Communications Research Centre

A NOTE ON THE PERFORMANCE OF THE AN/CPN-4 RADAR AT 1 WING EUROPE

by

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COMMUNICATIONS RESEARCH CENTRE

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ABSTRACT

At the request of Canadian Forces Headquarters,
an investigation of factors affecting the CPN-4
radar coverage at 1 Wing Europe has been carried
out. This Technical Note is the final report on
work performed in this regard, and includes ground
clutter profiles for 1 Wing and 4 Wing, a descrip-
tion of geographical features of importance, and
calculations of the range performance of the CPN-4.
The inability of the CPN-4 to track high-angle
targets is discussed.

1. INTRODUCTION

On 2 October 1969 the Radar Section of the Communications Research
Centre was requested by the Director of Electronic Systems Engineering,
Canadian Forces Headquarters, to investigate reported inadequate Air Traffic
Control radar coverage at Lahr, West Germany. Accordingly, the author visited
that base from 13 October to 17 October 1969.

The terminal radar in use at Lahr at that time was the well known short-
range CPN-4. Both the regional geography and meteorology conspire to create a
difficult radar environment, and within this environment the elderly CPN-4
was required to function against targets varying from supersonic jet fighters
(CF-104) to Yukon transport aircraft, which in turn operate at widely varying
altitudes and speeds. This note is intended to discuss the technical and
operational difficulties resulting from such a situation, and to provide a
permanent record of some of the factors which led to the replacement of the
CPN-4 radar at Lahr.

2. THE EQUIPMENT SITUATION

The radar equipment in use at 1 Wing suffered from the well know deficiencies of the CPN-4:

    (a) Moving Target Indicator (MTI) blind speeds due to the use of single pulse repetition frequency (PRF).

    (b) Inadequate MTI, resulting in target signal suppression due to over-cancellation of the high ground clutter levels at the site.

    (c) Unreliable detection of light aircraft and aircraft of small radar cross section due to inadequate radar sensitivity.

    (d) Poor high-angle coverage due to antenna beam shape and low radar sensitivity.

    (e) Marginal Secondary Surveillance Radar (SSR) performance.

These deficiencies are aggravated by the rugged terrain and difficult flying weather of the Rhine Valley. Also, while the CPN-4 performance has been found to be acceptable in some Canadian locations, the pecularities of the current air traffic situation at Lahr (which have been accurately described in Reference (1)), render such performance unacceptable at this location.

With reference to weather, it is unfortunate that the relevant statistics on rainfall rates are not available. Interviews with forecasters and controllers on the spot however do indicate that rain is not the major problem for the search radar, but does adversely affect the X-band precision equipment on occasion. Except in the case of isolated storms, circular polarization and Sensitivity Time Control (STC) normally reduce precipitation returns on search to a satisfactory level. The relatively high incidence of instrument weather conditions, largely due to restricted visibility in fog, smoke and haze, does impose a severe strain on the operational capability of the present system, even though the actual radar performance may not be materially worsened. For purposes of comparison, weather records for nearby Sollingen indicate that this base is below Visual Flight Rules (VFR) minima 35% of the time. The equivalent figure for Ottawa is 12%.

3. GEOGRAPHICAL SITUATION

Figure 1A shows the 40 mile range PPI presentation of ground clutter at Lahr, while Fig. 1B gives the same display but with all returns attenuated by 30 dB, the theoretical maximum clutter attenuation for the CPN-4 MTI at Lahr. Clutter returns which are visible in the latter figure are therefore greater than 30 dB above minimum detectable signal (MDS). Areas of clutter in this category will be areas of reduced sensitivity for the CPN-4 under any conditions. Only through enhanced clutter attenuation (and better subclutter visibility) can the fraction of the coverage area subject to this degradation be reduced. In both figures, range rings are at 5 nm intervals.
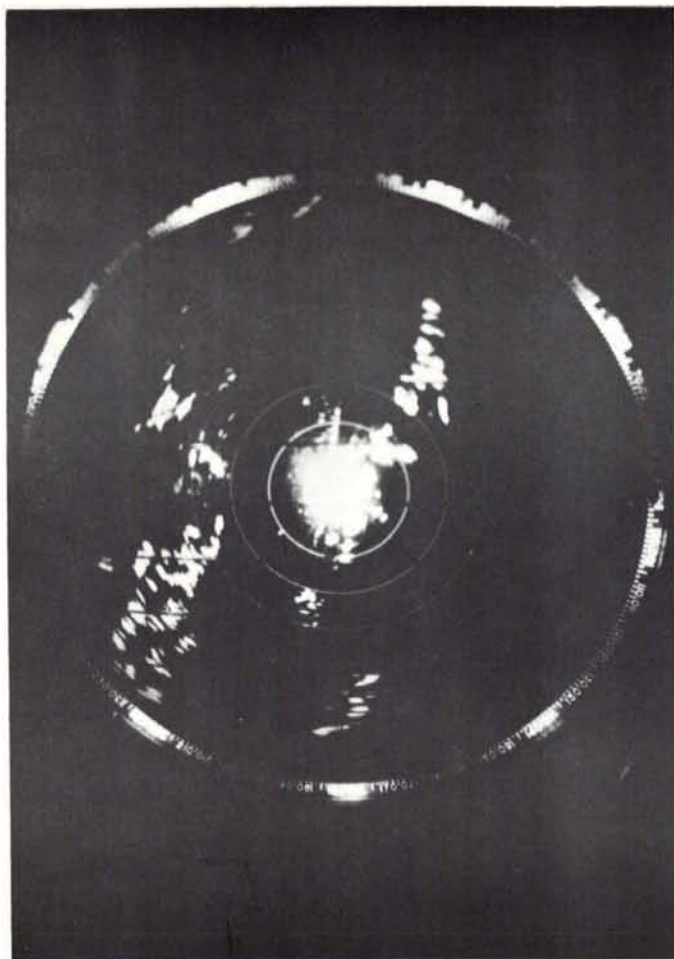
Fig. 1A.

0 dB ATTENUATION
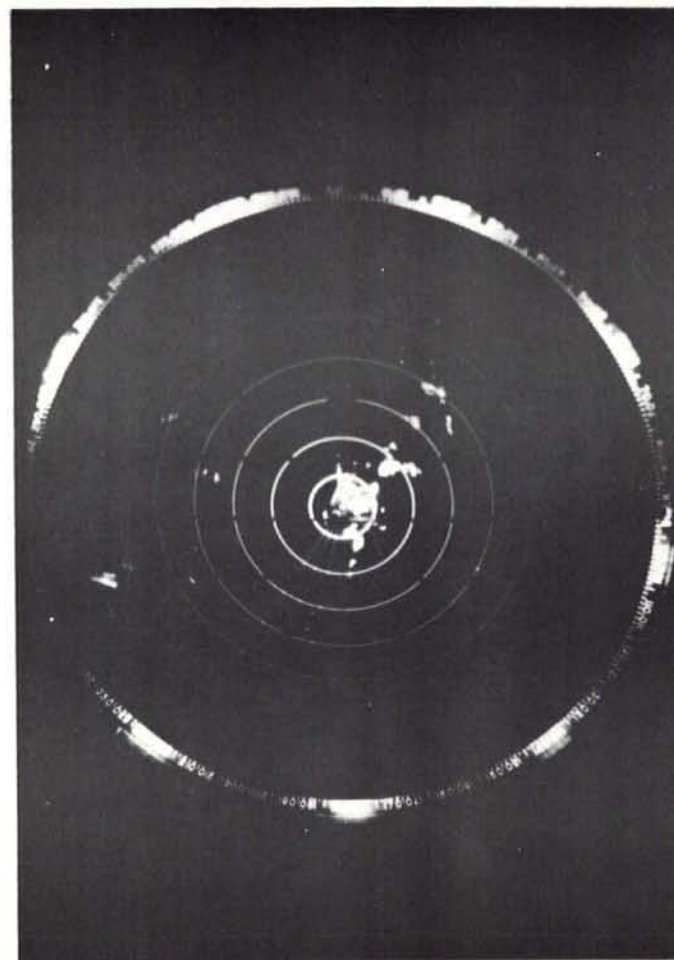
Fig. 1B.

30 dB ATTENUATION

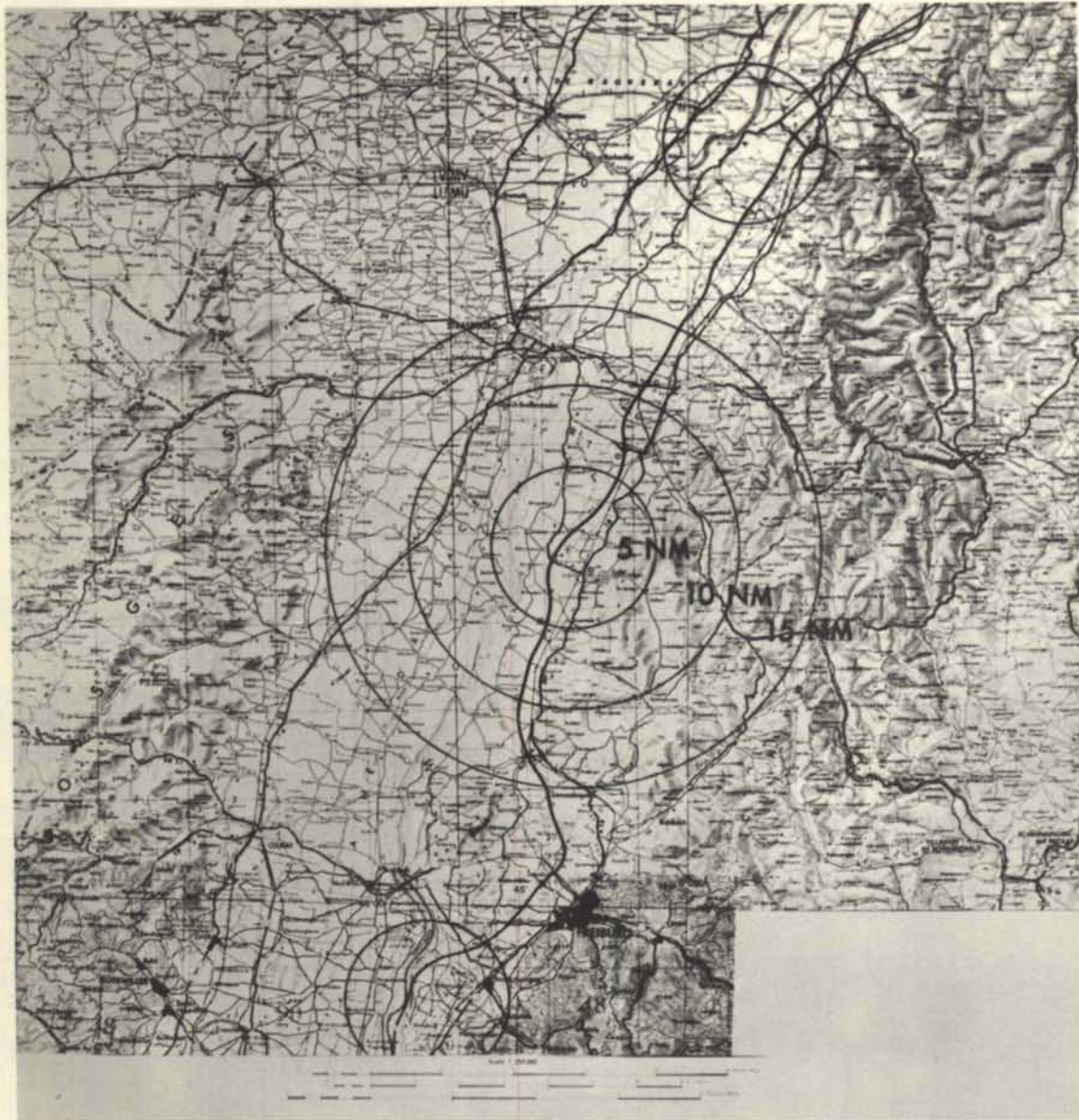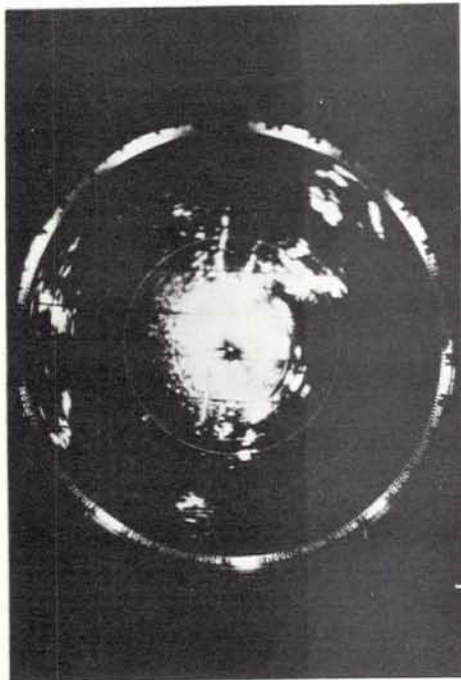*Ground clutter at 1 Wing (PPI range = 40 nmi).*

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Fig. 1C. Map of Lahr area. Range rings at 5 NM intervals.

Figure 1C shows a topographical map of the Lahr area. In this figure, and in the radar display photograph of Fig. 1A, the following geographical features should be noted.

(a) 4 Wing is located at bearing 020° and 26 nm, and is essentially in a clear radar path from 1 Wing.

(b) Bremgarten, a base operated by the German Air Force, is located at bearing 190° and 29 nm. A significant obstruction to visibility in this direction is an 1800 foot hill, the Kaiserstuhl, visible at bearing 190° and 17 nm. The importance of these features will be discussed in more detail in a later section.

(c) The Vosges mountain range, which runs north-south and is located 17 nm to the west, is not presently a major factor in the radar situation at Lahr.

(d) The terrain to the east of the field rises rapidly to a height of 1300 feet at 3 nm resulting in permanent echos of over 50 dB above MDS. Since this clutter is so close to the radar, it tends to appear as part of the normal local ground clutter. What is apparent in Figure 1A is the effect of severe terrain shielding to the east of the base at ranges beyond 5 nm. At a 15 nm range, this terrain shielding typically obscures airspace below 6500 feet, even though the ground level in the area is less than 3000 feet above sea level. This situation is of particular interest since the principal east-west airway in the region, Red 7 from Rottweil to Strassbourg, crosses the void area from the east-southeast in Figure 1A, to the centre of the PPI. This airway has a minimum obstruction clearance altitude of 5800 feet above sea level, and hence IFR traffic may be encountered down to this altitude, while VFR traffic may operate well below. Such traffic will not be seen by any radar located at Lahr, even though the PPI display appears clear of obstructions in this region.

(e) The mountains along the eastern edge of the Rhine Valley are visible to the northeast of Lahr. To 20 nm, these permanent echos are stronger than the MTI is able to cancel, and so aircraft returns from the area will be marginal. This particular azimuth and range will affect aircraft outbound to penetration turn during high level Tacan 3 approaches to runway 21. The outbound to the Tacan 4 approach to runway 03 on the other hand, while also being over rugged terrain but to the southeast, is protected to some extent by the natural "radar fence" formed by the near-in mountains in that direction.

0 dB ATTENUATION
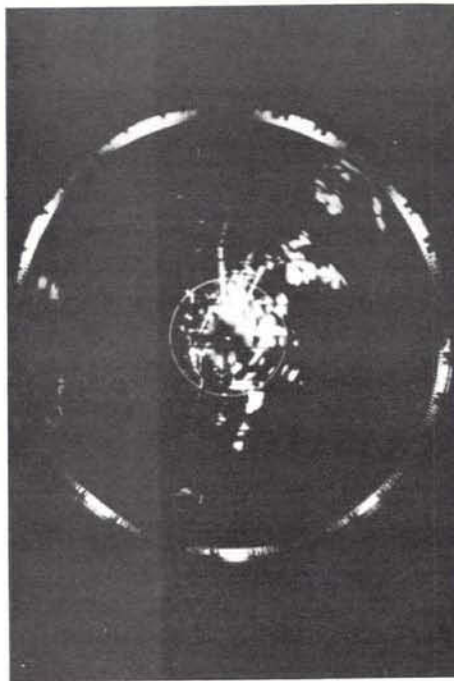
10 dB ATTENUATION
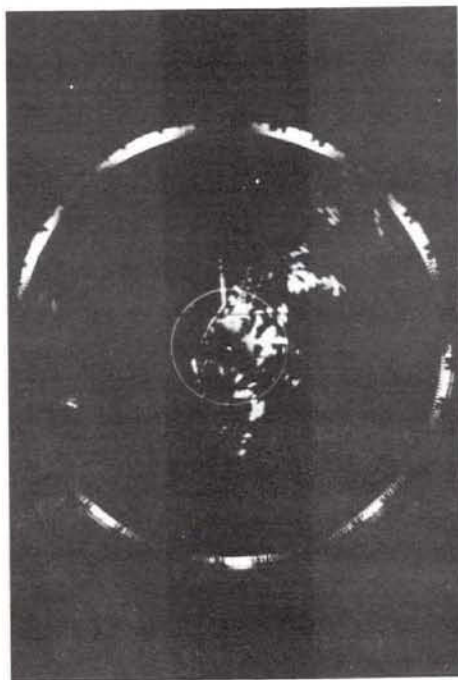
20 dB ATTENUATION

Fig. 2. Clutter signal strength at 1 Wing (PPI range = 20 nmi).

4. GROUND CLUTTER LEVELS

Figures 2 and 3 give an indication of the levels of ground clutter return experienced at Lahr. The measurements were carried out as follows:

After performing tests to ensure that the parametric amplifier remained linear over the 60 dB dynamic range of interest, a precision RF attenuator was introduced between the paramp and the preamplifier. The level of attenuation (in dB) indicated in the figures was set for each picture. Clearly, for a given setting of the attenuator, any clutter still appearing on the PPI must be stronger, with respect to MDS, than the indicated level. STC was "off" during these measurements.

It is interesting to compare the clutter levels at Lahr with those of CFB Comox (described in an earlier CRC report[2]). The clutter contour photographs in that report indicate that at Comox a significant amount of the clutter is stronger than 40 dB above MDS. In particular, the Island Range, 10 nm to the south of Comox, shows returns of nearly 60 dB above MDS over an extensive area of the display. Figure 3 shows that comparably strong clutter does not occur at Lahr. In this connection, three points should be made:

(1) While the terrain surrounding Lahr is quite rugged, the hills are rolling and generally more tree covered than is the case on Vancouver Island. Therefore, a less intense ground clutter return is to be expected.

(2) The area from which we would expect the strongest clutter returns is terrain-shielded by the rapidly rising ground to the east of the base. These hills act as a natural "radar fence".

(3) The "black hole" in the center of the PPI, especially visible in Figure 2, is due to receiver desensitization for a period of about 20 microseconds after the main pulse is transmitted. Such a long recovery time is not normal for the CPN-4 and indicates an equipment malfunction. Since receiver sensitivity is only seriously reduced in the first two miles of range, the fault, while undesirable, is not a major factor in relation to other system shortcomings. It does however create the false impression of a lack of near-in ground clutter in the photographs.

A thorough study of the clutter profile photographs in relation to operational flight patterns indicates that for a radar with parameters similar to the CPN-4, little would be achieved by attempting an MTI clutter attenuation of greater than 35 dB. If antenna scanning is the limiting factor, this clutter attenuation is theoretically achievable with 14 hits/beamwidth for a double canceller or 64 hits/beamwidth for a single canceller MTI[3]. The short range CPN-4, with a single canceller MTI and 29 hits/beamwidth, is limited to about 28 dB clutter attenuation by antenna scanning alone.
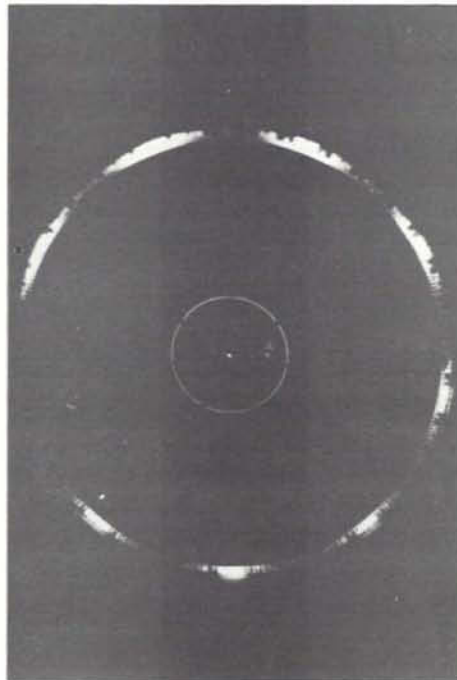
While in Europe, the author also performed clutter measurements on the CPN-4 radar at 4 Wing. These are presented in Appendix A of this report.

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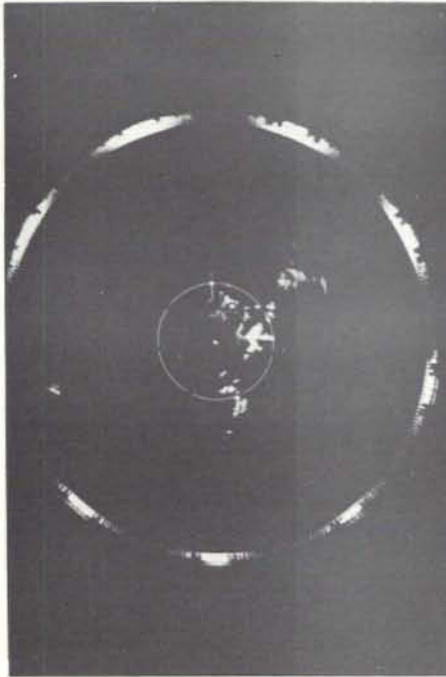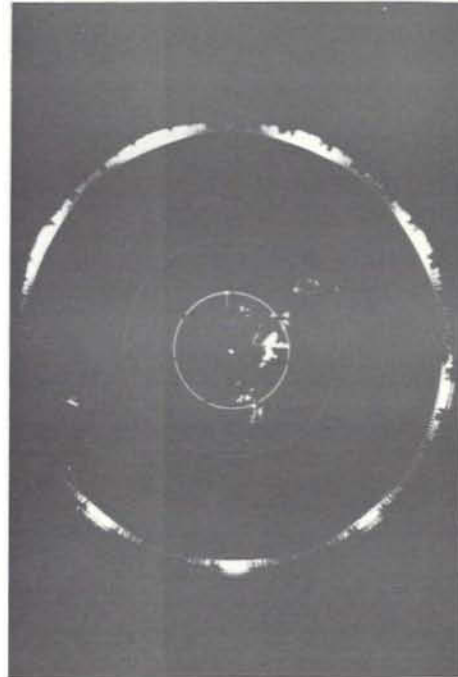
30 dB ATTENUATION

40 dB ATTENUATION

50 dB ATTENUATION

Fig. 3. Clutter signal strength at 1 Wing (PPI range = 20 nmi).

5. CPN-4 SYSTEM PERFORMANCE

Figure 4 shows the computed probability of detecting a 1 m² target in the "nose" of the beam versus range, using the CPN-4 radar under perfect conditions. This curve was computed using the statistical theory of detection due to Marcum[4] for a false alarm time of 2 seconds. It is easy to see that the original CPN-4 was designed for a maximum range of 40 nm under such conditions. There are, of course, adverse factors usually operating in practice to reduce the target return by many decibels. From a probability of detection point of view, application of such a loss is equivalent to replacing the target with an identical one, but located as a greater range from the radar. Figure 5 is a plot of the strength of target return versus range computed for the same situation as was Figure 4, and using the conventional $1/R^4$ relationship of the Radar Equation. We may use this curve to solve for the equivalent effective range of a target, taking into account losses, and hence relate theoretical optimum performance with that encountered in practice. For example, Figure 5 shows that a target at 30 nm gives a return of 13 dB above MDS, while the same target at 40 nm yields only 8 dB, or 5 dB less. This situation may be restated as follows: a target at 30 nm, suffering a system loss of 5 dB, will yield a return amplitude identical to that of the same target at 40 nm under optimum free-space conditions.


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PEAK POWER = .50E 06 W.
PULSE LENGTH = .5E-06 SECS.
ANT. GAIN = 32.0 DB
WAVELENGTH = .100 MTRS.
TARGET CROSS SECTION = 1.0 SQ. MTR.
PRF = 1500. HZ
RCVR. BANDWIDTH =.50E 07 HZ.
NOISE FIGURE = 5.0 DB
ANT. RPM = 20.
BEAMWIDTH = 2.3 DEG.
SYSTEM LOSS = 5.0 DB.
```
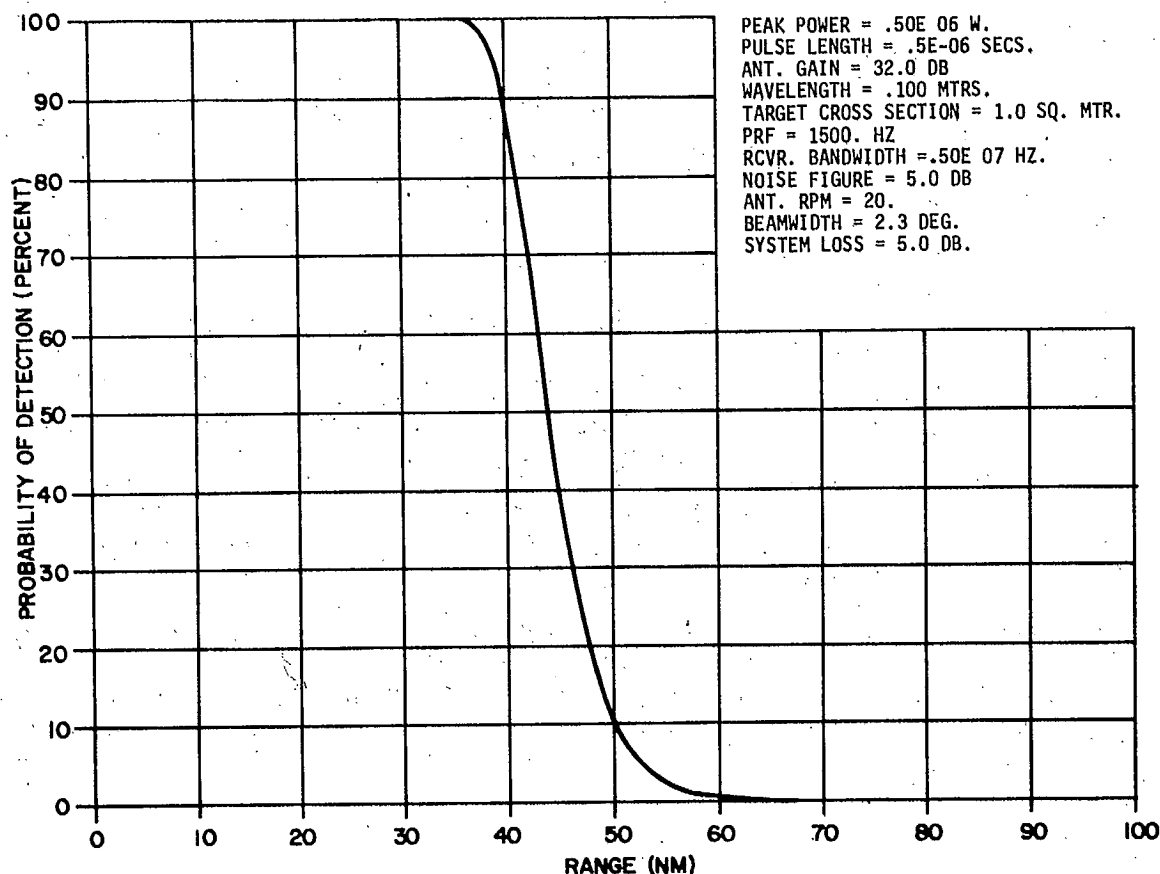
Fig. 4. Probability of detecting a 1 m² target with the CPN-4 under optimum conditions.

PEAK POWER = .50E 06 W.
PULSE LENGTH = .5E-06 SECS.
ANT. GAIN = 32.0 DB
WAVELENGTH = .100 MTRS.
TARGET CROSS SECTION = 1.0 SQ. MTR.
MDS = -110. DBM
SYSTEM LOSS = 5.0 DB

(Graph: SIGNAL RELATIVE TO RADAR MDS (dB) versus RANGE (NM), with a descending curve from about 57 dB at short range to 0 dB at about 64 nm.)

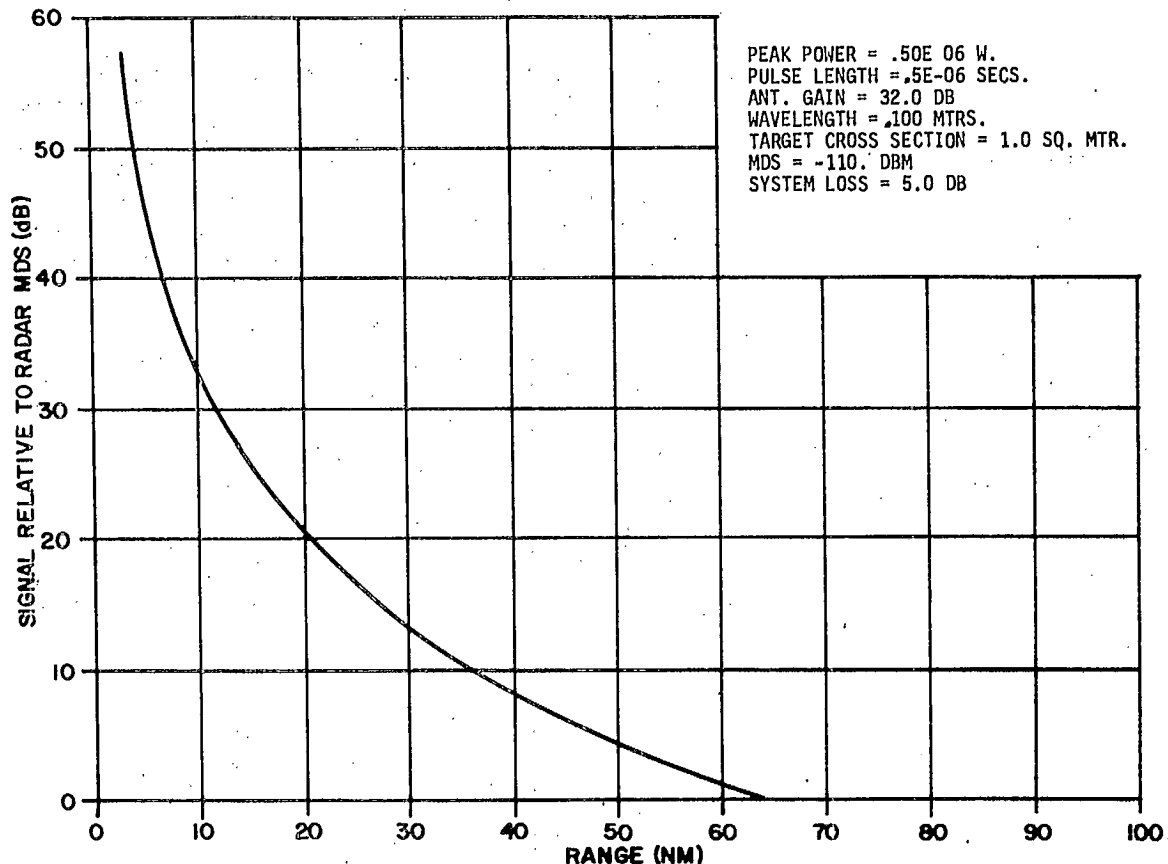**Fig. 5. Strength of return from a 1 m² target using the CPN-4 under optimum conditions.**

As a practical example, Swerling[5] has shown that under conditions theoretically leading to a high probability of detection, target fluctuations based on the Rayleigh model may reduce the effective signal return by 15 dB or more. Figure 5 shows that such a 15 dB loss is sufficient to reduce the target return from an aircraft at 20 nm to a level similar to what would have been received had the aircraft been at 45 nm, but not subject to these fluctuations. The effect on the probability of detection of this target is clear from Figure 4. What would have been a solid paint of 20 nm has become marginal due to normal target fluctuation.

Figure 6 has been computed to show the probability of detection versus range for a high powered radar of the type already installed at CFB Comox. The dramatic increase in performance is clear. The "brute force" excess range of this system will grant considerable immunity from adverse factors, since Lahr Terminal Control is not normally concerned with traffic much beyond 50 nm.
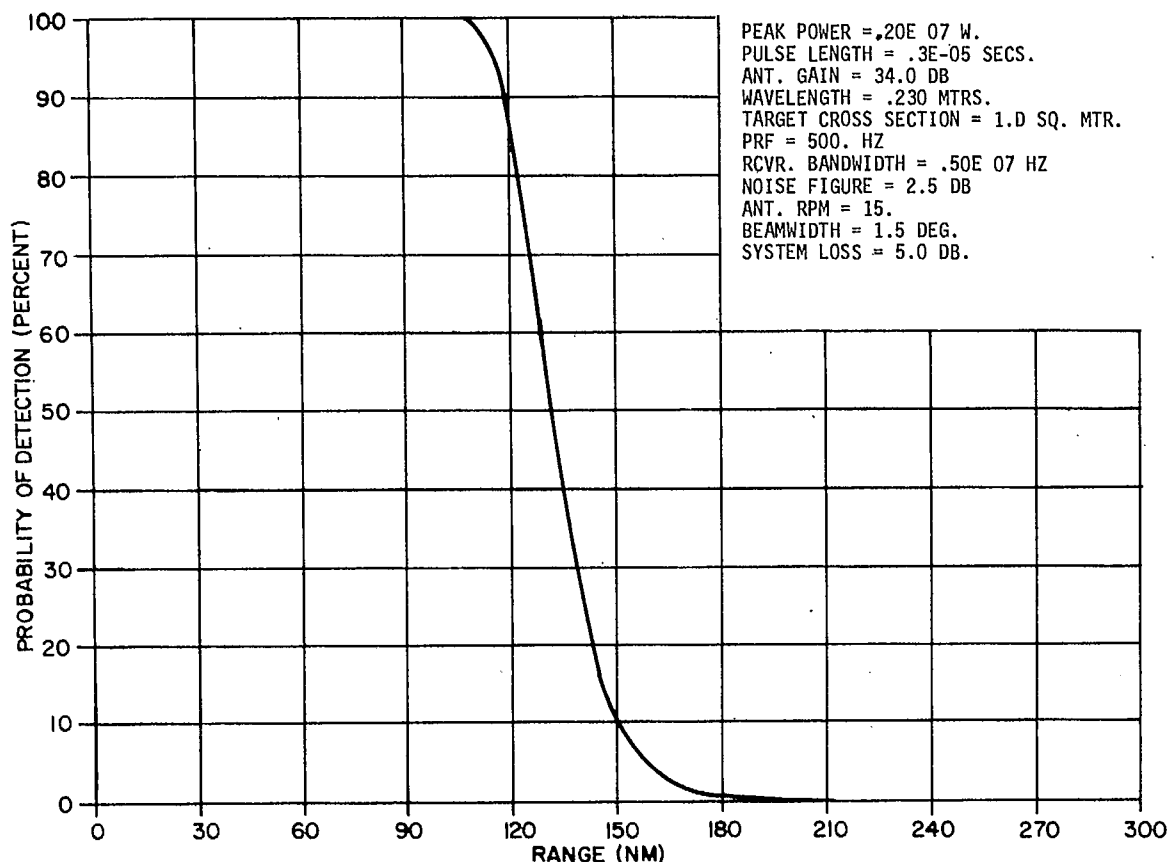
PEAK POWER = .20E 07 W.
PULSE LENGTH = .3E-05 SECS.
ANT. GAIN = 34.0 DB
WAVELENGTH = .230 MTRS.
TARGET CROSS SECTION = 1.D SQ. MTR.
PRF = 500. HZ
RCVR. BANDWIDTH = .50E 07 HZ
NOISE FIGURE = 2.5 DB
ANT. RPM = 15.
BEAMWIDTH = 1.5 DEG.
SYSTEM LOSS = 5.0 DB.

*Fig. 6. Probability of detecting a 1 m² target
with a typical heavy terminal radar.*

6. CPN-4 INADEQUACY FOR HIGH-LEVEL CONTROL

Of great concern at Lahr is the inability of the CPN-4 radar to control aircraft of small radar cross section in the airspace above 20,000 feet. In particular, the initial holding fix for a high level approach to runway 03 at Lahr is at 20,000 feet and 10 nm. Simple trigonometry shows that this corresponds to a look angle of approximately 18° upward from the terminal radar. The gain of the antenna used with the CPN-4 varies approximately as $csc^2 \phi$, where ϕ is the elevation angle. Clearly the strength of a radar return, based on a two-way path, varies as the fourth power of csc ϕ. The CPN-4 antenna was designed to yield a cosecant-squared pattern up to 30° elevation. Figure 7 has been plotted to show the resulting decrease in received power from targets at high angles. It is readily seen that a target at 18° elevation suffers a two-way loss of 26 dB, relative to a target in the nose of the beam. Reference to Figs. 4 and 5 indicates that such a target will be only marginally detectable with the CPN-4 installation, and confirms that the primary reason for this poor result is the cosecant-squared antenna pattern. It should be noted that the use of normal Sensitivity Time Control will substantially increase this loss.
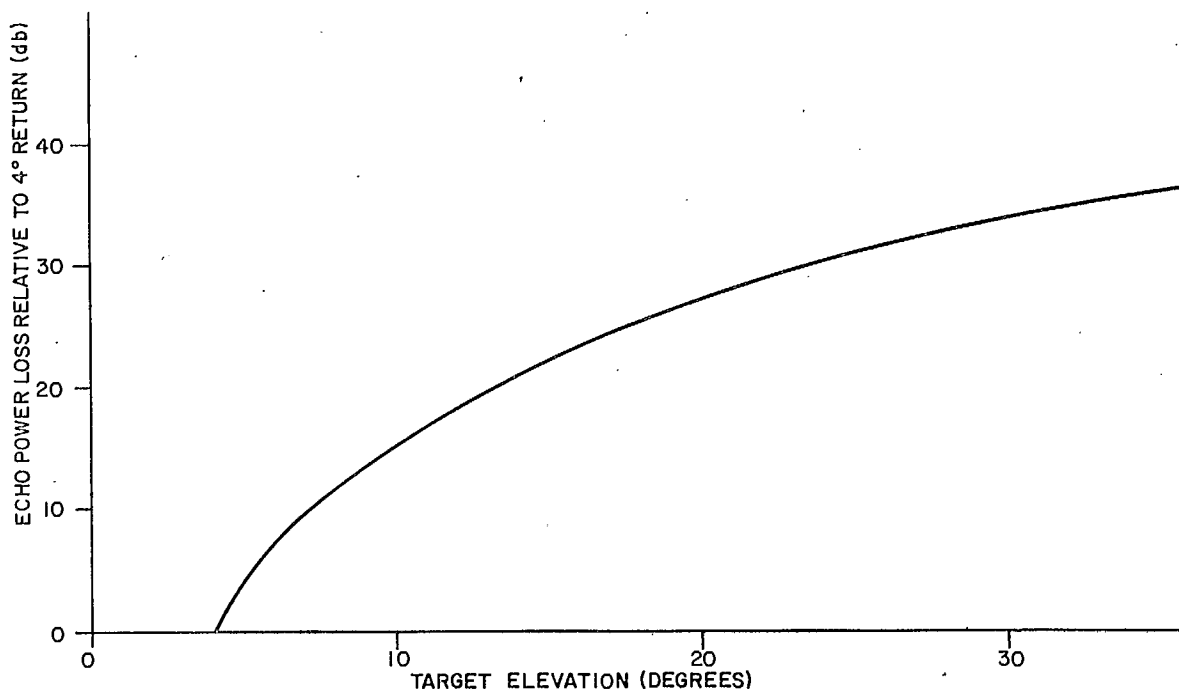
*Fig. 7. Power loss versus target elevation
for ideal cosecant-squared antenna.*

The cosecant-squared antenna is designed to yield a strength of target return which is independent of range for aircraft operating at fixed altitudes. This means that if an aircraft at 27,000 feet cannot be seen at 30 nm, it will theoretically still not be seen at 15 nm, provided that it remains at the same altitude. This is not a potential problem at civilian terminals, since high altitude civil traffic entering the control zone for landing *invariably* execute enroute descents, leaving the high level airways many miles from the airport. Military fighters, on the other hand, normally cross the approach facility (in the vicinity of the CGA) at 20,000 feet or above, then carry out a 'penetration' within a few miles of the airfield. Holding, if required, is carried out at high altitude due to the fighter's limited fuel resources. Clearly, while the cosecant-squared antenna is useful for civilian terminal control or long range radars, its use with short range equipment which is required to follow jet fighter activity in a military terminal is not desirable unless the search radar is powerful enough to provide good coverage above 25,000 feet.

7. RADAR COVERAGE OF BREMGARTEN AND SOLLINGEN FROM LAHR

It is probable that any new radar installed at Lahr will be required to provide ATC service to the Canadian base at Sollingen, and possibly also to the German base at Bremgarten. Figure 8 is an earth profile chart which has been prepared to show the principal terrain features affecting these two paths. It can be seen that the hill known as the Kaiserstuhl blocks radar coverage below

PROFILE
BASED ON 1.33 X EARTH'S RADIUS
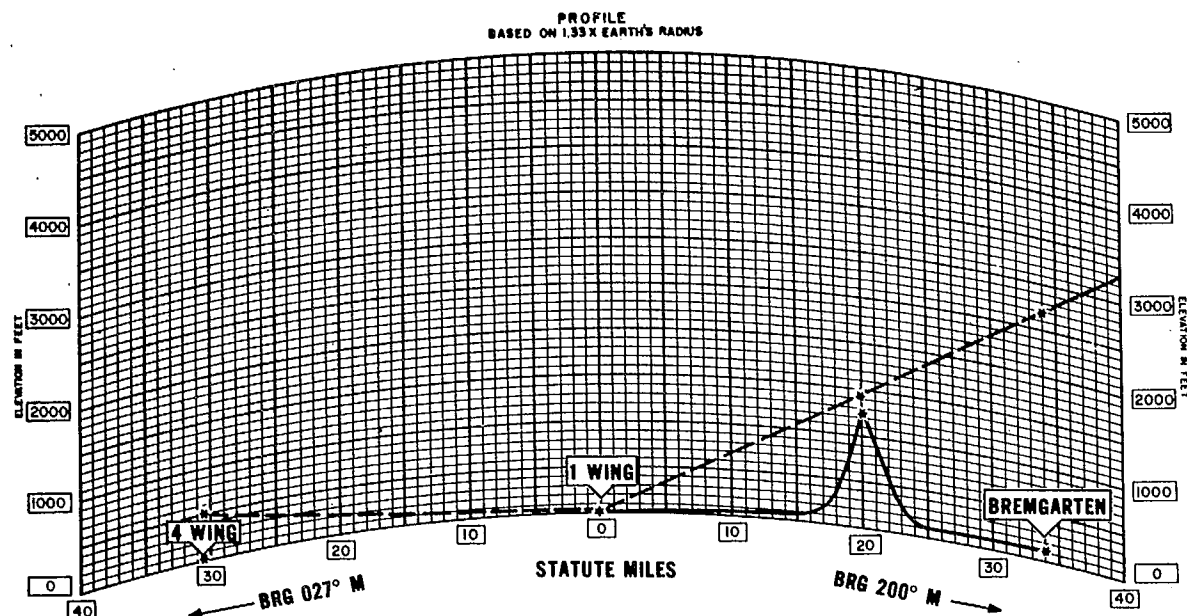
Fig. 8. Terrain profile in the Rhine Valley.
The plot is centered on Lahr.

about 3200 feet above sea level. For purposes of predicting this path, the direct ray is assumed to clear the peak of the Kaiserstuhl by 180 feet, corresponding to the first Fresnel zone for L band.

Propagation from Lahr to Sollingen is limited by the earth's curvature, if the radar antenna is sufficiently high for its beam to clear near-in obstacles. It should therefore be possible to detect aircraft shortly after take off at 4 Wing.

Depending on the degree of control which the Lahr radar will be required to exercise over 4 Wing airspace, other profiles will be necessary to predict coverage of aircraft in the various phases of the landing pattern.

It is likely that radar coverage of the Rhine Valley from Lahr will suffer because of multipath effects. The division of the free-space vertical antenna pattern into lobes, due to interference between the direct ray and ground reflection, is well known. Less generally appreciated is that a similar effect can occur in the horizontal plane where a radar is located close enough to a ridge so that both target and ridge are illuminated by the antenna beam simultaneously. In order to have a serious effect, the obstruction must extend for a distance in a direction roughly parallel to a line joining radar and target. The geography of the Rhine Valley suggests such a situation. The position of the radiation maxima and minima are fixed by the location of the radar relative to the valley wall, but the relative magnitude of the spatial fluctuation is a function of the azimuthal angle of the antenna beam, amongst

other things. The effect of horizontal lobes will thus be to decrease the effective number of pulses returned from a target in a null region, and hence reduce the probability of detecting that target. When both horizontal and vertical lobe structures are combined, it will be appreciated that an extremely complex pattern results. It is most likely that frequency diversity would be of benefit in ensuring good radar coverage within the Rhine Valley.

8. CONCLUSION

Geographical and operational features of the Lahr radar coverage area have been investigated briefly. Ground clutter strengths have been measured at both 1 Wing and 4 Wing and related, in the former case, to expected radar performance.

The CPN-4 radar was originally designed for Ground Controlled Approach applications at a time when the majority of aircraft operated at relatively low speeds and altitudes. The search portion of this system has since been employed as a terminal control radar by the Forces of Canada and other nations. While this application has been marginally successful at a number of sites, unacceptable performance results where physical and operational factors are demanding. The deficiencies of the older radar equipment are so fundamental that it is not reasonable to alleviate them by modification programs. In recognition of this, the Department of National Defence replaced the CPN-4 equipment at Lahr with a modern terminal control radar during the summer of 1970.

9. REFERENCES

1. *1 Air Division 2781-2 (COMD)*. 4 September 1969.

2. Smith, F.E. and F.R. Cross. *Private Communication*. February 1968.

3. Skolnik, M.I. *Introduction to Radar Systems*. McGraw-Hill, New York, 1962.

4. Marcum, J.I. *A Statistical Theory of Target Detection by Pulsed Radar*. Rand Research Memo. RM-754, December 1947.

5. Swerling, P. *Probability of Detection for Fluctuating Targets*. Rand Research Memo, RM-1217, March 1954.

APPENDIX A

Figures Al and A2 show the ground clutter levels encountered with the CPN-4 radar at 4 Wing. The method used in obtaining these pictures was as described in the body of this report for Lahr.
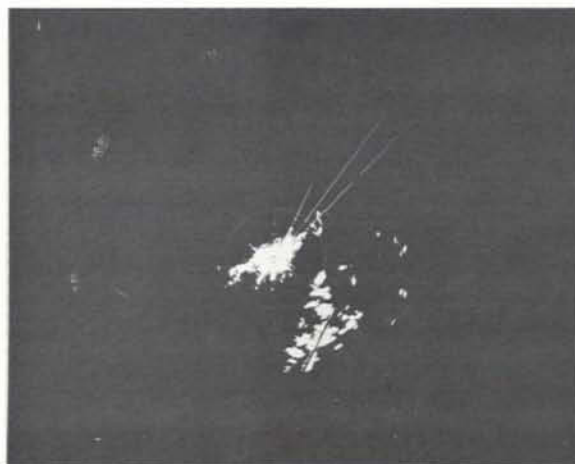
The clutter levels are seen to be comparable to those encountered at Lahr, and remarks made previously apply here.
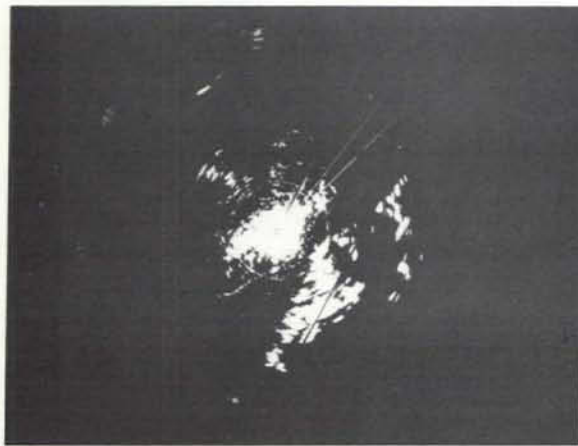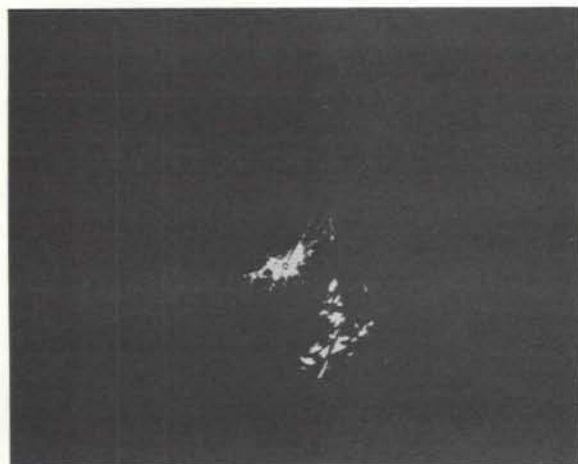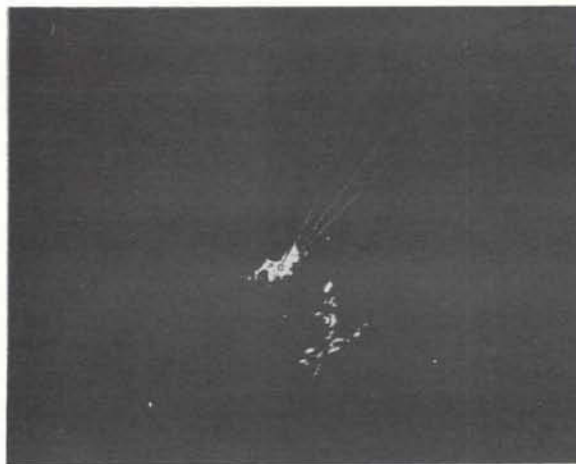

0 dB ATTENUATION

10 dB ATTENUATION

20 dB ATTENUATION

Fig. A-1. Clutter signal strength at 4 Wing (PPI range = 20 nmi).

30 dB ATTENUATION

40 dB ATTENUATION

50 dB ATTENUATION

Fig. A-2. *Clutter signal strength at 4 Wing (PPI range = 20 nmi).*