A graduate project submitted in partial satisfaction of the requirements for the degree of Master of Science in Engineering.

by

Roger Alan Lucic

May, 1975
The graduate project of Roger Alan Lucic is approved:

Committee Chairperson

California State University, Northridge

May, 1975
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>iv</td>
</tr>
<tr>
<td>PREFACE</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vii</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td></td>
</tr>
<tr>
<td>I INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>II PROCEDURE</td>
<td>6</td>
</tr>
<tr>
<td>Check-out of the Missile Test Bench</td>
<td>6</td>
</tr>
<tr>
<td>Captive Flight Data Analysis</td>
<td>9</td>
</tr>
<tr>
<td>Laboratory Clutter Simulation Investigation</td>
<td>15</td>
</tr>
<tr>
<td>Clutter Effects on Guidance Subsystem</td>
<td>18</td>
</tr>
<tr>
<td>III RESULTS</td>
<td>20</td>
</tr>
<tr>
<td>Missile Test Bench</td>
<td>20</td>
</tr>
<tr>
<td>Theory of Clutter</td>
<td>25</td>
</tr>
<tr>
<td>Captive Flight Data Analysis</td>
<td>29</td>
</tr>
<tr>
<td>Laboratory Clutter Simulation Investigation</td>
<td>31</td>
</tr>
<tr>
<td>Clutter Effects on Guidance Subsystem</td>
<td>34</td>
</tr>
<tr>
<td>IV CONCLUSIONS</td>
<td>36</td>
</tr>
<tr>
<td>V BIBLIOGRAPHY</td>
<td>38</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Data Link Message Digital Bits</td>
</tr>
<tr>
<td>2</td>
<td>Data Link Message Generator Connection Diagram</td>
</tr>
<tr>
<td>3</td>
<td>Target Generator Block Diagram</td>
</tr>
<tr>
<td>4</td>
<td>Captive Flight Test Geometry</td>
</tr>
<tr>
<td>5</td>
<td>SIM's Recording Block Diagram</td>
</tr>
<tr>
<td>6</td>
<td>Spectrum Analysis Equipment Block Diagram</td>
</tr>
<tr>
<td>7</td>
<td>Target and Clutter Generator Block Diagram</td>
</tr>
<tr>
<td>8</td>
<td>Two Target Test Equipment Block Diagram</td>
</tr>
<tr>
<td>9</td>
<td>Clutter Test Equipment Diagram</td>
</tr>
<tr>
<td>10</td>
<td>Missile Response to Data Link Message Pulse</td>
</tr>
<tr>
<td>11</td>
<td>Missile Velocity Tracking Response</td>
</tr>
<tr>
<td>12</td>
<td>Missile Angle Tracking Response to a Two Degree Target Shift</td>
</tr>
<tr>
<td>13</td>
<td>Clutter Geometry</td>
</tr>
<tr>
<td>14</td>
<td>Typical Actual Side-Lobe Clutter Spectra</td>
</tr>
<tr>
<td>15</td>
<td>Typical Simulated Clutter Spectra</td>
</tr>
</tbody>
</table>
In July 1974 CSUN (California State University, Northridge) initiated a Master of Science degree program at PACMISTESTCEN (Pacific Missile Test Center), formerly the Naval Missile Center, Point Mugu. The masters program, a combined effort of PACMISTESTCEN and CSUN, consisted of 20 hours a week of classroom work and 20 hours a week of work experience. Each participant in the program was assigned a project, to be completed in one year, to fulfill the requirement for the work experience. This paper reports the results of my assignment.

The subject of this work assignment was to construct a laboratory test bench for the PHOENIX missile and to determine the effects of clutter on the missile. The PHOENIX is one of the Navy's newest missiles. Most of the actual results and the details of how the missile works are classified. This report, by necessity will be limited as to content. For this reason, at times, if information is not presented and details of the results are not given, the reader's understanding is solicited.

I would like to extend my thanks to the staff at PACMISTESTCEN for making it possible for me to participate in this program. Although it took the hard work of many people at PACMISTESTCEN to make the program possible, I would like to personally thank Mr. Thad Perry for his insight, as to the need for this program, and his determination in starting the program. I would also like to thank
my Division Head, Bob Fries, for his willingness to let me take a year away from my regular assignment to participate in this program; David Barthuli for his "therapy sessions" when things would just not go right during the testing; Joe Eichblatt and Yoshitaka Sakazaki for their help in preparing the final report; Larry Sellers for his help in background research; Claudia Siebert for staying within the blue lines; and finally Dr. Zrnic of CSUN for his help during this project.

Last, but not least, thanks to Carol, for her understanding during the time I was working long hours on this assignment. She was a great help in correcting the final report, although complaining that she did not understand any of it.
ABSTRACT

PHOENIX MISSILE DEFICIENCY
TESTING AND ANALYSIS

by

Roger A. Lucic

Master of Science in Engineering

May, 1975

This graduate project presents guidance subsystem deficiency investigations performed on the PHOENIX missile. The PHOENIX missile, an air-to-air radar guided missile, was tested in an especially prepared laboratory test bench. A side-lobe clutter study was conducted to determine the cause of problems detected in the look down environments during captive flights. This report describes the laboratory missile test bench development, the side-lobe clutter test and presents the subsequent results.
CHAPTER I
INTRODUCTION

The PHOENIX missile is a long range air-to-air guided weapon for simultaneous attack from the Navy F-14 air superiority fighter against multiple target. The PHOENIX has been in development and testing since 1962 and underwent fleet introduction in the summer of 1974. The PHOENIX's mode of guidance is to track the target in velocity (doppler). If a CW (continuous wave) signal of frequency $f_0$ is transmitted and reflected from a moving target, the frequency $f_0$ is shifted by the amount $\Delta f$. The new frequency, $f_0 + \Delta f$, is called the doppler frequency. This doppler frequency can be related to the velocity of the target by the following formula:

$$f_d = \frac{2V f_0}{c}$$

were: $f_d$ = doppler frequency $= f_0 + \Delta f$

$f_0$ = transmitted frequency

$c$ = velocity of propagation

$V$ = relative velocity of target with respect to radar

As the relative velocity of the target changes with respect to the transmitting radar, the doppler frequency changes. The missile identifies and keeps a receiver tuned to the desired doppler shifted signal which is varying in frequency. When the missile is properly "velocity tuned" to the target, angle tracking of the target is enabled. Angle tracking results in generation of steering commands to the flight control subsystem and pointing commands to the missiles.
antenna to keep it aimed at the target.

The purpose of this graduate project was to complete the check-out of the PHOENIX missile laboratory test bench and to perform guidance subsystem deficiency investigations.

The missile test bench represents the near-ultimate in accessibility to missile components while retaining the missile functionally intact. The missile is broken down as close as possible to breadboard form without violating the shielding integrity of sensitive units or introducing extraneous noise. Subsystem, printed circuit board, and in some cases component level signals are accessible for signal tracing and quality evaluation of processing techniques mechanized in the missile hardware.

The missile test bench was in the final stages of construction when this project was started. Final check-out of the missile was needed to ensure that it was fully working and that it meet all applicable specifications.

Tail-chase captive flight tests have shown some problems in the look-down environment. When a missile is in this environment the transmitted signal is not only reflected from the target but also from the surface of the land or sea. This reflected signal is called clutter. Normally, for a doppler tracking missile, the reflections off the land or sea surface are so much lower in doppler frequency than the target return that land or sea clutter does not effect the missiles target tracking ability. But in the tail chase environment, the target return, can have a low enough doppler frequency so that clutter can start to effect the missile tracking ability. Actually,
there are two types of clutter returns from the sea or land surface. The first type of clutter return is called main-lobe clutter. The second type of clutter return is called side-lobe clutter. A typical antenna radiation pattern is of a $\sin x / x$ type. The largest lobe of this curve is considered the main-lobe and all the smaller lobes are considered the side-lobes. Since the main-lobe contains most of the power, its clutter return is strong. Since the side-lobes contain less power than the main-lobe, its clutter returns are weaker. However, there are many side-lobes covering a large angle, so clutter returns are spread over a wide frequency range. Theoretically, side-lobe clutter has always been modeled as white noise. Analysis of the SIM's tapes was done to see if this was a good approximation. Careful studies were done to make sure all assumptions made concerning clutter could be justified.

The problem was that the missile has some limitation due to clutter. This clutter problem is not well defined, in that it is not known to what degree the missile is affected. A study was needed on the different guidance unit subsystems to determine how and to what degree each was affected by clutter.

A significant amount of clutter data has been gathered during the SIM (specially-instrumented-missile) captive flight tests. Spectral analysis of the clutter data was performed to determine an actual clutter "signature" for the specific captive flights flown. The specific spectrum was duplicated by standard laboratory equipment. The spectrum was presented to the missile as a static worst case "snapshot" of clutter. The missiles limits and capabilities
in a high clutter environment were defined by studying in detail the
effect clutter had on the guidance signals processing circuitry.

Questions that were answered by this study are:

1. What kinds of clutter signatures are seen by the
missile in flight?

2. How and to what degree are the different subsystems
of the guidance signal processing circuitry affected by clutter?

3. What is the subclutter visibility of the missile?

4. How close to main lobe clutter can the missile track
a target of various amplitudes?

5. How close to main lobe clutter can the missile lock on
to a target signal of various amplitudes?

The major assumptions that are made or supported by the work
are:

1. The results obtained by the study will have some
correlation to what would happen in the "real world".

2. What is recorded on the SIM tapes have some correlation
to what the missile saw in flight.

3. That a good clutter model can be found by analyzing
the SIM's tapes.

4. That this clutter model can be mechanized with standard
laboratory equipment.

The relationship between: "real world" clutter; the clutter
spectrum recorded on the SIM's tapes; and the clutter spectrum pre-
sented to the lab missile needs to be well defined. A careful study
of all these relationships was done to make sure that the results of
the laboratory tests reflect the results of what would happen in the "real world". Laboratory test results were compared to flight tests where possible.

Since clutter changes for different terrain and sea states, and different altitudes, only the conditions that are available on SIM's tapes can be analyzed. Thus, this study will not try to generalize the missile performance to clutter in general. The study will only be conducted for the conditions during which the SIM's tapes were recorded.
CHAPTER II

PROCEEDURES

Check-out of the Missile Test Bench

When work was started on this study the bench was in the final stages of construction. The missile was disassembled (i.e. Radome removed, outer metal shell taken off) to a point where the five sub-assemblies could be separated. The five subassemblies are; seeker head unit, transmitter-receiver unit, electronic unit, control unit, and electrical conversion unit. Each of these separate units was mounted to a bench. New interconnecting cables were fabricated to connect the units together. A missile control console contained the necessary switch functions and power supplies to activate and control the operation of the missile. Also, many common test points were brought out to display lights and BNC jack in the control console.

The first test needed was to check for any wiring errors. Next, the missile requires a series of data link messages in order to operate. A data link message is a group of digital bits (Figure 1) containing a number of commands that is transmitted to the missile. One of the commands to the missile is to "turn on" its front receiver and accept target information. A data link message generator had been built but it had never been tested on the missile. Therefore, the next test was to determine if the missile would accept the data link message and respond to it correctly. The data link message generator was connected to the missile as shown in Figure 2. Various different data link messages were sent to the missile. The responses
Figure 1 - Data Link Message Digital Bits
Figure 2 - Data Link Message Generator Connection Diagram
of the missile to these messages were recorded on a strip chart recorder.

Next, a target generator was constructed as shown in Figure 3. The target generator consists of a very stable X-band frequency source (either an external oscillator or the missile's own internal frequency source), a doppler generator, and a TDRF (target doppler reference frequency) generator. The rear signal out in Figure 3 goes to the rear receiver of the missile. The TDRF signal (generated by a TWT amplifier and a sawtooth generator) and the rear signal are used to initially tune the missile to the proper doppler frequency. Tests were performed to determine if the missile would track the target signal in doppler and angle. The missile was placed in one end of an anechoic chamber and a target horn in the other. The missile was locked to an initial target frequency. Then this frequency was slowly increased and decreased while monitoring the missile velocity tracking circuits to determine if it responded correctly. Next, the single horn was replaced by two horns which were separated by two degrees. The target signal was shifted from one horn to the other while the missile angle tracking response was monitored. Finally the target signal was decreased to determine at what power level the missile lost lock.

Captive Flight Data Analysis

On 27 November 1974, and 3 and 5 December 1974 three SIM captive flights were conducted. The basic flight geometry was a shown in Figure 4. The missile was carried on the launch aircraft. The TCA (track crossing angle), from the nose of each aircraft, was twenty
Figure 3 - Target Generator Block Diagram
Figure 4 - Captive Flight Test Geometry

Simulated Launch Point

Launch Aircraft

4 Miles Separation

Target

35°

20°

Note: Target performs a 6G maneuver 6 seconds after simulated launch of the missile.
degrees. Six seconds after simulated missile launch, the target did a 6G turn into the launch aircraft. The basic purpose of the flight was to collect side-lobe clutter data. The SIM tape recorder records a mixed down version of the missile's IF (Intermediate Frequency). Thus what the missile "saw" was recorded on tape. Actually, two channels of IF information (wide and narrow) are recorded as shown in Figure 5. The wide channel has a IF bandwidth of 50 kHz and the narrow channel has a 6 kHz bandwidth. Spectral analysis was performed on these two channels to determine the clutter to target signal ratio necessary to cause the missile to drop track.

Spectral analysis was performed to determine the characteristics of clutter. Figure 6 is a block diagram of the equipment set up used to perform these tests. The captive flight tapes were played into the model UA-6A Ubiquitous Spectrum Analyzer, which is capable of fourier-analyzing all frequencies within a selected frequency band. This analysis was performed in real time on continuous signals, enabling the complete spectrum of a dynamic process to be observed. The output of the spectrum analyzer was averaged for either 250 milliseconds or 500 milliseconds. The averager was a high resolution digital device which accumulates the short term spectra (produced by the UA-6A Ubiquitous Spectrum Analyzer) and obtains the mean spectrum characteristics in real time. The averaged output was then recorded on a X-Y plotter. This procedure was repeated for each run (8 to 10 runs per flight) that was of interest for all three flights.
Figure 5 - SIM's Recording Block Diagram
Figure 6 - Spectrum Analysis Equipment Block Diagram
Laboratory Clutter Simulation Investigation

Three techniques for clutter simulation were investigated. The first was to simulate the clutter at the missile's IF frequency. For the PHOENIX missile this was not feasible. The second method was to translate the information on the SIM's tape to "X" band but it was found to be impractical in the time frame of this project. The third technique, which was used to simulate clutter, was to use standard laboratory equipment as depicted in Figure 7. The incoming X-band signal was split. One of these split signals was AM modulated using band limited white noise to simulate the clutter signal. The other signal was doppler shifted to simulate the target signal. Both these signals were sent to separate horns (separated by 2°), and then transmitted to the missile. Another test that was performed was to determine if or to what degree the missile was affected by signal outside the band of doppler information that the missile accepts. The equipment set up was as depicted in Figure 8. Two target signals were offset from each other by 10 kHz. The missile was locked to one of these signals. The other signal was set to as high a power level as possible. Then the target signal that the missile was tracking was decreased to determine the minimum lock point. This process was viewed on the Ubiquitous Spectrum Analyzer. The spectrum analyzer monitored the IF of the missile. The point where the missile lost lock was then compared to the minimum lock point that was found when no other signal was present. This test was repeated with the target signals 1 kHz apart (both signals were within the acceptance band of the missile). The target signal levels were adjusted to determine
Figure 7 - Target and Clutter Generator Block Diagram
Figure 8 - Two Target Test Equipment Block Diagram
when the missile will change track from one target signal to the other.

**Clutter Effects On Guidance Subsystem**

This section is the final step in this project. The configuration for this series of tests is shown in figure 9. The missile was tested in an anechoic chamber. The target and clutter signals were transmitted from two different target horns to the missile. Different levels of target signals and clutter signals were transmitted while the AGC, target lock, angle tracking, and velocity tracking circuits were monitored to determine the effect clutter has on the missile.
Figure 9 - Clutter Test Equipment Diagram
CHAPTEr III
RESULTS

MISSILE TEST BENCH

A wiring error (a ground wire was misplaced) caused the failure of two regulators in the seeker head unit of the missile. Replacement regulators were ordered and installed. The seeker head unit was then found to be in working order. No other wiring errors were discovered.

The results of the initial testing on the data link message generator indicated an error in the format of the message. The output of the generator was high until the pulse train came along. After the pulse train was finished the output would remain high. This had to be changed to just the opposite. The output of the data link message generator has to be low until the pulse train comes along, then go positive for each pulse. After the final pulse, the output must again stay low. The change was accomplished by running the clock signal and the message pulse signal through a nand gate. The output of the nand gate was sent to the strobe input (previously only the clock signal went to the strobe input) of an 74151, which is an 8 line to 1 line data selector/multiplexer. Negative pulses on the strobe input enable the 74151 and clock out the separate inputs sequentially. The message pulse signal only goes low when a message should be sent. So if the message pulse signal is nanded with the clock signal (which clocks the separate pulse of the message out) then the 74151 is enabled only when a data link message should be sent. After the change was implemented
the missile would accept the missile messages and respond to them correctly. Figure 10 is a graph depicting the front "receiver on" command with the timing of the data link missile message. If the missile responds correctly to a data link message then the front receiver on pulse (bottom trace, Figure 10) should occur a short time after the message pulse (top trace).

Next, the missile's antenna was placed at one end of an anechoic chamber with the two target signal horns at the other end (Figure 8). The missile was activated. The TDRF was used to pretune the missile's velocity tracker to a 30 kHz doppler. The missile was then transferred to the simulated launch mode. A target doppler signal of 30 kHz was transmitted via one of the horns to the missile. The missile detected and locked to the 30 kHz doppler of the target signal. Next, the target signal was swept up 20 kHz to a new doppler frequency of 50 kHz, then down 40 kHz to a doppler frequency of 10 kHz. During this time the analog velocity tracking signals were recorded as shown in Figure 11. Judging from this signal, the missile was able to track a target in velocity. Next, the missile was locked to a target signal coming from one of the horns in the anechoic chamber. The signal was then shifted to the other horn (which is offset by two degrees). The voltage from the pick-off pots on the seeker antenna was monitored. This voltage is the analog of the position of the antenna. Figure 12 depicts how this voltage shifted when the target signal was shifted. Thus, the missile was tracking the target in angle. Finally, the target signal was decreased until the missile lost lock. It was determined that the missile would track the target signal down to the specified minimum tracking power level. The minimum lock point
Figure 10 - Missile Response to Data Link Message Pulse
Figure 11 - Missile Velocity Tracking Response
Figure 12 - Missiles Angle Tracking Response to a Two Degree Target Shift
was found to be the same for each target horn.

Theory of Clutter

Some approximations about clutter that have been researched from the available literature are given below. This information, along with the information contained on the SIM's clutter tapes, was used to derive a clutter model. The assumptions derived from the literature will be presented in this section. The results of the analysis on the SIM's tapes will be presented in the next section. The combined information from these two sections will be integrated to form the clutter model as detailed in the third section.

Picquenard\(^1\) indicated the following assumptions could be made concerning clutter:

1. The frequency of the clutter will not be modified by reflection or refraction.
2. The phase of the clutter will be the phase difference introduced by reflection.
3. The greater the irregularities of the reflecting surface, the smaller the reflection coefficient.

Skolnik\(^2\) stated that:

1. The chief difference between clutter and other fundamental limitations to radar performance (i.e. receiver noise) is that correlations often exist between successive radar echos from clutter.


The clutter spectrum can be computed by assuming that the surface is composed of many independent scatterers (with cross section defined by \( \sigma_0 \) and summing the contribution of each along isodop (curves of constant doppler) curves. If it can be assumed that the geometry is monostatic (transmit and receive antenna at same point), then the isodops become conic sections, otherwise the isodops are higher order polynomials which make clutter computations almost impossible.

The geometry of the clutter return is given in Figure 13. With reference to Figure 13, the generalized clutter spectrum can be computed by:

\[
W(f) = \frac{\int P_c \lambda^2 G_T(\theta) G_R(\theta) L_c h \sigma_0(\beta) dS}{(4\pi)^3 f_m R^4 \cos \beta \sin \phi}
\]

Where:
- \( P_c \) = centerline power transmitted
- \( \lambda \) = wavelength
- \( R \) = slant range
- \( G_T \) = transmitter antenna pattern
- \( G_R \) = receiver antenna pattern
- \( h \) = altitude
- \( L_c \) = total system losses
- \( f_m \) = maximum clutter frequency

To implement this equation it would be necessary to program it for machine computation. Then a large amount of computation would be required to describe the clutter environment for various attack geometries. Even if this was completed the manner in which the important factors affect clutter is not clear in this form. Thus, if we break the clutter into its three main parts a great deal of
Figure 13 - Clutter Geometry

\[ dS = dR \cos \beta \sin \phi \]
simplification is achieved without much loss in accuracy. The three areas are:

1. Peak mainlobe clutter spectral density \( W_{MLC} \)
2. Average sidelobe clutter spectral density \( W_{SLC} \)
3. Altitude return spectral density \( W_{AR} \)

The simplified expressions would then be:

\[
W_{MLC} = \frac{K \sigma_o (\beta) \Theta_b}{2 \text{ fm h}^2}
\]

\[
W_{SLC} = \frac{K \sigma_o \sin^2 \beta \eta_t \eta_r \pi (d_r(1-d_t/3d_r))}{2 \text{ fm h}^2}
\]

\[ d_r > d_t, \ d_r + d_t < 1 \]

\[
W_{AR} = \frac{K \sigma_o (90^\circ) \eta_t (90^\circ) \eta_r (90^\circ) \delta}{2 \text{ fm h}^2}
\]

Where: \( K = \frac{P_c G_t G_r \lambda^2 L_c}{(4 \pi)^3} \)

And in addition to the symbols defined previously:

- \( G_t \) = transmitter antenna gain
- \( G_r \) = receiver antenna gain
- \( \eta_t() \) = transmitter antenna relative gain
- \( \eta_r() \) = receiver antenna relative gain
- \( \Theta_b \) = two-way 3-dB antenna beamwidth
- \( \delta \) = 3-dB angular width of \( \sigma_o (\beta) \) about vertical incidence
- \( d_t \) = transmitter duty factor
- \( d_r \) = receiver duty factor

These expressions can be obtained from \( W(f) \) using either of the
following simplifying conditions:

1. The major contributor is confined to a relatively small area, defined by $\vartheta_b$ or $\delta$ because of the rapid falloff of the antenna gain or $\sigma_o (\beta)$, or

2. Replacement of $\sigma_o (\beta)$ by $\overline{\sigma}$ and $g_t (\Theta) g_r (\Theta)$ by $g_t g_r$ is possible in integrating over the isodop, where $\sigma_o (\beta)$ is relatively flat and the antenna sidelobe structure is fairly uniform.

Broken down into these three equations, the dependence of clutter on the various factors affecting its magnitude can be easily seen. It is seen that clutter varies inversely with the product $fm$ $h^2$ and the relative magnitudes of the three clutter areas are readily evaluated. With the use of these equations a graph can be made to depict how clutter level behaves with changes in various parameters.

Captive Flight Data Analysis

The analysis of the SIM's tapes resulted in a number of spectral cuts taken at a number of different points in time for each run for each flight. One of these spectra is depicted in Figure 14. (Frequency increases to the left due to the way the signal is recorded in the SIM). All of these spectra were used to determine what the typical clutter signal would look like as seen by the missile in captive flight. From these tapes it was determined that the clutter signal level was highly dependent on the look angle. Clutter signal levels were observed anywhere from non-existent to 10 db higher than the target signal. Insufficient data was available to determine the actual point where the missile would lose track of the target. However, it was determined that for clutter signals stronger than the
Figure 14 - Typical Actual Side-Lobe Clutter Spectra
target, the missile would lose track. The clutter signal was determined to be more peaked than expected from the theoretical studies. The cause was found to be the side-lobe structure of the illuminating antenna. The illuminating antenna had very deep and distinct nulls.

The rolloff of the clutter signal was difficult to determine. This was partly due to the peaked nature of the clutter signal and partly due to the noise level on the tape which at times was as strong as the signal. The peaked nature of the clutter signal made it difficult to determine if the rolloff was due to the side-lobe structure of the antenna or the actual rolloff of the clutter signal. The clutter signal was very weak on the tape. In some cases it was difficult to determine what was tape noise and what was actual clutter. Due to these limitations the clutter rolloff could only be roughly approximated to be between 12 db and 24 db per octave. It was also determined that the side-lobe clutter regions for these flights extended to approximately 10 kHz above zero doppler.

Laboratory Clutter Simulation Investigation

Several ways were investigated to recreate the clutter spectrum. The first was to recreate it at the missile IF frequency. This was not feasible because of the way the missile tracks a target. The PHOENIX missile shifts the frequency of the LO (local oscillator) in such a manner as to keep the doppler frequency constant. So when the doppler goes up in frequency, the LO is shifted down in frequency to keep the output of the front mixer at a constant frequency. Injection of the clutter and target signal at the missiles IF resulted in the missile not being able to continuously track either the target signal
or the clutter signal because any shift in frequency at this point could not be corrected by missile tracking circuits.

Another possible way to recreate the clutter signal was to up convert the clutter information in the SIM's tapes. The information would have to be up converted to "X" band for the reason stated above. This would require a great deal of specialized equipment which was not readily available, and it was not certain that the resulting spectrum would be a "true" representation of the original.

The third alternative was to recreate the clutter spectra using laboratory equipment. An "X" band signal was FM (frequency modulation) modulated. This was unacceptable because the resulting signal was not a true gausian noise signal. It was just a radome offsetting of the carrier. Since the FM process is not linear, there is no easy way to determine the spectral density of the resulting signal. Next, AM (amplitude modulation) modulation was attempted. This was an acceptable solution. The target and clutter generator was constructed as shown in Figure 7. The clutter signal generator consisted of a gausian noise source that was low pass filtered with bandwidth and rolloff characteristics of the clutter signal. Next, this band limited noise was sent to a pin diode modulator. The pin diode was used to AM modulate an "X" band signal. The resulting spectrum is depicted in Figure 15. Since the AM modulation process is linear up to 100% modulation, the noise envelope is gausian distributed. The modulated "X" band signal was attenuated to represent clutter level.

The target signal generator used the same "X" band signal as the clutter signal generator. By doppler shifting the same "X" band
Figure 15 - Typical Simulated Clutter Spectra
signal, the clutter signal is centered at zero doppler. Thus, the target signal can be positioned with respect to the clutter signal. This technique resulted in a clutter and target signals that fit the criteria generated in the previous two sections. The only possible exception was the peaked nature exhibited in the actual clutter signal as seen on the SIM's tapes. The peaked nature of the actual clutter signal was due to the type of radar used. It was felt that gaussian noise of the same average amplitude would be an acceptable simulation of clutter.

The results of the two target tests indicated that the minimum lock level was only reduced by 3 db when the two signals were separated by 10 kHz (one signal outside missile acceptance band). When the two target signals were set to 1 kHz separation (both within acceptance band), it was determined that it took only 3 db increase or decrease to get the missile to shift track from one target signal to the other. If the target signal that the missile was tracking was reduced by 3 db then the missile would shift track to the other target signal. When the target signal (the one the missile was not tracking) was increased 3 db then the missile would shift track to this signal. For both of these tests the relative doppler difference, not the absolute doppler, was what determined the results.

**Clutter Effects On The Guidance Subsystem**

In this last section the clutter simulation and target signals were presented to the missile. The clutter had a 3 db bandwidth of 10 kHz and a 24 db per octave rolloff. The doppler offset of the target signal was set to 5 kHz and then to 11 kHz. The missile was
locked onto the target signal. The clutter signal was increased until the missile would lose lock. When the signal to clutter ratio reached zero dB the missile would lose lock. This was true for both doppler offsets. The AGC level indicated a clutter level comparable to the target level before the missile lost lock. The angle tracking circuits were relatively unaffected by the clutter. At the point of lost lock the antenna would stay still. If the target signal was increased again, within a short time, the missile would relock to the target signal.
CHAPTER IV
CONCLUSIONS

It was concluded that:

1. The missile bench and all its peripherals are fully functional.

2. A typical actual clutter signature as seen by the missile in captive flight is depicted in Figure 14. The clutter amplitude is a function of look angle and missile altitude. The clutter 3 dB bandwidth was approximately 10 kHz and the rolloff was estimated to be between 12 to 24 dB per octave.

3. A reasonable approximation of the clutter signature is depicted in Figure 15. This approximate clutter signature was derived from assumptions researched from the literature and measurements made on the clutter spectrum from the SIM's tapes. An "X" band carrier was AM modulated with bandlimited gaussian noise. The simulated clutter amplitude was adjustable. The 3 dB bandwidth was set to 10 kHz and the rolloff was set to 24 dB per octave.

4. The missile is relatively unaffected by signals outside its band of acceptance. The minimum target signal level where the missile could still track was not affected by a very strong signal offset 10 kHz from the target signal.

5. When the signal to clutter ratio reaches zero dB then the missile is unable to track the target signal.

6. Other missile circuits (i.e., angle tracking, velocity
tracking) are unaffected by the clutter signal.

7. When there are two target signals inside the missile band of acceptance, the missile will lock onto and track the larger of the two.

8. The AGC level is controlled by the largest signal in the missiles band of acceptance.

9. The missile bench is an invaluable tool for laboratory testing of the PHOENIX missile.
BIBLIOGRAPHY


