DESIGN CRITERIA, CONSTRUCTION, AND EVALUATION OF A MEDIUM-POWER WEATHER RADAR SYSTEM

by

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>THEORY</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>DESIGN CRITERIA</td>
<td>9</td>
</tr>
<tr>
<td>IV</td>
<td>CONSTRUCTION OF THE SYSTEM</td>
<td>15</td>
</tr>
<tr>
<td>V</td>
<td>SYSTEM PERFORMANCE EVALUATION</td>
<td>24</td>
</tr>
<tr>
<td>VI</td>
<td>CONCLUSIONS</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>BIBLIOGRAPHY</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>APPENDIX</td>
<td>39</td>
</tr>
</tbody>
</table>
The use of radar to detect weather phenomena came about as a by-product of the military radar program of World War II. Radar operators found that characteristic fuzzy echoes would sometimes appear on their radar scopes from areas where precipitation was known to be occurring. Further experience with rain echoes showed that their direction and speed of movement could often be plotted, and arrival over a specific point prognosticated. This was intriguing to meteorologists, for here was an instrument which could give them specific data on storm movements rather than the general data obtained by synoptic methods.

Shortly after the close of World War II, the Massachusetts Institute of Technology began an extensive research program in applications of radar to weather forecasting. About the same time, Ryde (10) did a classical study of the backscattering properties of raindrops. These two endeavors marked the beginning of quantitative research in the weather radar field. Since that time, weather radar research has become one of the prime areas of investigation by the weather branches of the armed services.

In 1949 the United States Army Signal Corps Engineering Laboratory, located at Belmar, New Jersey, designed the
first radar to be used solely for weather detection. This was a high-power three centimeter system designated the AN/CPS-9, and is still in use. Experience with the AN/CPS-9 has shown that it is very sensitive to light and moderate rain. For severe storms, however, the precipitation attenuation at the three centimeter wavelength is so serious that in the case of a hurricane the AN/CPS-9 can only detect the outermost spiral bands. It may be shown that precipitation attenuation is an inverse fourth power function of the wavelength of the incident radiation, providing the drop diameter is less than one-tenth the wavelength (4, p.107), so attenuation falls off rapidly with increasing wavelength. It was for this reason that the United States Weather Bureau chose a wavelength of ten centimeters for their new weather radar, the WSR-57. The WSR-57's are now being installed in the Midwest and Atlantic coast areas. Their prime mission is to provide advance information on the movements of approaching hurricanes or tornadoes. It should be mentioned that although an increase in wavelength decreases attenuation, the energy scattered by raindrops is also an inverse fourth power function of wavelength, so by increasing the wavelength to minimize attenuation, an accompanying decrease in sensitivity results (6, p.1283). This may be partly compensated for by an increase in transmitter power output, an increase in receiver sensitivity, or both.
It may be seen then, that when choosing the wavelength for a weather radar system one must take into account the type of weather on which it will be most used. For severe weather, a wavelength of ten centimeters should be specified. For moderate weather, three centimeter radar offers superior sensitivity without excessive attenuation.

Most of the research to date has been with high-power three centimeter and medium-power ten centimeter equipment in the Midwest, and high-power three and ten centimeter equipment on the East coast. The East coast work has been primarily concerned with the detection and tracking of hurricanes. The work in the Midwest has been with tornadoes, areal extent of rainfall, and attempts to determine empirical relationships between rainfall drop-size distribution and rainfall rate. These research activities have two common factors. They are interested in weather situations occurring over flat land or sea, and are concerned primarily with severe weather phenomena.

The purpose of this thesis is then

1) to determine optimum design criteria for a medium-power weather radar to be used primarily in an area where mountains limit the usable range and where the rainfall rate is generally moderate,

2) to construct a weather radar system based on the findings of 1) above, and
3) to evaluate qualitatively and quantitatively the performance of the resultant system.
CHAPTER II
THEORY

Consider the case of an omni-directional antenna radiating microwave power at a rate $P_t$. At a distance $R$, this power is spread over the surface of a sphere of radius $R$. The power density at any place on the surface of the sphere is $P_t/4\pi R^2$, and the power intercepted by an object on this surface is $P_t\sigma/4\pi R^2$ where $\sigma$ is the backscattering cross section of the object. Now if this object scatters the incident power, the same conditions apply as did in the original radiation by the antenna, that is, the power being radiated by the scatterer ($P_t\sigma/4\pi R^2$) is spread over the surface of a sphere of radius $R$. Therefore the power density of the scattered radiation at the original site of transmission is:

$$\text{(1)} \quad \frac{P_t\sigma}{4\pi R^2} = \frac{1}{4\pi R^2}$$

If the effective area of the receiving antenna is $A_e$, the power at the antenna terminals is:

$$\text{(2)} \quad P_r = \frac{P_tA_e\sigma}{(4\pi R^2)^2}$$

This is valid only for an omni-directional antenna and must be modified to be used for a directional antenna. This may be done by introduction of $G$, the antenna gain factor. This is the ratio of power radiated in a given direction to
that which would be radiated in any direction by an omnidirectional antenna emitting the same power. Multiplying the right side of (2) by \( G \) makes it valid for a directional transmitting antenna.

\[
(3) \quad P_r = \frac{P_t A_e \sigma G}{(4\pi R^2)^2}
\]

The antenna gain factor may be computed from the relationship given by Ridenour (9, p.20) for a parabolic reflector.

\[
(4) \quad G = \frac{\lambda^2}{4\pi A_e}
\]

The effective area of the receiving antenna \( A_e \) is usually from 0.5 to 0.7 of the actual area of the parabolic reflector (6, p.1267). Solving (4) for \( A_e \) and substituting this into the right side of (3), the radar equation becomes,

\[
(5) \quad P_r = \frac{P_t \sigma G^2 \lambda^2}{(4\pi)^3 R^4}
\]

and the maximum distance at which a point target of known cross section may be detected is

\[
(6) \quad R_{\text{max}} = \left( \frac{P_t \sigma G^2 \lambda^2}{(4\pi)^3 P_{r\text{min}}} \right)^{\frac{1}{4}}
\]

where \( P_{r\text{min}} \) is the minimum signal detectable by the radar.

In the case of a rainstorm, since we are interested in the magnitude of the power scattered by a volume target rather than a point target, we replace \( \sigma \), the backscattering cross section, by \( NV \) where \( N \) is the reflectivity per unit volume and \( V \) is the volume from which power is being
reradiated. If we approximate the conical radar beam as a cylindrical beam, we may write the cross sectional area of this beam as \( \pi R^2 \theta^2 / 4 \), where \( \theta \) is the beamwidth between half power points of the antenna. The depth of this illuminated volume is \( h/2 \), where \( h \) is the pulse length in space, so the volume may be written

\[
V = \frac{\pi R^2 \theta^2 h}{8}
\]

Substituting \( NV \) for \( \sigma \) in (5), we obtain the radar equation for volume targets.

\[
P_r = \frac{P_t G^2 \lambda^2 \theta^2 h N}{512 \pi^2 R^2}
\]

This equation holds for any consistent set of units, but it is frequently desirable to use mixed units. Equation (9) gives the range at which a radar volume target of known reflectivity per unit volume, \( N \), may be detected. Introduction of the constant \( C \) allows one to use the units shown in the table below equation (9).

\[
R = \left( \frac{C P_t G^2 \lambda^2 \theta^2 h N}{P_r} \right)^{1/2}
\]

<table>
<thead>
<tr>
<th>( C )</th>
<th>( 2.4 \times 10^{-28} ) units of length(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>Reflectivity per unit volume in millimeters(^6)/meters(^3) and is equal to ( \frac{\pi^5 \lambda^4}{K^2 Z} ) where ( K ) is the dielectric constant for water, and ( Z ) is the drop size-distribution per unit volume</td>
</tr>
<tr>
<td>( R )</td>
<td>Range in statute miles</td>
</tr>
<tr>
<td>( P_t )</td>
<td>Transmitter power in watts</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Wavelength in centimeters</td>
</tr>
<tr>
<td>( G )</td>
<td>Antenna gain (unitless)</td>
</tr>
</tbody>
</table>
\( \theta \) : Antenna beamwidth in degrees  
\( h \) : Pulse length in meters

Equation (5) will be used in the evaluation of the system losses, and equation (9) will be used to compute the maximum distances at which precipitation of a given \( N \) value may be detected.
CHAPTER III
DESIGN CRITERIA

Based on the needs described in chapter I and the theory developed in chapter II, the following characteristics were considered.

1. **Wavelength.** Two very important relationships to consider when selecting the wavelength for a weather radar system are (4, p.107):

   \[
   (1) \quad W \sim \frac{D^6}{\lambda^4} \\
   (2) \quad Q_t \sim \frac{D^6}{\lambda^4}
   \]

   where \( W \) is the backscattering cross section of a spherical raindrop, \( \lambda \) is the wavelength of the radiation incident on the drop, \( D \) is the diameter of the drop, and \( Q_t \) is the total absorption cross section of the drop. These proportionalities are valid if the sphere diameter is less than one-twentieth the wavelength of the incident radiation, and valid to a good approximation for sphere diameters up to one-tenth the wavelength of the incident radiation (6, pp.1283-1284). Backscattering occurring under these conditions is called Rayleigh scattering, after Lord Rayleigh who first investigated the problem.

An analysis of raindrop camera data taken at Oregon State College during the 1957-58 school year reveals that the vast majority of the raindrops falling in this area are
between one and two millimeters in diameter (3). This means, then, that for wavelengths greater than two centimeters proportionalities (1) and (2) are valid. On examining these proportionalities it may be seen that by decreasing the wavelength the backscattering, and hence the sensitivity of the system, increases; by the same token the total absorption cross section, and hence the attenuation, also increases.

Based on the preceding theory and the availability of components, two possible wavelengths, three centimeters and ten centimeters were considered. At ten centimeters attenuation is not a problem (9, p.61), but sensitivity to moderate rainfall is poor. At three centimeters sensitivity to moderate rainfall is excellent, but attenuation may severely limit the useful range in a heavy storm. Employing Haddock's attenuation curves (4, p.123), attenuation of three centimeter radiation was calculated for fifty miles of intervening rainfall of four millimeters per hour intensity. The attenuation loss was approximately ten decibels for a storm of this magnitude. This means that an object beyond fifty miles of rainfall of four millimeters per hour intensity would be detectable only to approximately thirty-one per cent of its unobstructed maximum detectable range. It is significant to note that the decrease in effective range for a three centimeter radar system due to this attenuation is just offset by the threefold increase in
maximum detectable range gained by using a three centimeter wavelength instead of ten centimeters.

Since raindrop camera data (8) indicates that attenuation this severe rarely occurs in this area, and in view of the superior sensitivity of the shorter wavelength, three centimeters appears to be the most satisfactory wavelength for the system.

2. **Pulse length.** It is desirable to have available two pulse lengths, one of about five-tenths microsecond, and one from five to ten times this for use at long ranges.

3. **Power output.** It is desired to have the largest power output available and still have equipment of modest bulk.

4. **Range.** It is felt that a range of much over one hundred miles would probably not be necessary for the work for which we desire to use the equipment. Also, for our particular location, mountains to the east make it impractical to range much beyond one hundred miles.

5. **Antenna beamwidth.** For weather use it is desirable to have a narrow, conical beam. Antenna gain and hence range capabilities increase as the beam is narrowed. Also the narrower the beam the closer it may be tilted to the earth without being bothered with ground clutter.

6. **Method of video presentation.** Since this equipment will be used by radar meteorologists for forecasting the onset of storms, a linear video presentation to allow
tracking of storm echoes is necessary. A plan position indicator presentation in which a rotating sweep traces a plan view of the surrounding area is most commonly used for this application.

Based on the previous considerations of this chapter, and the availability of components, the following system was suggested.

We had available the transmitter-receiver unit of an AN/APS-4 Navy airborne radar. It operates on a wavelength of three centimeters. This fulfilled the initial condition of our design criteria, so it was decided to build the system around this unit. The only pulse length available was 0.6 microseconds, but examination of the circuitry revealed that the beacon section used a pulse shaping network which produced a 2.1 microsecond pulse. This circuit was adapted to the radar section, and the beacon function discarded. The power output of the transmitter was only thirty-five kilowatts, somewhat below what was desired, but in light of the other desirable features of the unit, this was considered acceptable. The original antenna, mounted on the transmitter receiver unit, was impractical for conversion to 360 degree rotation so it was decided to discard this and secure an antenna-pedestal unit that more closely approximated our design criteria. A satisfactory unit was secured from the University of Illinois. This antenna has a beamwidth of three degrees, quite adequate for the
anticipated system, and was designed for 360 degree rotation. We also had available a plan position indicator unit from an AN/APS-2 Navy radar. This was originally used as the indicator for the system, but subsequent procurement of a Navy model VD-2 seven inch plan position indicator better satisfied the indicator needs.

Using the components described above, our radar system has the following characteristics:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWER OUTPUT</td>
<td>35 kilowatts</td>
</tr>
<tr>
<td>ANTENNA GAIN</td>
<td>$3.67 \times 10^3$</td>
</tr>
<tr>
<td>ANTENNA BEAMWIDTH</td>
<td>3° conical</td>
</tr>
<tr>
<td>PULSE LENGTH</td>
<td>0.6 and 2.1 microseconds</td>
</tr>
<tr>
<td>WAVELENGTH</td>
<td>3.2 centimeters</td>
</tr>
<tr>
<td>MINIMUM DETECTABLE SIGNAL</td>
<td>$4 \times 10^{-13}$ watts</td>
</tr>
<tr>
<td>INDICATOR</td>
<td>7 inch plan position indicator</td>
</tr>
</tbody>
</table>

Inserting these parameters into the radar volume target equation, we arrive at the following values:

$$N \text{ mm}^6/\text{M}^3$$ | Detectable range in statute miles | Rainfall rate in mm/hour
---|---|---
$4 \times 10^2$ | 19.4 | 0.55
$3 \times 10^3$ | 53.1 | 2.40
$2.25 \times 10^4$ | 146 | 7.90

$N$ is the reflectivity per unit volume, $R$ is the range to the storm under observation, and $r$ is the rainfall rate. Rainfall rate was calculated using the following relationships from Jones (5, p.11):
for thundershowers \[ Z = 486 \ r^{1.37} \]

for moderate showers \[ Z = 380 \ r^{1.24} \]

for continuous light rain \[ Z = 313 \ r^{1.25} \]

where \( Z \) is the drop size-distribution per unit volume.

\( Z \) values were chosen as typical for light, moderate, and heavy rainfall based on local raindrop camera data (8). In making these calculations, it is assumed that the beam is completely filled, that there is no intervening rain between the radar and the storm, and that there is an over-all system loss of approximately seven decibels.

We may say, then, that based on theoretical and practical considerations our radar system should perform satisfactorily at ranges near one hundred miles for heavy rain, fifty miles for moderate rain, and fifteen miles for light rain, assuming the over-all power loss in the system does not greatly exceed seven decibels.
CHAPTER IV
CONSTRUCTION OF THE SYSTEM

Construction of the system consisted of modification of the component parts to approximate the conditions of the design criteria, and the integration of these components into a workable weather radar. The following electrical and mechanical modifications were made.

Transmitter-receiver unit:

A. The fourteen inch parabolic antenna and its associated positioning motors were removed from the AN/APS-4 transmitter-receiver unit. Electrical connections to the antenna were removed and taped to prevent possible contact with other connections.

B. The range and alarm unit was removed from the transmitter-receiver frame. The original function of this unit was to provide range markers for the indicators and two stages of amplification for the video signal from the second detector. Since both of these functions are provided for in the VD-2 indicator, this unit was unnecessary.

C. To enable the 2.1 microsecond beacon pulse to be used to pulse the radar magnetron, wire #10 from P(5)15 which connects with J(5D)4 on unit 5D, was disconnected. This disables the radar-beacon relay and allows the 2.1 microsecond pulse to be used with the radar. Details of this modification may be found in the Appendix.
D. The modified transmitter-receiver unit was then mounted on the roof of the meteorology laboratory, and cabling was installed between this unit and the AN/APS-4 transmitter-receiver control unit located in the laboratory. The transmitter-receiver unit was located as close as possible to the anticipated site of the antenna unit in order to reduce transmission line loss.

Antenna:

A. The antenna-pedestal unit used in this system was originally from an airborne AN/APS-15 radar. The synchro output of this antenna unit was not compatible with the synchro requirements of the VD-2 indicator. A suitable (5G) synchro generator was obtained and mounted in place of the original synchro.

B. The antenna was originally designed to tilt twenty degrees above and twenty degrees below the horizon, but for our application a tilt of zero to forty degrees was desired. This was accomplished by lengthening the bell crank that connects the antenna dish to the tilt drive motor.

C. The drive motor of the AN/APS-15 antenna will rotate the antenna at either twelve or twenty-four revolutions per minute. The tilt motor will tilt the antenna dish forty degrees. The switching circuits to accomplish these functions are incorporated in the main panel of an AN/APS-2 indicator. Details of these antenna control circuits may be found in the Appendix.
D. The antenna was mounted on a plywood platform built atop the railing on the west side of the meteorology laboratory roof. A fibre radome, transparent to three centimeter radiation, was obtained to protect the antenna mechanism from the weather. Details of this installation may be seen in figure 1.

Waveguide transmission line:

The transmission line between magnetron and antenna consists of approximately twelve feet of RG-52 X-band waveguide. All joints are standard choke to butt joints with rubber gaskets to keep out moisture. There are two rotating joints in the antenna pedestal unit. When the transmission line was first installed no gaskets were used at the joints. A severe drop in performance was noted after a heavy rain, and upon inspection the waveguide was found to be filled with water. The line was dismantled, thoroughly cleaned in a boiling soda solution, and reinstalled using rubber gaskets at the joints. No further trouble has been experienced with moisture in the line.

Indicator:

The indicator used in the system is a Navy model VD-2 radar repeater. It is mounted in the meteorology laboratory. It was originally used aboard ship as a repeating indicator from the ship's master air and surface search radars. The unit is completely self contained requiring only video and synchronizing inputs from the transmitter-
receiver unit, and a one hundred ten volt single phase power input. Available range scales are four, ten, twenty, eighty, and two hundred miles. Since this unit was entirely satisfactory in its original form no modifications to it have been made.

Transmitter-receiver control unit:

This is the master control unit for the radar system. It contains the four major controls of the system, the on-off switch, the receiver gain, the receiver tune, and the pulse length switch. The pulse length switch has three positions giving pulse lengths of 0.6 microseconds at a repetition frequency of one thousand pulses per second in position one, 0.6 microseconds at a repetition frequency of six hundred pulses per second in position two, and 2.1 microseconds at a repetition frequency of three hundred fifty pulses per second in position three. The receiver gain control varies the gain of the intermediate frequency amplifier. The receiver tune varies the repeller voltage on the local oscillator such that if the automatic frequency control is unable to keep the oscillator on frequency, it may be manually corrected. The on-off control is a three position switch; off, wait one minute, and on. The wait position allows the filaments in the modulator tube and magnetron to warm up before plate voltage is applied. This prevents damage to these costly tubes.
This unit was mounted in the meteorology laboratory near the VD-2 so that tuning and other adjustments can be made while viewing the indicator.

**Power supplies:**

The power requirements for the transmitter-receiver unit are supplied by a Navy type CDO 21648 motor generator set, and a Lincoln SAE-200 welding generator. The motor generator supplies a maximum output of 1.18 kilovolt amperes at a frequency of four hundred cycles per second, and the welding generator supplies a maximum output of two hundred amperes at twenty-eight volts direct current. Since both of these units are quite noisy in operation, they were mounted in the basement of the Physics building, and wiring was installed between basement and meteorology laboratory.
Figure 1

ANTENNA PEDESTAL UNIT
Figure 2
TRANSMITTER-RECEIVER UNIT
Figure 3

VD-2 INDICATOR CONTROL PANEL
Figure 4

VD-2 INDICATOR TOP VIEW
CHAPTER V
SYSTEM PERFORMANCE EVALUATION

In any radar system there are losses in the radio frequency section which tend to make the actual performance of the equipment fall short of the theoretically predicted performance. If one is aware of these losses and is able to measure their magnitude, a much more accurate prediction of system capabilities may be made. A quantitative system performance evaluation requires, therefore, that these losses be measured.

Two methods were employed to measure the system loss. The first was similar to that used by Austin and Williams (1, p. 7) to determine the system loss of their SCR-615B weather radar. Rather than measure the transmitting and receiving losses independently this method lumps these into an over-all system loss. Referring to equation (5) chapter II, if we insert into this equation the known parameters of our radar, we obtain the magnitude of the theoretical power returned by a point target of backscattering cross section $\sigma$, located a distance $R$ from the radar site. By measurement of the actual power returned by such a target and comparison with the theoretical power returned, the over-all system loss is revealed.

A metallic mesh balloon cover three feet in diameter, especially designed for use as a three centimeter radar
reflector, was used as the standard target. The effective backscattering cross section for this reflector is 0.62 square meters. Two series of measurements were made using this method. For the first, a one hundred gram meteorological balloon encased by the reflecting cover was tethered from a hilltop approximately five miles north of the radar site. For the bottom of the beam to clear the hilltop, the length of the tethering line had to be at least \( \frac{\theta}{2} \) where \( \theta \) is the antenna beamwidth in radians and \( r \) is the line of sight distance to the sphere. At a range of five miles this means the line would have to be a minimum of 780 feet long. To minimize any possibility of error by ground reflections the sphere was tethered approximately two thousand feet above the hilltop. Line of sight distance to the sphere from the radar site was measured by the range markers on the VD-2 indicator. Using the same equipment and procedure, a second series of measurements was made with the sphere tethered approximately two miles north of the radar site.

The magnitude of the actual returned power was measured by comparison with a signal injected into the system by a TS-13 microwave signal generator. This signal generator is equipped with an attenuator calibrated in decibels below one milliwatt (dbm). When the attenuator is adjusted such that the signal returned by the reflector and the injected signal are of equal amplitude, the dial setting of
the attenuator indicates the power returned by the reflector in dbm providing there is no coupling loss between the signal generator and the radar system. However, since there are coupling losses between the generator and the system, the attenuator dial reading must be corrected for these losses. There is a loss of four decibels in the cabling and adaptors between the generator and the injector feed horn (3, pp.5-12). Another coupling loss appears between the injector feed horn and the radar antenna. When injecting a signal into the system, the feed horn is suspended by a boom 114 centimeters above the radar antenna. For this particular feed horn placed 114 centimeters from the radar antenna, the computed coupling loss is 12.5 decibels (7, p.244, p.905). The total coupling loss, then, between signal generator and radar system is 16.5 decibels, and this must be subtracted from the attenuator dial reading to give an accurate measure of the power returned by the reflector. A Tektronix model 514D cathode ray oscilloscope connected to the video output of the system was used as the comparator in making these measurements. The results of this evaluation are shown in table I.

The second method employs the same equipment as the first with the exception of the standard sphere. Since we know the theoretical values of the minimum detectable signal and peak power output of the system, a determination of the actual minimum detectable signal and actual
transmitter power output would reveal the system loss. These quantities are both measurable by the TS-13 signal generator and power meter.

To measure the minimum detectable signal, an accurately controllable amount of pulsed power is injected into the system by the TS-13. This signal is diminished by the calibrated attenuator until it is equal in amplitude to the noise level of the receiver as viewed on the oscilloscope. The reading of the attenuator dial plus the coupling loss between the TS-13 and the system reveals the actual minimum detectable signal. The difference between this and the theoretical value is the receiving system loss.

The TS-13 employs a balanced bridge thermistor circuit to measure the average power output of the transmitter. When the TS-13 is properly pre-calibrated, it indicates the average power output of the transmitter directly in milliwatts. The ratio in decibels of the theoretical average power output to the actual average power output equals the sum of the transmitting system loss and the TS-13 coupling loss. Subtraction of the coupling loss from the above value gives one the transmitting system loss.

The total system loss is, then, the sum of the transmitting and receiving system losses. The results of this evaluation are shown in tables II and III.

From a qualitative standpoint, the system has performed up to expectations. On several occasions thunderstorms over
the Cascade Mountains at ranges of seventy to one hundred miles have been observed. Cold front showers have been detected to ranges of fifty miles. Warm front stratiform precipitation has been observed to ranges of fifteen miles. Figures 5 through 8 show examples of precipitation echoes as seen on the original APS-2 indicator. Unfortunately, photographic records of all the situations described above are not available as the camera unit to date has proved unreliable.
**TABLE I**

**OVER-ALL SYSTEM LOSS**

<table>
<thead>
<tr>
<th>RANGE TO SPHERE</th>
<th>THEORETICAL POWER RETURNED</th>
<th>ACTUAL POWER RETURNED (MEAN VALUE)</th>
<th>OVER-ALL SYSTEM LOSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 miles</td>
<td>74.8 dbm</td>
<td>82.5 dbm</td>
<td>7.7 db</td>
</tr>
<tr>
<td>(location I)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 miles</td>
<td>64.5 dbm</td>
<td>71.0 dbm</td>
<td>6.5 db</td>
</tr>
<tr>
<td>(location II)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A total of 116 readings at location I and 116 readings at location II were taken.
<table>
<thead>
<tr>
<th>Watts</th>
<th>Milliwatts</th>
<th>Decibels</th>
<th>Decibels</th>
<th>Decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.6</td>
<td>112</td>
<td>20.5</td>
<td>16.5</td>
<td>4.0</td>
</tr>
<tr>
<td>12.6</td>
<td>97</td>
<td>21.1</td>
<td>16.5</td>
<td>4.6</td>
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Mean 4.05 decibels
### Table III

**Receiving System Loss**

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**Mean**: 3.85 decibels
Figure 5

STRATAFORM PRECIPITATION
FIVE MILE MARKERS

Corvallis, Oregon
6 June 1958
9:40 A.M.
Figure 6

COLD FRONT SHOWERS
TEN MILE MARKERS

Corvallis, Oregon
9 June 1958
4:30 P.M.
Figure 7

COLD FRONT SHOWERS
TEN MILE MARKERS

Corvallis, Oregon
9 June 1958
2:28 P.M.
Figure 8

THUNDERSTORMS
TWENTY MILE MARKERS

Corvallis, Oregon
22 May 1958
4:00 P.M.
CHAPTER VI
CONCLUSIONS

The success or failure of this project can best be judged by the performance of the radar system in terms of what was originally desired. Qualitative observations indicate that the system is capable of detecting heavy rainfall to ranges of one hundred miles, moderate rainfall to ranges of fifty miles, and light rainfall to ranges of twenty miles. These qualitative observations are borne out by the quantitative evaluation of the system. The system loss as measured by the standard target method is 7.7 and 6.5 decibels for data taken at locations I and II respectively. The system loss as measured by the TS-13 signal generator and power meter is 7.9 decibels. The maximum spread between these three values is 1.4 decibels, well within the ±2 decibel measuring accuracy of the TS-13's attenuator. This means, then, that the theoretical detectable ranges for given rainfall rates as tabulated in chapter III are approximately correct for this radar system. In actual practice, the detectable ranges would be somewhat less since these calculations are based on a filled beam with no intervening rain. The beam is rarely filled at long ranges, and intervening rain is frequently present.

In completing a project such as this one always finds details that could have or should have been done but
somehow never were. The following suggestions for future improvement of the system fall into this category.

1. A dual balance mixer should be installed to replace the present mixer circuit. The dual balance mixer employs a noise cancellation scheme that will decrease the receiver minimum detectable signal by about 2 decibels.

2. In the present system the pre-I.F. amplifier employs a pentode in its initial stage. Installation of a low noise cascode circuit at this point should further reduce the receiver minimum detectable signal.

3. The switches for antenna control, power, pulse length, receiver gain, and receiver tune should all be incorporated into one main control panel. This would greatly simplify operational adjustment of the equipment.

4. It would be advantageous to have an "A" scope located at the operating position. This would allow the operator to make qualitative estimations of the relative intensity of different echoes.
1. Austin, Pauline M. and Edwin L. Williams, Jr.  


3. Handbook of maintenance instructions for model AN/APS-4 aircraft radar equipment. Washington, U. S. War and Navy departments, October 1944. 9 sections


APPENDIX

In order to understand fully the operation of a radar system, it is necessary to examine the circuitry of its individual components. For this reason, a set of schematic diagrams for each unit is included. These diagrams should also prove helpful to personnel called upon to service the equipment.
Figure 9

AUTHOR CALIBRATING EQUIPMENT
Figure 10
CALIBRATION EQUIPMENT
Figure 11
SYSTEM BLOCK DIAGRAM
Figure 12 TRANSMITTER-RECEIVER WIRING DIAGRAM
Figure 13  RECEIVER SCHEMATIC DIAGRAM
Figure 14

I.F. AMPLIFIER SCHEMATIC DIAGRAM
Figure 15

LOW VOLTAGE POWER SUPPLY
ANTENNA CABLING

5G SYNCHRO ON ANTENNA
S1    GREEN
S2    BLUE
S3    BLACK

10     TERMINAL BOARD
11     E-102 ON VI-2
12
13

PLUG P203 ON APS-2 INDICATOR
M    SHIELD
F    BLUE
H    RED
J    BROWN

ANTENNA PLUG P607
T
S
D
E

PLUG P203 ON APS-2 INDICATOR
F    BLACK
E    YELLOW/ORANGE
J    YELLOW
    GREEN

Figure 16
Figure 17
ANTENNA CONTROL SWITCHES
Figure 18
ANTENNA PEDESTAL UNIT
SCHEMATIC DIAGRAM

NOTE:
“UP” AND “DOWN” DESIGNATION SHOWN FOR TILT LIMIT SWITCHES REFERS TO “DISH” POSITION WHEN SPINNER IS UPRIGHT (“DISH” ABOVE BASE).
Figure 19  VD-2 CASE ASSEMBLY SCHEMATIC DIAGRAM
Figure 20
VD-2 CONTROL CIRCUIT ASSEMBLY SCHEMATIC
Figure 21

POWER SUPPLY AND SERVO ASSEMBLY SCHEMATIC DIAGRAM