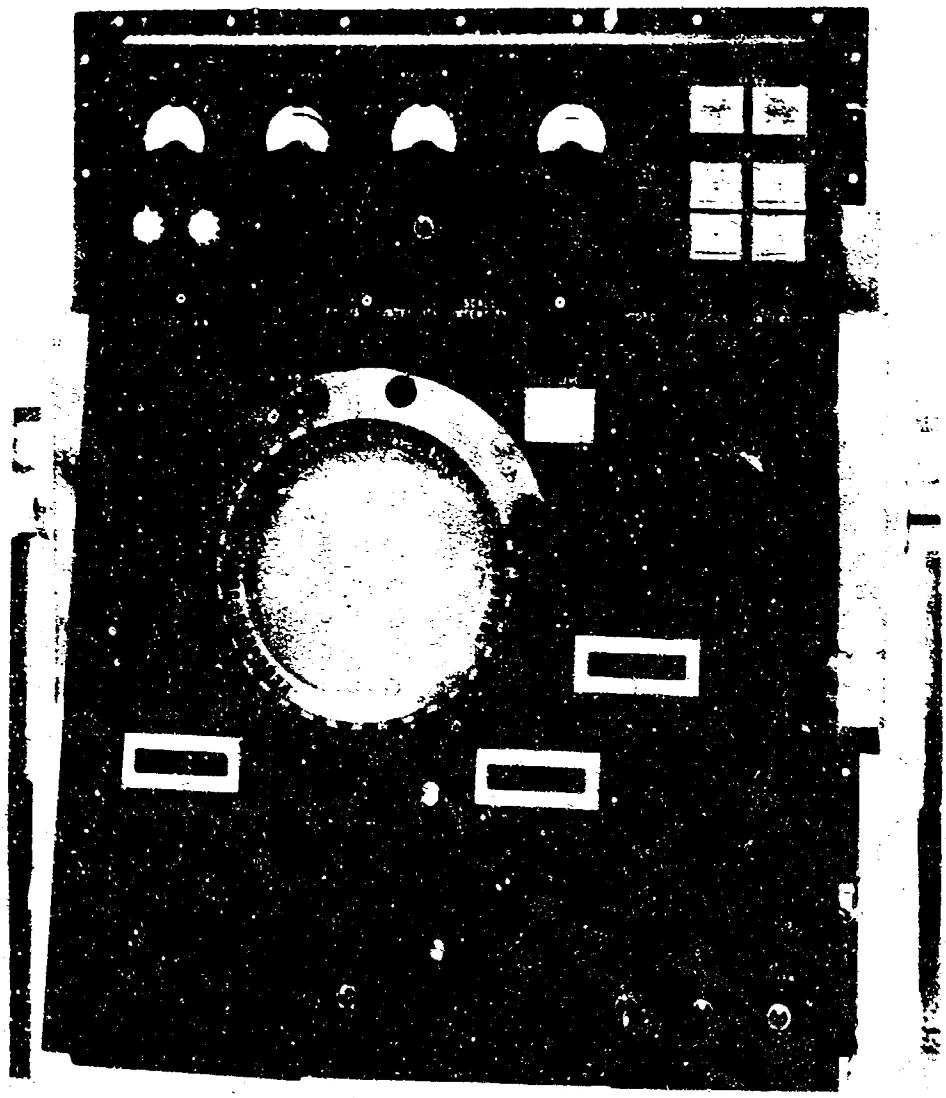


Figure 10. Console - Radar Set AN/TPS-41.

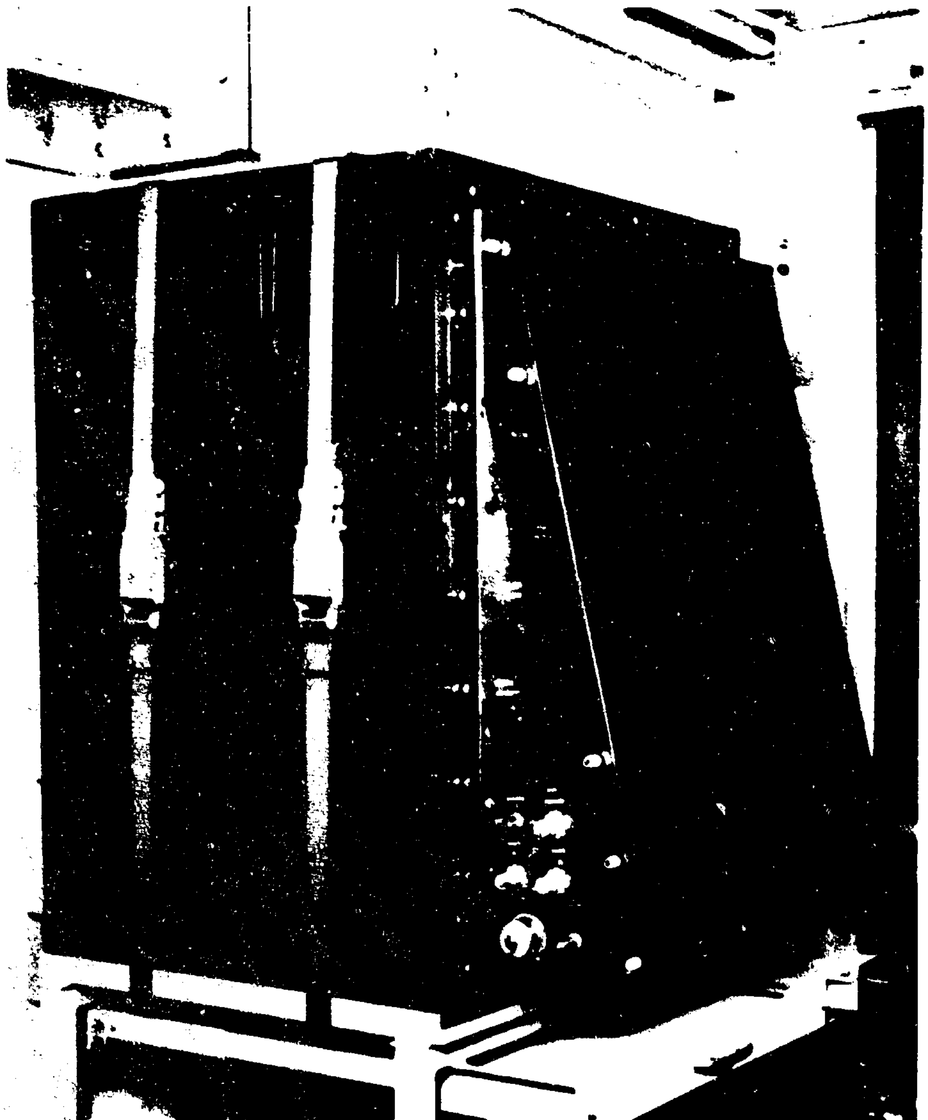


Figure 11. Console with protective cover, Radar Set AN/TPS-41.

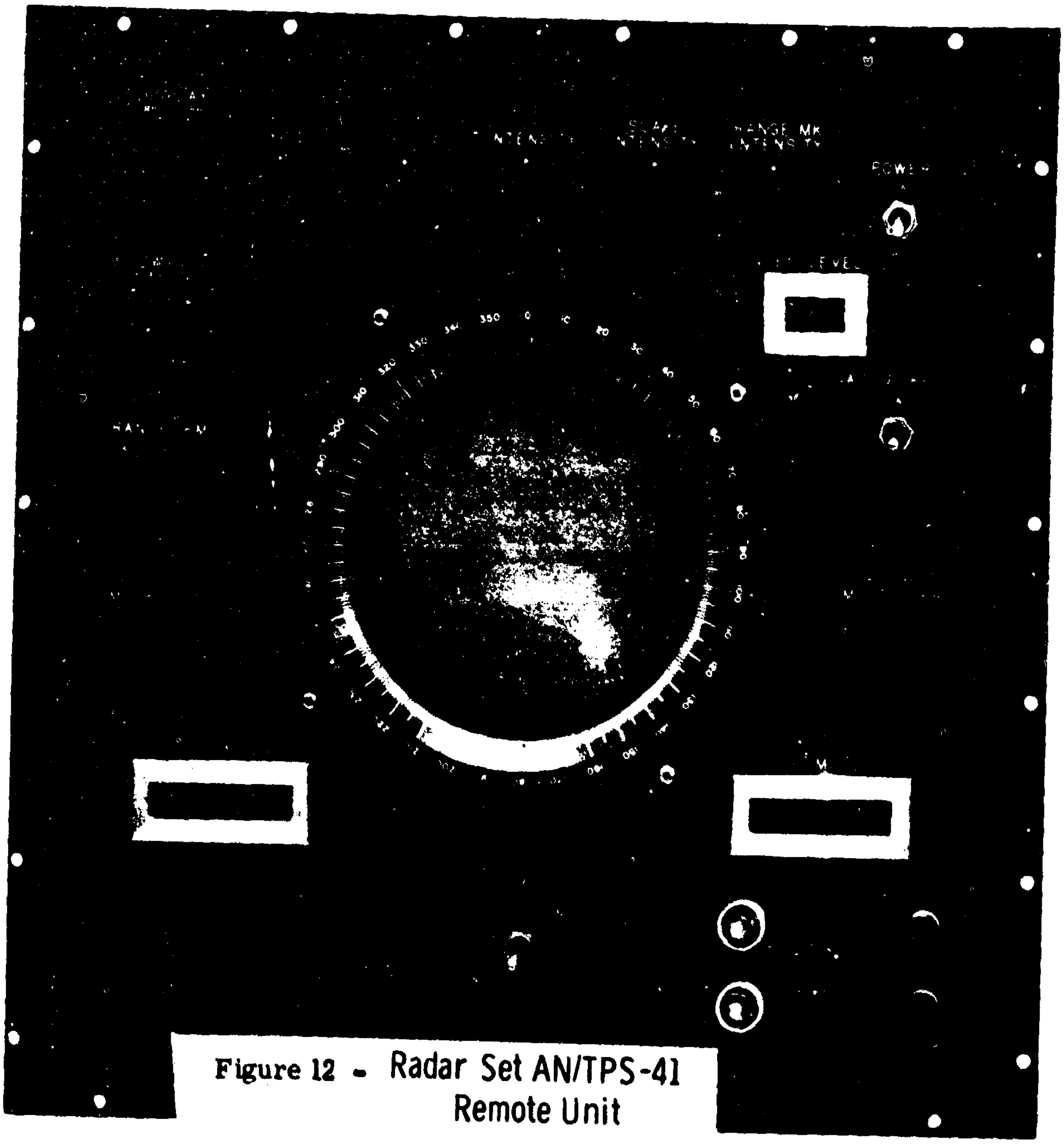


Figure 12 - Radar Set AN/TPS-41
Remote Unit

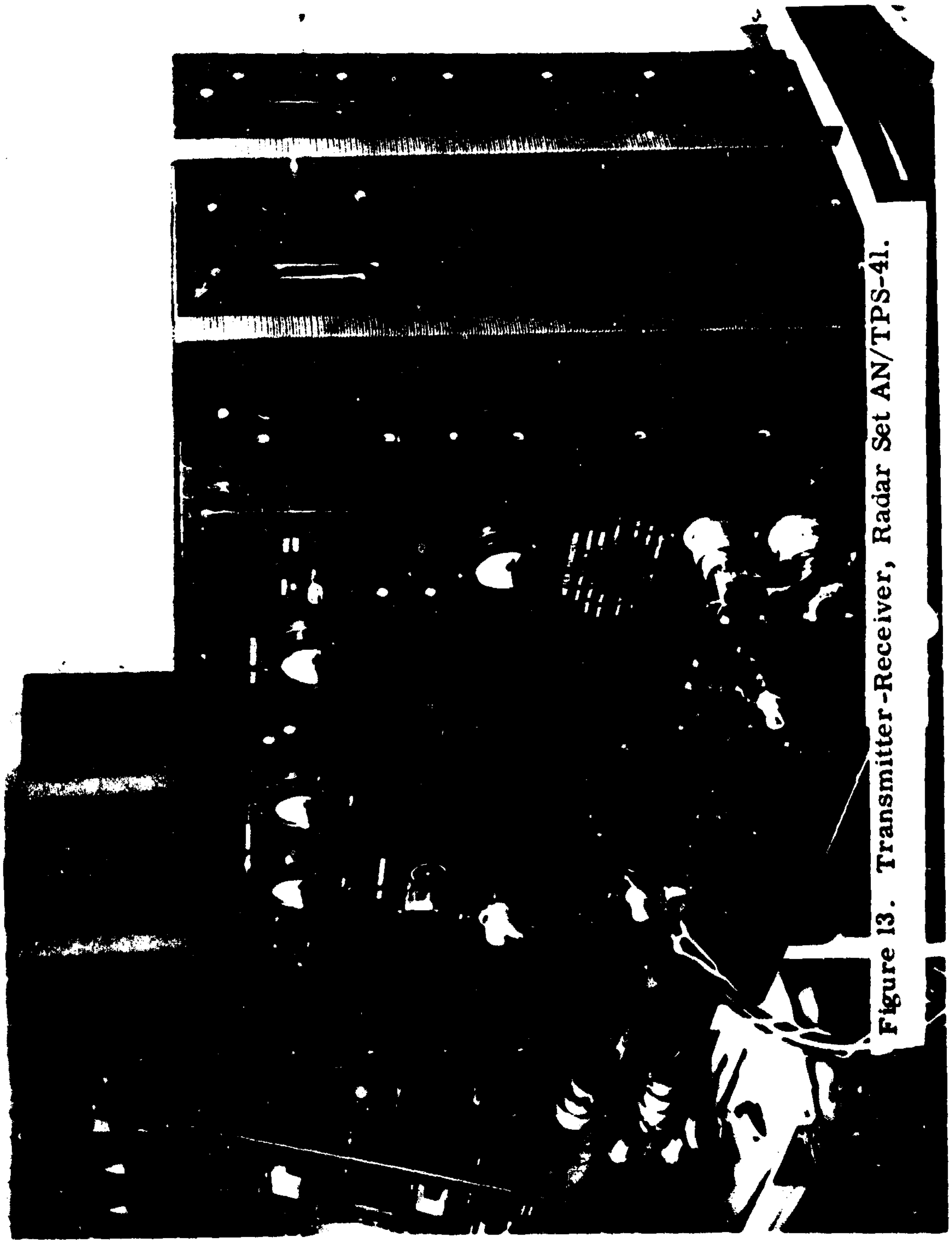


Figure 13. Transmitter-Receiver, Radar Set AN/TPS-41.

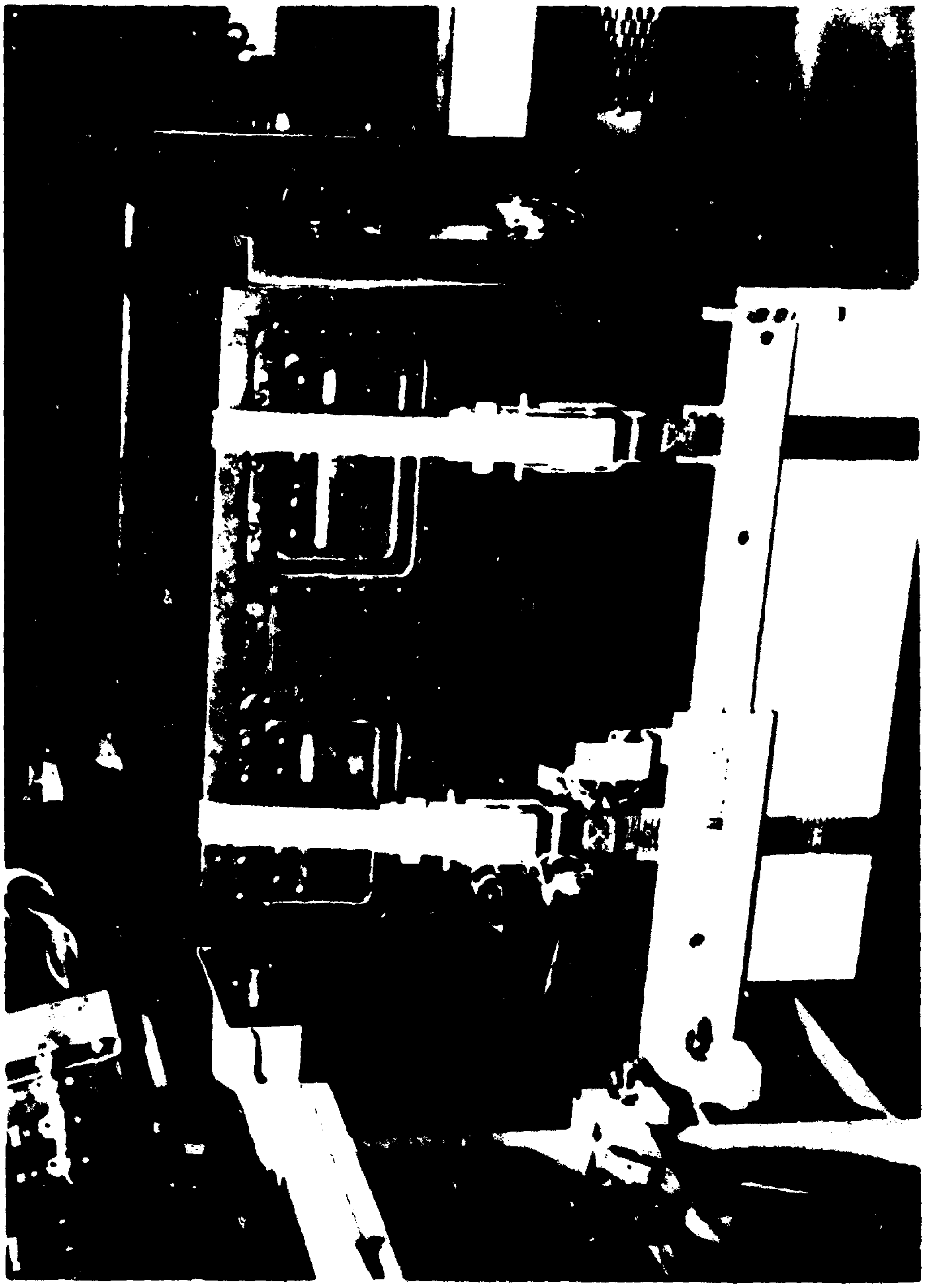


Figure 14. Modulator, Radar Set AN/TPS-41.

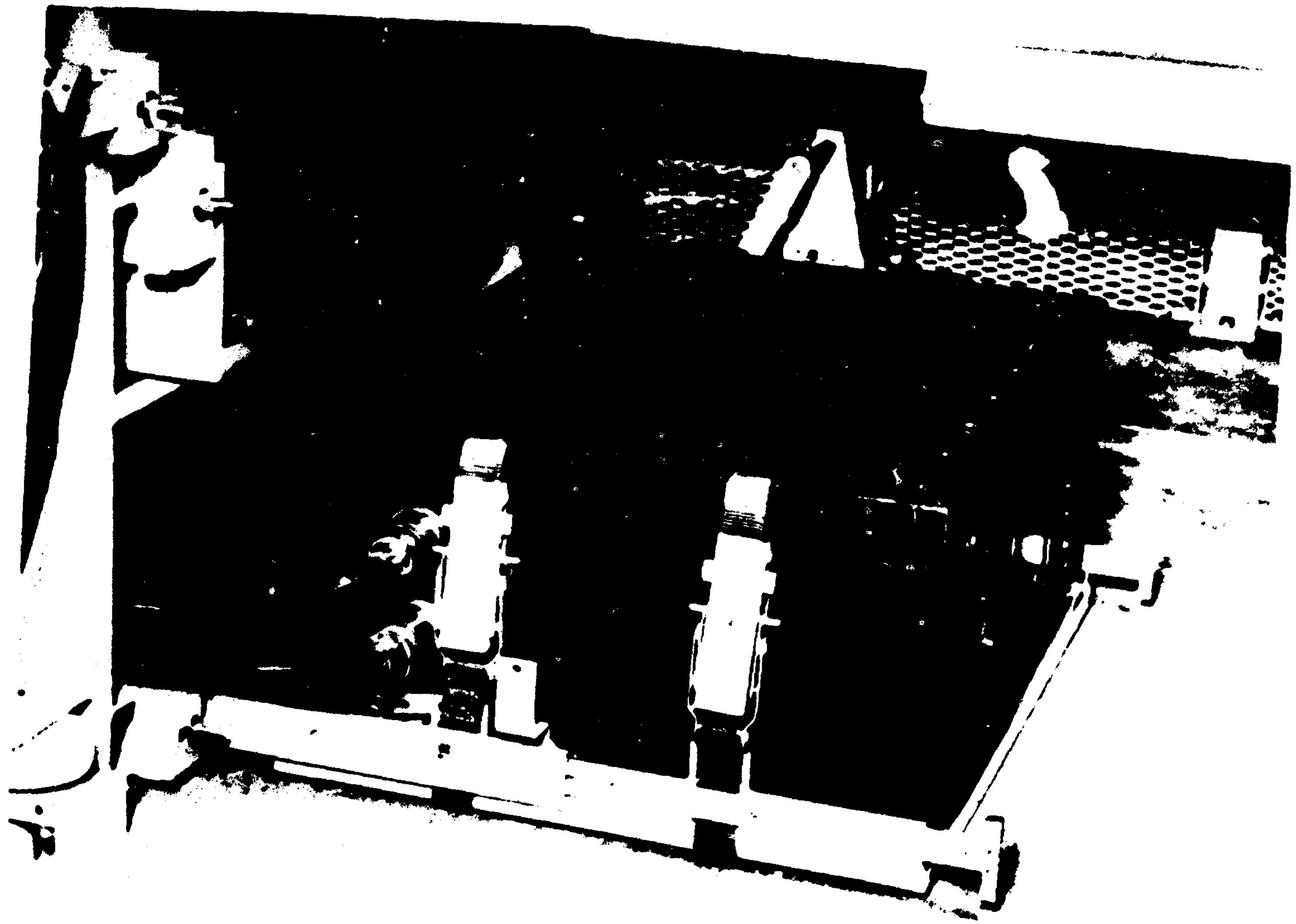


Figure 15. Servo Draw - Radar Set AN/TPS-41.

Figure 16. Junction box, Radar Set AN/TPS-41.

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13. ABSTRACT

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