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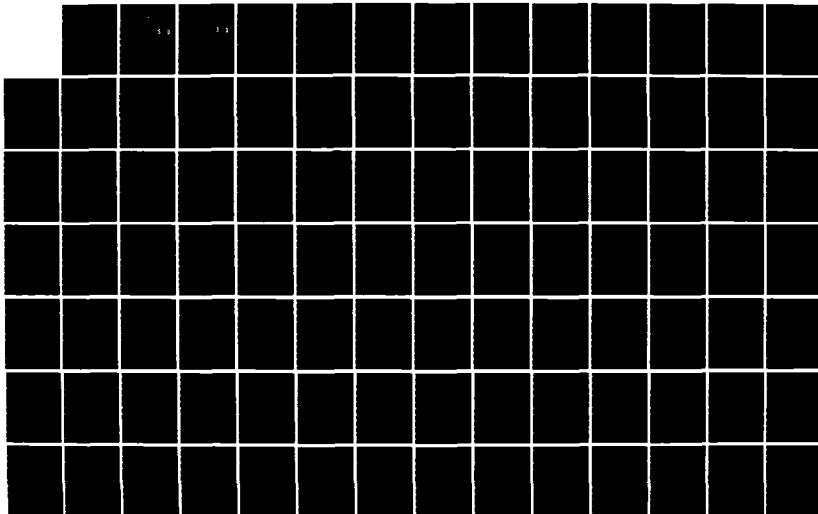
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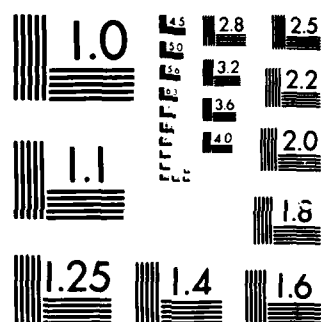
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THESIS

David G. Mazur
First Lieutenant, USAF

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SCATTERING MEASUREMENT FACILITY

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Electrical Engineering

David G. Mazur
First Lieutenant, USAF

December 1985

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Preface

The purpose of this thesis was to investigate the design methodology behind an automated scattering measurement facility. Perhaps the main benefit to the U.S. Air Force from this thesis was the establishment of an operating facility at the Air Force Institute of Technology (AFIT) WPAFB, OH. Being a student myself, the software from this thesis was written with students in mind. They should find the operation of AFIT's facility relatively easy, thus letting them concentrate more on the results of the measurements rather than the procedures.

I would like to thank some of the people who gave me direction and assistance throughout this thesis effort. First, I would like to express my appreciation to my thesis advisor, 1Lt Randy Jost, for his insight into RCS measurements and his patience throughout the whole year. I would also like to acknowledge 2Lt John Joseph for his assistance in the hardware configuration used in the chamber. He allowed me the luxury of being able to concentrate on the software side of the house. Also I would like to thank Jack Tiffany and his men at AFIT's Model Fabrication Shop for providing high quality professional help in the manufacture of the standard sphere and tunnels for the horn antennas. Finally I would like to thank my lovely wife, Sandy, for putting up with what seemed an endless series of sacrifices throughout the year and a half here at AFIT. Pau Hana.

David G. Mazur

Table of Contents

	Page
Preface.....	ii
List of Figures.....	v
List of Tables.....	vi
Abstract.....	vii
I. Introduction.....	1
Problem.....	2
Scope.....	3
General Approach.....	3
Sequence of Presentation.....	4
Historical Survey.....	4
II. Theoretical Background.....	7
Electromagnetic Theory.....	7
Background Cancellation.....	15
Communication Theory.....	22
III. Hardware.....	25
Anechoic Chamber.....	26
RF System.....	28
Positioning of Target.....	36
Data Acquisition.....	40
Interface/Bus Structures.....	42
Controller.....	47
Output Devices.....	48
IV. Software.....	49
Objective.....	49
System.....	50
Applications.....	50
V. Results and Discussion.....	57
Recommendations.....	59
Appendix A: Equipment List.....	63
Appendix B: Device's HP-IB Address and Capabilities.....	64

	Page
Appendix C: Software Description.....	65
Appendix D: Software Listing.....	80
Appendix E: Sample RCS Plots.....	93
Bibliography.....	96
Vita.....	98

List of Figures

Figure	Page
1. Relationship of Incident and Scattered Waves.....	8
2. Spherical and Plane Wave Fronts at the Scatterer.....	10
3. CW Cancellation Requirements.....	14
4. CW System Components.....	16
5. Vector Subtraction.....	17
6. RCS of Sphere.....	20
7. Error in RCS due to Background Reflections.....	24
8. AFIT's Anechoic Chamber.....	27
9. RF System.....	29
10. Waveguide Configuration.....	33
11. Limit Light Circuit.....	39
12. Multiplexer Terminal Card.....	41
13. HP-IB Connector Pin Designators.....	44
14. HP-IB Structure.....	45
15. HP-IB Message Format.....	46
16. Printer Output.....	54
17. Plotter Output.....	55
18. Main Program.....	65
19. Pplot Subroutine.....	68
20. RCS Subroutine.....	73
22. Flat Plate RCS.....	94
23. Corner Reflector and Sphere RCS.....	95

List of Tables

Table	Page
1. Scaled Parameters.....	13

Abstract

This thesis addresses the design methodology surrounding an automated scattering measurement facility. A brief historical survey of radar cross-section (RCS) measurements is presented. The electromagnetic theory associated with a continuous wave (CW) background cancellation technique for measuring RCS is discussed as background. In addition, problems associated with interfacing test equipment, data storage and output are addressed. The facility used as a model for this thesis is located at the Air Force Institute of Technology, WPAFB, OH. Even though this paper addresses a particular facility, the design methodology applies to any automated scattering measurement facility. A software package incorporating features that enhance the operation of AFIT's facility by students is presented. Finally, sample outputs from the software package illustrate formats for displaying RCS data.

DESIGN METHODOLOGY OF AN AUTOMATED SCATTERING MEASUREMENT FACILITY

I. Introduction

Since the advent of radar during WWII, builders of aircraft have attempted to circumvent the detection process by a variety of techniques. These have included everything from crude noise jammers to chaff. These countermeasures in turn have led to more sophisticated radars that attempt to negate any electronic countermeasures (ECM) with techniques such as phase encoded pulses and coherent detection. The electronic warfare (EW) community has also risen to its current level of technology employing digital radio frequency memories (DRFM) and sophisticated techniques attacking the processors of the modern radar.

The common thread that relates the performance of all radars is the radar cross-section (RCS) of the target. By exploring the radar cross-section of different targets in the laboratory environment, much insight can be gained on how to reduce the radar cross-section. Reducing the radar cross-section leads to a reduction in the maximum detection range of the radar. An automated scattering measurement facility provides the user the capability of quickly making the radar cross-section measurement, of storing radar cross-section data for future reference or comparison, and enhancing the repeatability of the measurement.

Much effort has been expended, and progress has been made on analytical techniques for establishing the RCS of specific targets. However, when one considers that there are only a few simple bodies where the exact solution of its electromagnetic scattering cross-section is known, the importance of experimentally establishing the RCS becomes apparent. While there are very good approximate solutions to many "simple" scattering problems, these usually break down at certain aspect angles and frequencies. Even with the present emphasis on these solutions, experimental results play a very important part in the development and verification of these solutions. More complicated targets, such as aircraft, often prove to be too complex for either exact or approximate solutions, and so experimental data becomes a very important avenue for collection of needed RCS data.

An anechoic chamber that is to be used primarily for measuring RCS will have stricter requirements than a chamber that is primarily used for antenna measurements. This is due to the two way path involved with RCS measurements. In a continuous wave (CW) system the background components of the return signal must be cancelled out so as to obtain the true RCS. One technique is to mix a properly adjusted portion of the transmitted signal with the received signal, such that the background signal is cancelled. At this point the target is placed into the chamber, being careful not to disturb the chamber in any manner, and an RCS measurement is taken.

Problem

The purpose of this study is to address the methodology involved

with the design of an automated scattering measurement facility and the problems encountered in this endeavor.

An automated chamber offers several advantages over a standard chamber. An automated chamber utilizes a computer as a controller to provide a way of extracting data automatically, processing the data and storing the radar cross-section data for future use. The stored data may then be retrieved at a later date for computer processing. Since all measured scattering data is relative data and frequently requires normilization and scaling to operational frequencies, receiving equipment capable of digital storage is highly desirable.

Scope

While design methodology is system independent, it will be examined in the form of a specific system. This study will be limited in scope to the anechoic chamber, with associated equipment, located at the Air Force Institute of Technology (AFIT), Wright-Patterson AFB, OH. More specifically, a near monostatic chamber whose primary purpose is as much educational as research orientated.

General Approach

The total design concept for a chamber of this nature can be broken down into two broad categories: Hardware and Software. Since hardware and software are intimately associated with each other, both topics will be discussed in this study. In addition, the system stability and sensitivity will be addressed, as measurement of low RCS targets is a major driving force of this chamber.

More specifically, the hardware topics will cover the following:

1. Chamber
2. RF System
3. Positioning of Target
4. Data Acquisition
5. Interface/Bus Structures
6. Controller

The software topics cover the following concepts:

1. Easy Start Up
2. User Friendliness
3. Menu Driven
4. Soft Keys/Default Values
5. CRT Viewing
6. Data Output
7. Plotting Multiple Data Sets
8. Error Trapping
9. Exit to BASIC

Sequence of Presentation

A historical survey of RCS measurement is presented to give the reader a perspective in the development of RCS measurements. In Chapter II the theory of RCS measurements is discussed in relation to a CW near monostatic system and what factors are involved when automating the system. The hardware and its associated problems will be covered in Chapter III with the software being discussed in Chapter IV. Results and discussion are presented in Chapter V with recommendations following in Chapter VI.

Historical Survey

To better prepare the reader to understand the concepts involved in RCS measurements, a brief historical survey is appropriate. Ever since the initial experiments with radio waves the phenomenon of scattering has been observed. As early as 1886, Heinrich Hertz showed

that radio waves could be scattered by both metallic and dielectric bodies. Skolnik [1:8] writes that a German engineer by the name of Hulsmeyer designed an "obstacle detector" that detected the scattering from ships. In 1904 he obtained patents in several countries, but the device was rejected by the German Navy. The technology of the day allowed a detection range of only one nautical mile; not much better than a visual observer.

Marconi, in a speech delivered to the Institute of Radio Engineers [2:215-238] in 1922, suggested the use of radio waves for detection of targets miles away. Marconi recognized the plausibility of designing an apparatus to "screen the receiver from the local transmitter." This concept is the basis for modern unmodulated CW RCS measurement techniques.

Work investigating the reflection and scattering of radio waves from the ionosphere led to two widely used techniques in RCS measurement. In 1925 Breit and Tuve [3:554-575] applied a pulse technique to measure the height of the ionosphere. In addition, Appleton and Barnett [4:333-334] used frequency modulation in their work with the ionosphere.

The first attempt to quantify RCS measurements occurred during World War II when radar was becoming more widely used. It came as no surprise that the people involved in the development of radar also became involved with RCS measurement. The M.I.T. Radiation Laboratory investigated the radar returns from operational targets such as aircraft and ships. As early as 1942 measurements of models in anechoic rooms were being made by the laboratory [5].

Military applications again provided the driving force behind the development of RCS measurements. Ohio State University (OSU) [6] established the first comprehensive RCS measurement facility to obtain aircraft RCS data for to use in the design of decoys to confuse radar operators. The OSU system [7:902] started out as a CW system utilizing a three element Yagi array inside a waveguide to achieve the required separation between transmitted and received signals. The Yagi array inside the waveguide had the same directivity as a many-element Yagi and was capable of a relatively high degree of isolation, albeit for a short period of time. The Yagi array was eventually replaced by a waveguide hybrid tee. This configuration, conceived during World War II, is still in use today.

Blacksmith [7:903] writes that within a few years following the end of World War II, CW measurements were being made by the Naval Research Laboratory, Evans Signal Laboratory, Air Force Cambridge Research Center and McGill University.

What was probably the first anechoic chamber designed well enough to allow accurate indoor measurement of low RCS targets was described in a 1956 report [8] by Upson and Hines of Ohio State University. It is from these roots that RCS measurements in anechoic chambers have risen. Today there are approximately 400 chambers in existence [9:484]. Most are involved with antenna measurements, but more and more are being designed and utilized as RCS measurement facilities.

II. Theoretical Background

Principles governing the radar cross-section measurements of a target are relatively few. These principles, when correctly applied in the design of an automated chamber, allow a high degree of quality in radar cross-section measurements.

These principles can be summarized as follows:

1) Electromagnetic theory. This includes the definition of radar cross-section, plane wave approximation, electromagnetic similitude and power relationships.

2) Background cancellation. This includes the techniques used to reduce the effects of clutter from the walls and leakage from RF components.

3) Communication Theory. This includes the errors caused by the background signals and their effect on the accuracy of the measured radar cross-section.

Electromagnetic Theory

Definition of Radar Cross-Section. The radar cross-section can be defined as [10:33]

$$\sigma(\theta, \phi, \theta_i, \phi_i) = \lim_{R \rightarrow \infty} 4\pi R^2 \frac{|\overline{S_r^s}(\theta, \phi)|}{|\overline{S^i}(\theta_i, \phi_i)|} \quad (1)$$

where R, θ, ϕ are spherical coordinates with the target not located at the origin (Fig. 1). $\overline{S^i}$ is the time average Poynting vector of the plane wave incident on the target from the direction θ_i, ϕ_i and $\overline{S_r^s}$ is the radial component of the scattered time averaged Poynting vector in

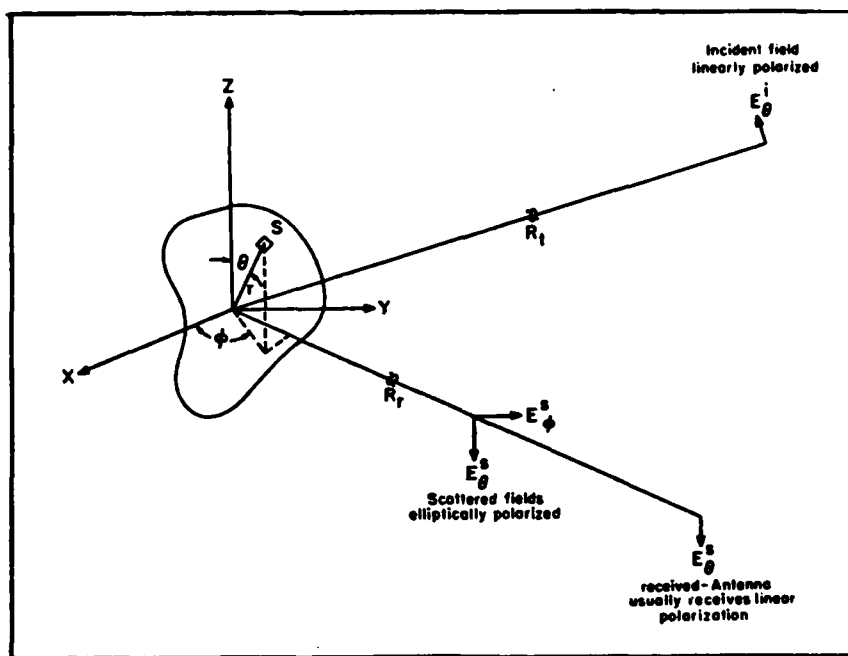


Fig. 1. Relationship of Incident and Scattered Waves

the direction θ, ϕ at the far field distance R from the target.

In AFIT's chamber, R is evaluated in the direction of the backscatter. Under these conditions σ is called the backscatter cross-section. If R was evaluated in any other direction it would be called the bistatic cross-section. If R is of sufficient distance (to be defined in a later section) the scattered wave will be planar and will have only transverse components. Therefore, using the definition for the Poynting vector [11:8]

$$\begin{aligned} S_r^S(\theta, \phi) &= [\text{Re } \hat{r} \cdot (E^S \times H^{S*})] / 2 \\ &= \text{Re} [E_\theta^S(\theta, \phi) H_\phi^{S*}(\theta, \phi) - E_\phi^S(\theta, \phi) H_\theta^{S*}(\theta, \phi)] / 2 \end{aligned} \quad (2)$$

where E^S and H^S are the scattered electric and magnetic fields and $\hat{r}$ is

the unit vector in the radial direction.

A typical target would generally take a linearly polarized incident wave and scatter a wave that is elliptically polarized. Since an elliptically polarized wave would contain both θ and ϕ components, both components would have to be measured to correctly define the radar cross-section of a particular target. For the purpose of this paper the definition will be limited to a preferred polarization, since most radars use the same polarization in both transmit and receive channels. Thus the definition of radar cross-section will be [7:903]

$$\begin{aligned}\sigma(\theta, \phi, \theta_i, \phi_i) &= 4\pi R^2 [W^s(\theta, \phi) / W^i(\theta_i, \phi_i)] \\ &= 4\pi R^2 [|E^s(\theta, \phi)|^2 / |E^i(\theta_i, \phi_i)|^2]\end{aligned}\quad (3)$$

where $E^s(\theta, \phi)$ is the scattered electric field (E-field) whose polarity is parallel to the polarization of the incident wave, $E^i(\theta_i, \phi_i)$. The power density associated with the scattered E-field is $W^s(\theta, \phi)$ and the power density associated with the incident E-field is $W^i(\theta_i, \phi_i)$. R is the distance from the scatterer in the far field. It should be noted that there are some targets, such as flat plates, that don't depolarize and Eq (3) would be the true radar cross-section.

Plane Wave Approximation. The phase and amplitude of the scattered wave from a target has a direct relationship to the incident wave. Since most targets are detected in the far field, an attempt is made to define this same area inside the anechoic chamber. The target is placed at a distance R that will guarantee, within prescribed limits, the incident wave will approach the characteristics of a plane

wave. In effect, that is saying that the measurement is independent of R .

To determine the minimum distance where this can be achieved, assume that a uniformly illuminated circular antenna with aperture of diameter D illuminates a target with a maximum dimension of L at a distance R . The far-zone field from this antenna and the plane wave field are [7:906]

$$E_a = [A_1 \exp(-jkR) J_1(\pi D \sin \theta / \lambda)] / (\pi D \sin \theta / \lambda) \quad (4)$$

$$E_p = A_2 \exp(-jkR)$$

where A_1 and A_2 are proportionality constants, λ is the wavelength, k is the propagation vector and $J_1(u)$ is the Bessel function of order one. In the design of a chamber, R is chosen such that E_a and E_p are the same over the area concerned within acceptable limits. When working with Eq (4) three minimum values of R are obtained. These are due to the transverse variation in phase (R_p), the radial variation in amplitude (R_{ra}), and the transverse variation in amplitude (R_{ta}).

From Fig. 2 the following information can be obtained.

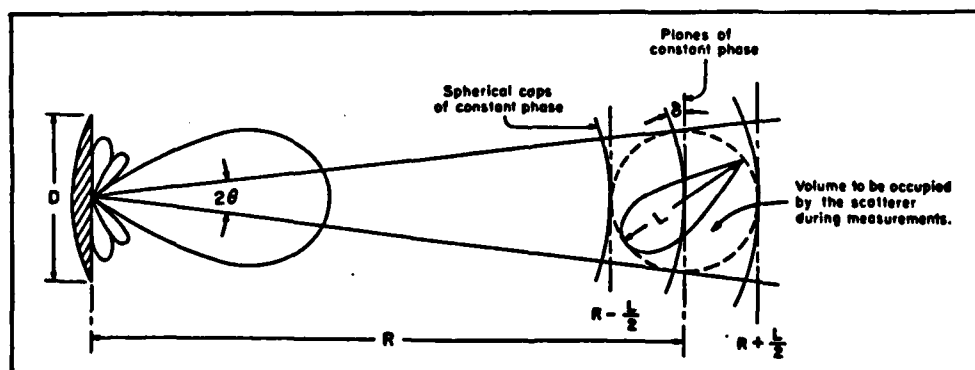


Fig. 2. Spherical and Plane Wave Fronts at the Scatterer

Let ϵ and δ represent the deviation from a plane wave for amplitude and phase respectively. From the geometry of Fig. 2

$$(R + \delta)^2 = (L / 2)^2 + R^2 \quad (5)$$

which leads to

$$R^2 + \delta^2 + 2R\delta = (L^2 / 4) + R^2 \quad (6)$$

$$\delta^2 + 2R\delta - (L^2 / 4) = 0 \quad (7)$$

if $R \gg \delta$ then Eq (7) can be approximated by

$$\delta = L^2 / 8R \quad (8)$$

or

$$R = L^2 / 8\delta \quad (9)$$

For the purpose of this paper the acceptable phase error will be 22.5 degrees which corresponds to a path difference of $\lambda/16$. Therefore R_p represents the minimum range that the target can be placed at and not have the phase error exceed 22.5 degrees over the target.

For the radial variation in amplitude

$$[E(R - L/2) - E(R + L/2)] / E(R) = \epsilon \quad (10)$$

combining Eqs (4) and (10)

$$R_{ra} = L / \epsilon \quad (11)$$

A typical value for ϵ might be 0.05. Therefore R_{ra} represents the minimum range where the target can be placed and the incident wave does

not vary by more than 5%.

The transverse amplitude variation, when the maximum target dimension is perpendicular to the direction of propagation, is

$$R_{ta} = (L\pi D / \lambda) / (4\sqrt{2\epsilon}) \quad (12)$$

When determining the minimum distance the three values (R_p , R_{ta} , R_{ra}) are calculated and the largest one is chosen to ensure all three requirements are met.

Electromagnetic Similitude. Fortunately one principle of electromagnetics allows measurement of the radar cross-section of targets that are too large to be practical in a chamber. Often the radar cross-section of aircraft, ships or land vehicles can be obtained through the use of models. The principle that guarantees reliable results is electromagnetic similitude. Simply put, an electromagnetic system will give equivalent results at all frequencies as long as linear passive quantities/parameters are properly scaled with respect to the frequency used [12:11]. For example,

$$L_2 = (\lambda_2 / \lambda_1)L_1 = (f_1 / f_2)L_1 \quad (13)$$

where L_2 is the linear model dimension at frequency f_2 and L_1 is the linear model dimension at f_1 . Table I shows the relevant relationships.

TABLE I
Scaled Parameters

Quantity	Full-Scale System	Model System
Length	l	$l' = l/p$
Time	t	$t' = t/p$
Frequency	f	$f' = fp$
Wavelength	λ	$\lambda' = \lambda/p$
Propagation constant	k	$k' = pk$
Conductivity	σ_c	$\sigma_c' = p\sigma_c$
Inductive capacity	ϵ	$\epsilon' = \epsilon$
Permeability	μ	$\mu' = \mu$
Impedance	z	$z' = z$
Antenna gain	g	$g' = g$
Scatter cross section	σ	$\sigma' = \sigma/p^2$

Scale models of targets can be employed in the chamber to obtain the true radar cross-section of the full size target when linear media and materials are used. The limiting factor is the accuracy of models involved. At low frequencies some of the physical structures such as openings, gaps, or stores do not contribute to the radar cross-section as they would at higher frequencies. The radar cross-section from a UHF, VHF or HF radar can be easily modeled because the electrically small features don't contribute significantly. But as the radar frequencies rise these small features become electrically larger. Therefore, for the measurement frequency, the model must duplicate these features accurately, with high tolerances.

Power Relationships. When measuring targets with low radar cross-section the power requirement become the limiting factor. Take, for example [7:911], a target with 35 dB variation in cross-section. As will be explained later in this chapter, an accuracy of $\pm 1/2$ dB requires the difference between the target signal and the residual or uncanceled signal to be 25 dB. This represents the difference between level (D) and (E) in Fig. 3. A reasonable estimate of the difference

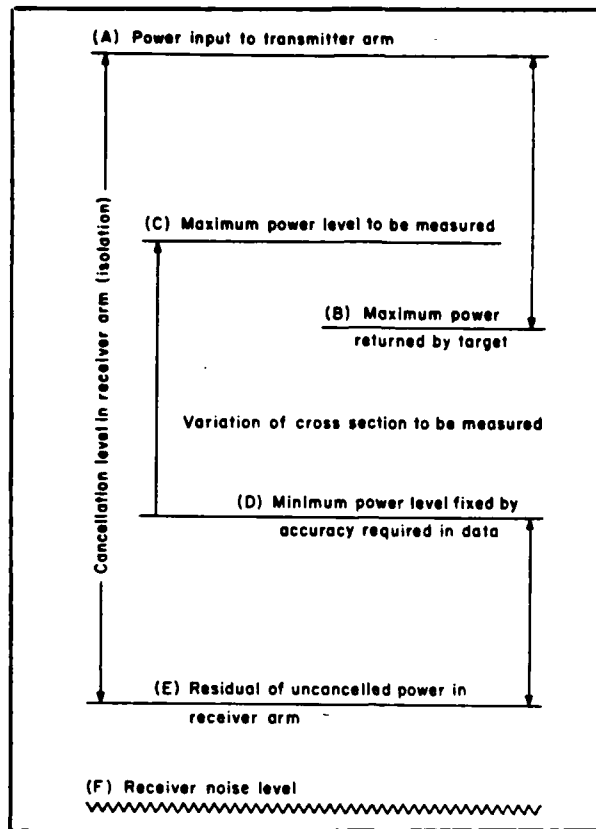


Fig. 3. CW Cancellation Requirements

between the power transmitted and the power received from the target can be derived from the power relationship [1:4]

$$P_r/P_t = G_t G_r \lambda^2 \sigma / (4\pi)^3 R^4 \quad (14)$$

where G_t and G_r are the gain of the transmit and receive antennas respectively, λ is the wavelength, R is distance from the antenna to the target and σ is the minimum radar cross-section that will be measured. The gain of the horn antennas can be approximated from [11:413]

$$G = 4\pi(AB) / 2\lambda^2 \quad (15)$$

where A and B are the physical dimension of the aperture of the horn. Using a gain of 19 dB for both antennas, a wavelength of 0.03 meters (10 GHZ), a target radar cross-section of -40 dBsm and a range of 9 meters Eq (14) gives

$$P_t / P_r = 103 \text{ dB} \quad (16)$$

Thus, the uncanceled signal at the receiver (no target) must not be greater than $35\text{dB} + 103\text{dB} + 25\text{dB} = 163\text{dB}$. This represents the difference between levels (A) and (E) in Fig. 3. This is what is referred to as 163 dB isolation. The power requirements can be derived from these calculations. With a receiver noise level at -120 dBm the power at the transmit arm must be at least 43 dBm. This power level can be achieved from the sweep oscillator (15 dBm) and power amp (30 dBm).

Background Cancellation

CW System Description. There are several methods to obtain radar cross-section measurements. They include Pulse, Frequency Modulation-Continuous Wave (FM-CW) and Continuous Wave (CW). The system used for this paper is the CW system. The components of the CW system are illustrated in Fig. 4.

The transmitted CW signal from the synchronized sweep oscillator is amplified before being sent to the transmit antenna. The received signal is added to a signal that was coupled off of the transmit arm through a 10 dB coupler. This coupled signal is adjusted in phase and amplitude so that it cancels the received signal from the empty

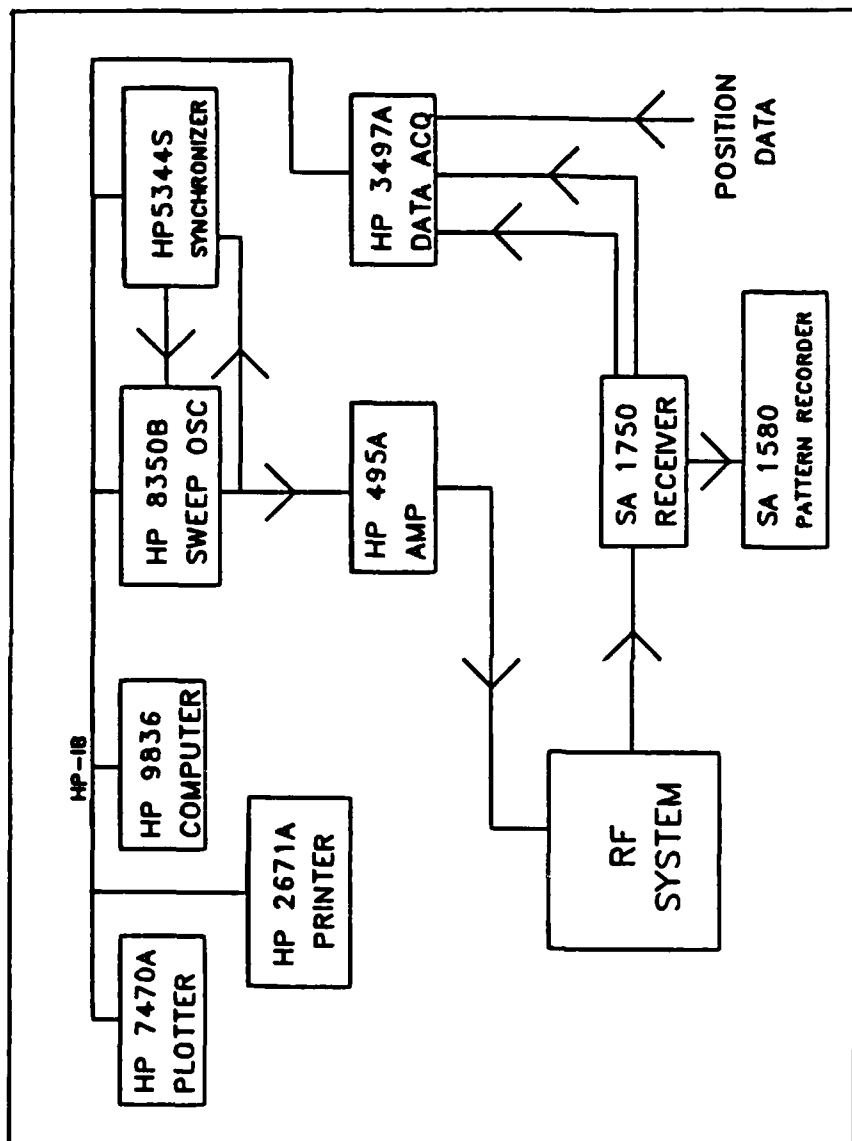


Fig. 4. CW System Configuration

chamber. This cancellation must hold for the 5-10 minutes required to take a set of measurements to ensure accurate measurements. If numerous measurements are to be taken, this tuning and retuning can be very time consuming and a possible source of error in measurements. The use of the computer aids in the measurement process.

The general procedure is as follows: The system is manually tuned to achieve the maximum cancellation with no target in the chamber. The receiver is configured to indicate the amplitude of the signal in the receive arm and the phase difference between the receive and transmit arm. These two quantities are a superposition of all contributions from the empty chamber. Therefore a requirement for placing a target in the chamber is that every effort be made not to disturb any object already in position.

The phase and amplitude information of the empty chamber is stored in the computer as a vector. With the target in place, the new phase and amplitude information, in vector form, is also stored in the computer. The empty chamber vector is then subtracted from the target vector (Fig. 5).

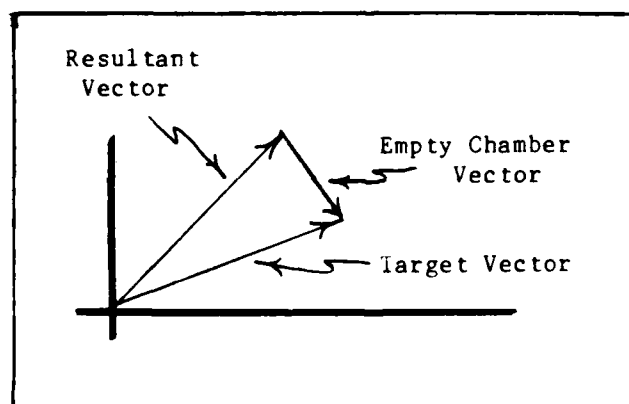


Fig. 5. Vector Subtraction

The amplitude of the resultant vector is plotted as the target's radar cross-section for that particular aspect angle.

Typically the radar cross-section of a target is made relative, in decibels, to a target with a radar cross section of 1 meter squared (dBsm). This is accomplished by taking the measurement of a known calibrated target, i.e. an object whose radar cross-section is exactly known. In AFIT's facility a 5" sphere is utilized. To ensure high quality measurements, two spheres are used. The first is a high precision calibration sphere used to calibrate the solid aluminum 5" sphere manufactured by AFIT's model fabrication shop for day-to-day use. The calibration sphere is made with higher tolerances. By using the AFIT made sphere the possibility of damaging the calibration sphere is reduced.

The bistatic radar cross-section of a conducting sphere in the far field is given by [13]

$$\sigma(\theta, \phi) = (|S_1(\theta)|^2 \cos^2 \phi + |S_2(\theta)|^2 \sin^2 \phi) 4\pi/k^2 \quad (17)$$

where S_1 and S_2 are the E plane and H plane scattering coefficients respectively and are given by

$$S_1(\theta) = j \sum_{n=1}^{\infty} (-1)^n [b_n \frac{dP_n'(\cos \theta)}{d\theta} - a_n \frac{P_n'(\cos \theta)}{\sin \theta}] \times (2n+1)/n(n+1) \quad (18)$$

$$S_2(\theta) = j \sum_{n=1}^{\infty} (-1)^n [a_n \frac{dP_n'(\cos \theta)}{d\theta} - b_n \frac{P_n'(\cos \theta)}{\sin \theta}] \times (2n+1)/n(n+1) \quad (19)$$

where

$$a_n = j_n(\rho) / h_n(\rho)$$

$$b_n = [e j_n(\rho)] / \rho h_n(\rho)$$

$$\rho = ka$$

For the backscatter case where $\theta = 0$

$$dP'_n(\cos\theta) / d\theta \Big|_{\theta=0} = n(n+1) / 2 \quad (20)$$

$$P'_n(\cos\theta) / \sin\theta \Big|_{\theta=0} = n(n+1) / 2 \quad (21)$$

the radar cross-section becomes (E field)

$$\sigma(0,0) = (\pi/k^2) \left| \sum_{n=1}^{\infty} (-1)^n (2n+1) (b_n - a_n) \right|^2 \quad (22)$$

This solution is plotted in Fig. 6. The solution to Eq (22) can be divided into three regions: Rayleigh, Mie and Optics. The optics region is the desired region since the value of the radar cross-section asymptotically approaches $\sigma = \pi r^2$. In other words the size of the sphere is chosen such that the radar cross-section is constant over the frequency range desired.

The lowest frequency projected for use in AFIT's chamber is 8.2 GHz (X band). The 5" sphere was chosen because it is the smallest standard sphere that still had a constant radar cross-section from 8.2 GHz and up. Therefore the radar cross-section of AFIT's standard sphere is

$$\sigma = \pi(2.5 \times .0254)^2 = 0.013 \text{ m}^2 \quad (23)$$

in decibels relative to one meter squared

$$\sigma_{\text{stdrd}} = -19 \text{ dBsm} \quad (24)$$

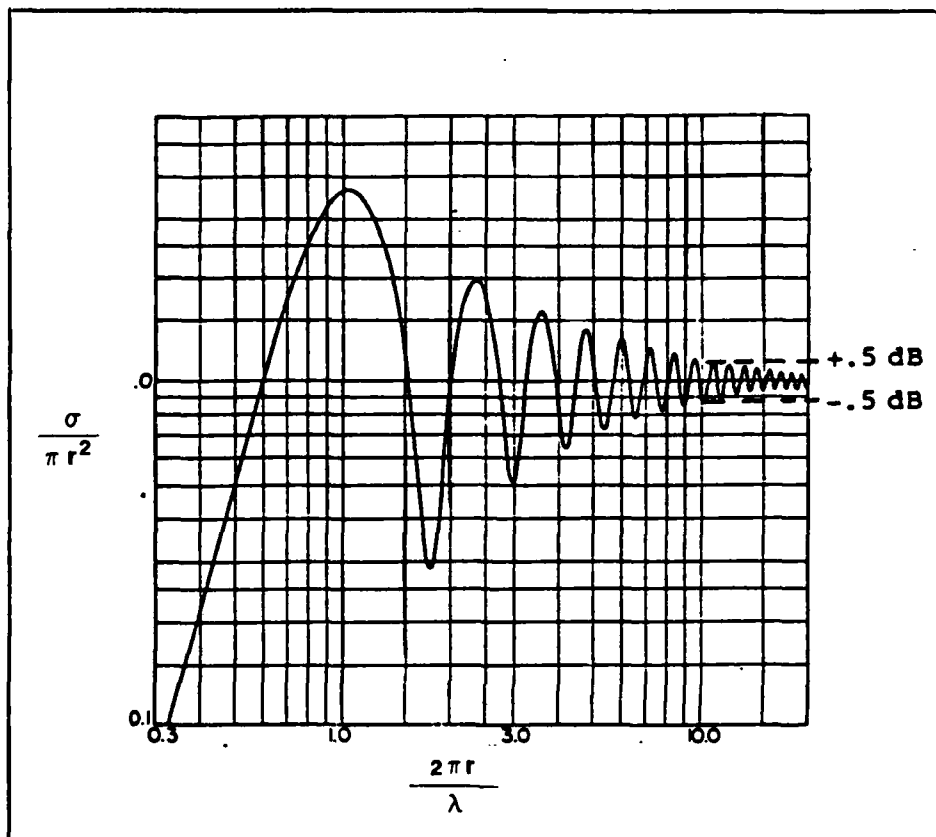


Fig. 6. RCS of Sphere

To obtain the relative radar cross-section of the target (to lm^2) the standard is placed in the chamber and measured. Again the empty chamber vector is subtracted from the standard vector. The amplitude of the resultant vector (measured in volts) is related to the power by

$$P_{\text{stdrd}} \approx V_{\text{stdrd}}^2 \quad (25)$$

This in turn is related to the target radar cross-section by

$$P_{\text{stdrd}}/P_{\text{trgt}} = \sigma_{\text{stdrd}}/\sigma_{\text{trgt}} = V_{\text{stdrd}}^2/V_{\text{trgt}}^2 \quad (26)$$

in decibels

$$20 \log V_{\text{stdrd}} - 20 \log V_{\text{trgt}} = \sigma_{\text{stdrd}}(\text{dBsm}) - \sigma_{\text{trgt}}(\text{dBsm}) \quad (27)$$

V_{trgt} is the amplitude of the resultant vector for the target and stored in a matrix in the computer. Likewise V_{stdrd} is the amplitude of the resultant vector of the standard target. σ_{stdrd} is known from Eq (23) (-19 dBsm). Therefore the radar cross-section (dBsm) of the target is

$$\sigma_{\text{trgt}}(\text{dBsm}) = \sigma_{\text{stdrd}}(\text{dBsm}) - 20 \log V_{\text{stdrd}} + 20 \log V_{\text{trgt}} \quad (28)$$

The true advantage of an automated system can be seen from these formulas. The radar cross-section data can be processed and stored by the computer in matrix form, thereby allowing the data to be later retrieved to compare to a new target or the same target that has been modified. This information can then be plotted on the same graph for comparison.

A CW configuration is very phase sensitive and typically is stable for only 10-15 minutes. With an automated system any variation in phase can be accounted for by taking a quick (5-10 sec) measurement of the empty chamber. The new empty chamber vector takes into account any variation in phase that might have occurred due to instabilities in the components. This can be done without any further manual tuning thereby reducing the possibility for error in the measurement process. It is because of these instabilities that the user is required to take an empty chamber and standard target measurement before taking the target measurement. The user is not required to null out the CW circuit each time since a complete measurement (empty chamber, standard target and then target) takes into account the instabilities of the system.

Communication Theory

Background Signal Errors. Unwanted signals from walls or leaky components produce errors in the radar cross-section data. These errors drive the power requirements up. To properly account for these errors, let $\bar{E}_m$, $\bar{E}_t$, and $\bar{E}_e$ be the measured field, the true scattered field and the net extraneous field (unwanted field) respectively. Then [7:907]

$$E_m = \hat{e} (\bar{E}_t + \bar{E}_e) = E_t [1 + S_e \exp(j\phi)] \quad (29)$$

where $\hat{e}$ is the unit vector parallel to the receiver's polarization, ϕ is the relative phase between $\bar{E}_e$ and $\bar{E}_t$ and $S_e = |\hat{e} \cdot \bar{E}_e / \hat{e} \cdot \bar{E}_t|$. For this paper $\bar{E}_t$ is assumed parallel to $\hat{e}$.

The radar cross-section can be now written as

$$\sigma_m = kE_m E_m^* = \sigma_t (1 + 2S_e \cos \phi + S_e^2) \quad (30)$$

where σ_m is the measured radar cross-section, σ_t is the true radar cross section and k is a proportionality constant. The maximum variation between σ_m and σ_t is

$$(\sigma_m - \sigma_t) / \sigma_t = \pm 2S_e + S_e^2 \quad (31)$$

In decibels

$$\sigma_m(\text{dBsm}) = \sigma_t(\text{dBsm}) + \sigma_e(\text{dBsm}) \quad (32)$$

where

$$\sigma_e(\text{dB}) = 10 \log(1 + 2S_e \cos \phi + S_e^2) \quad (33)$$

The upper and lower limits of the bracketed portion of Eq (33) are plotted in Fig. 7.

The left hand scale gives the percentage error for a given background level. The right hand scale gives the corresponding error in dB. As an example, to maintain an accuracy of ± 0.5 dB, the background signal after cancellation must be 25 dB lower than the desired scattered signal level. This is the figure used earlier in the chapter when defining the power requirements for AFIT's facility. In other words, taking in to consideration the physical layout of AFIT's chamber, the power sources available (HP 8350B and HP 495A) and an accuracy of 1/2 dB, the theoretical minimum RCS measurable in AFIT's facility is -40 dBsm.

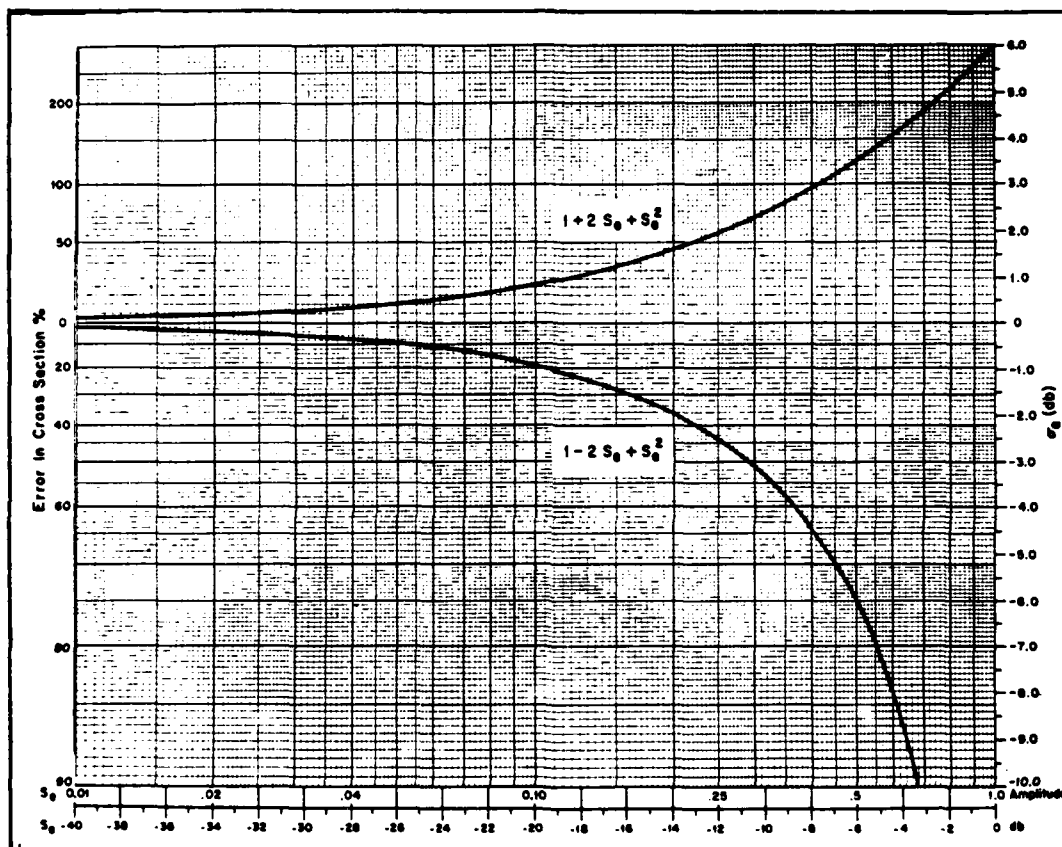


Fig. 7. Error in RCS Due to Background Reflections

III. Hardware

Occasionally an operator works with equipment whose purchase was driven by financial constraints more than by compatability or capability. In this environment one often faces the formidable task of ensuring that equipment from manufacturer A can be made compatable with manufacturer B. Fortunately some standards do exist, such as the IEEE standard 488-1978 interface, that allows a certain level of compatability to be achieved. Problems with compatability may be encountered with any automated radar cross-section measurement facility. Solving these problems is the task of the system designer. As with any large task, it is often easier to solve if the task is broken down into several smaller tasks. Keeping in mind the purpose of automating a radar cross-section facility, the hardware can divided into groups that can be attacked separately.

The purposes of automating a facility are twofold: First, through the use of a computer controlled system the effects of phase variation in the RF "plumbing" due to temperature, vibration, etc., can be more easily reduced and accounted for mathematically. This can drastically increases the repeatability and accuracy of radar cross-section measurements. Second, the digitized data can be stored and later retrieved for analysis. For example, this analysis may be a comparison with the radar cross-section of a target that has been modified. This dictates that the radar cross-section information be capable of being stored and retrieved for temporary (CRT) or permanent (plotter, disk) record. With these purposes in mind the hardware associated with an

automated radar cross-section measurement facility can be broken into the following groups:

1. Anechoic chamber
2. Radio frequency (RF) system
3. Positioner
4. Data acquisition
5. Interface/Bus structure
6. Controller

The remaining portion of this chapter was written using information obtained from the test equipment operating manuals. The reader is directed to Appendix A for complete listing of the test equipment used.

Anechoic Chamber

The basic and perhaps most unique component of a radar cross-section measurement facility is the anechoic chamber itself. The anechoic chamber discussed in this paper is located in building 168, Wright-Patterson AFB, Dayton OH. The tapered design of the facility (Fig. 8) was utilized in order to minimize the wide-angle specular reflection from walls and ceilings. The near monostatic configuration places the receive and transmit antennas at the tapered end of the chamber eight feet above ground level in line with the target located 30 feet down range on top of the positioner. The walls, ceilings and floor are covered with Rantec pyramidal absorber.

The transmit and receive antennas are secured to a removable two foot circular insert. This insert can be rotated in order to measure the radar cross-section at different polarization. In addition the insert can be removed and replaced with different inserts so that different antenna configurations or frequency bands can be used. To

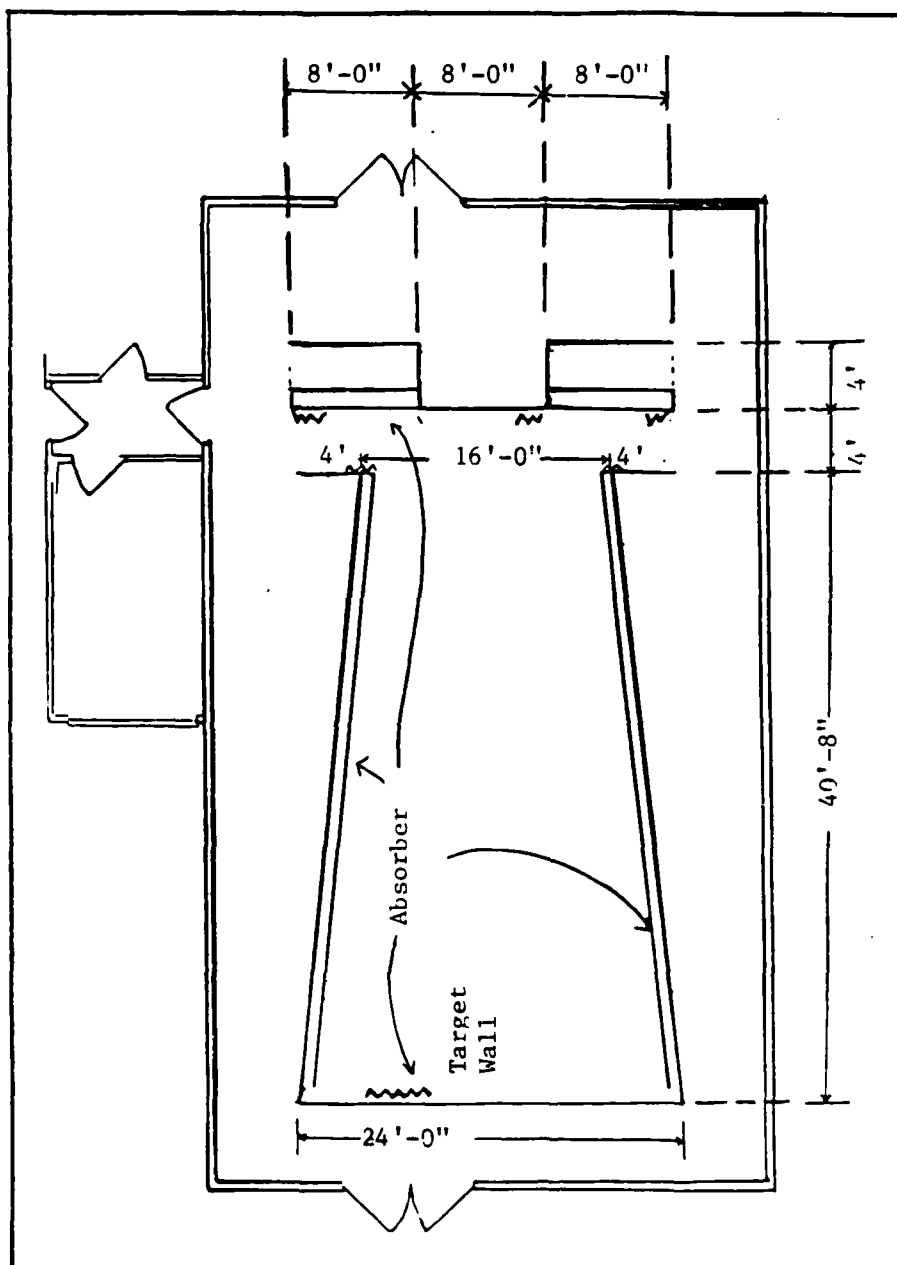


Fig. 8. APIT's Anechoic Chamber

further reduce sidelobes from influencing the measurements, "tunnels" were fabricated by the AFIT Fabrication Shop. These tunnels are flared in the H-field direction and parallel in the direction of the E-field. The tunnels are lined with AN-75 absorber to reduce the sidelobes. It has been experimentally shown [14] that in order for the tunnels to reduce the sidelobes by up to 20 dB, the tunnel length must be approximately 20 wavelengths long.

To further improve isolation between the transmit and receive channels the transmit antenna is positioned 1/2 inch closer to the target than the receive antenna. This improvement in isolation was implemented on suggestion from the personnel at the Wright Avionics Lab, WPAFB.

RF System

The RF system (Fig. 9) provides the means to generate a stabilized continuous wave (CW) signal, transmit this signal into the chamber, receive the backscattered signal, mix it with a signal coupled off the transmit channel and provide this signal to the receiver to measure the amplitude and relative phase. There are several manufacturers of test equipment capable of performing the required operations. It would be unreasonable to discuss all the combinations possible. Therefore this paper will be limited to the equipment available in AFIT's chamber. Whenever possible the capabilities that are generic to different manufacturers will be highlighted.

RF Source. A CW radar cross-section measurement technique requires a source that is extremely stable and synchronized. This

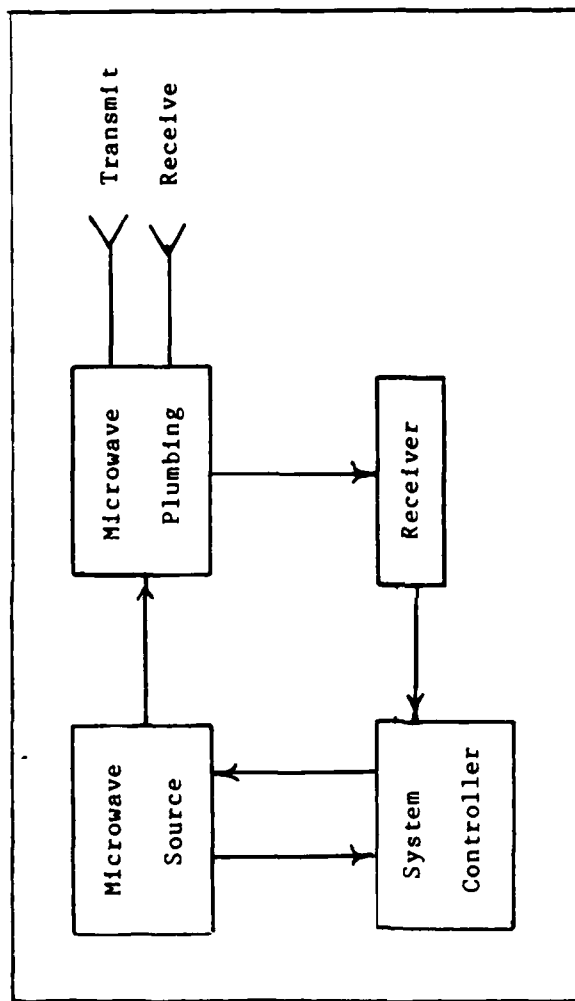


Fig. 9. RF System

usually requires two pieces of equipment: an oscillator and synchronizer. The oscillator used for this chamber is a Hewlett-Packard Model 8350B Sweep Oscillator with an 5.9 to 12.4 GHz RF plug-in. Together they provide a complete, solid state, swept signal source. For the purpose of this paper the 8350B will be limited to a CW mode. In this mode the instrument is tuned to a single frequency RF output.

All front panel controls except the power line switch may be controlled manually or programmed remotely. This remote programming capability in the signal source is a much desired capability. The 8350B uses the Hewlett-Packard Interface Bus (HP-IB), which is equivalent to the IEEE standard 488-1978 interface. This interface provides a remote operator with the same control of the instrument available to a manual (local) operator if the capability is built into the instrument. Remote control is maintained by a system controller (in this case a HP 9836 desktop computer) that sends commands or instructions to and receives data from the 8350B using the HP-IB.

RF Amplifier. To further increase the sensitivity of the overall facility a Hewlett-Packard Model 495A Amplifier is inserted to provide an additional 20 to 30 dB gain. As seen from Chapter II this will increase the minimum radar cross-section measurable in the chamber.

Source Synchronizer. Since a CW system relies on a phase shifted, attenuated signal to cancel the effects of a background signal the accuracy of the system is very sensitive to the stability of the source. This requires the use of a synchronizer to lock the source at the desired frequency. Without the synchronizer the signal may be off

by as much as 10 KHz. When properly configured the synchronizer will tune the signal source to output the correct frequency to within 1 Hz. The microwave counter/synchronizer used for this system is the Hewlett-Packard Model 5344S Microwave Source Synchronizer. The 5344S is comprised of the 5344A Source Synchronizer and the 5342A Microwave Frequency Counter with an Option 001 High Stability Timebase and Option 001 HP-IB Interface. The two units are mechanically and electrically connected for use as a source synchronizer. Again all front panel controls may be programmed by the controller via the HP-IB.

The counter is fed a signal that is coupled off the output from the 8350B Signal Source. The 5344A synchronizer generates a correction signal for the signal source by comparing the phase of the down converted signal in the counter with an internal crystal controlled synthesizer. This lock-on procedure, initiated over the HP-IB, will occur if the signal source is within the 25 MHz capture range of the synchronizer.

Other source synchronizers may be used in place of the 8344S. To fully exploit the automation concept it is desirable that the substituted source synchronizer be able to communicate over an IEEE 488-1978 interface. One such synchronizer that is used in AFIT's chamber when the 8344S is being calibrated is the EIP Microwave Inc Model 575 Source Locking Microwave Counter. To minimize software changes it is helpful to change the HP-IB address of the substituted synchronizer to that of the 8344S.

Waveguide Configuration. The synchronized signal is fed by a low loss coaxial cable to the waveguide. The signal basically follows two

paths. Referring to Fig. 10, the signal first goes through an isolator. The ferrite isolator is a unidirectional device which provides a lossless, or very low loss, transmission in one direction and provides a good load, or attenuates the signal, going in the opposite direction. The isolator at the input provides a good means of ensuring that reflections are not allowed to propagate back into the source. The isolation between transmit and receive channels is very critical and therefore isolators should be inserted whenever there is a possibility of reflections in the transmit branch finding their way into the receive branch.

After the signal passes through the isolator a signal is coupled off with a 20 dB directional coupler. This coupled signal will be used to cancel the backscattering from the empty chamber and will be discussed later. Back in the transmit arm the signal travels through a slide-screw tuner before going through a coax cable to the transmit antenna. The slide-screw tuner provides a means to better match the transmit arm to the transmit antenna. This increases the power transmitted and reduces the reflected waves. At these frequencies (8-12 GHz) coaxial cable can be very lossy. Therefore it is desirable to reduce the cable length as much as practical. Note, however, that a change in polarization requires that the antenna mount be rotated 90 degrees. For this reason low loss coaxial cable was used between the antennas and waveguides. The cable has an attenuation of .38 dB/ft in 8-12 GHz region. With a cable length of 9 ft. only a loss of 3.5 db is encountered. This is well within the capability of the system to handle.

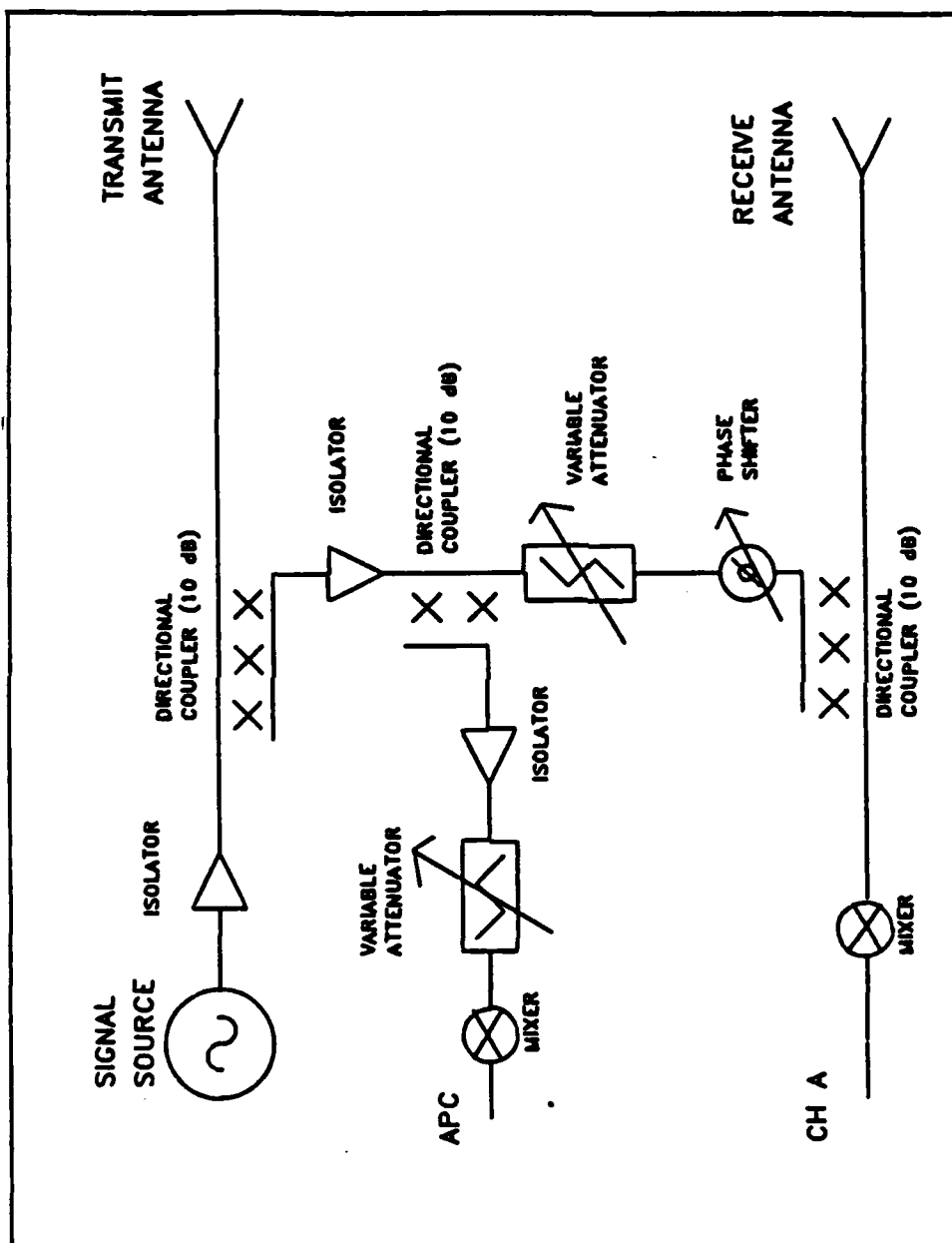


Fig. 10. Waveguide Configuration

The signal that is coupled off the transmit channel through the directional coupler is used to cancel out the backscattering of the empty chamber. After being coupled off, the signal goes immediately into a 10 dB directional coupler. This coupled signal is connected to the receiver as a reference for the phase measurement. The cancellation signal continues down the waveguide through a phase shifter and variable attenuator and a slide-screw tuner before being connected to the secondary arm of another directional coupler. The slide screw tuner provides a means by which to better match the cancellation arm with that of the directional coupler. The cancellation signal is mixed with the signal received that is traveling in the reverse direction through the directional coupler.

With an empty chamber the cancellation signal is tuned, phase shifted and attenuated until it cancels the backscatter signal from the chamber. With a target in place the combined cancellation signal and received signal is passed through a coaxial mixer before being sent to the receiver for phase and amplitude measurements.

Receiver. The receiver used is a Scientific-Atlanta series 1750 Phase/Amplitude Receiver. This receiver was chosen because of its capability to provide both phase and amplitude measurements. This capability is a requirement because the actual determination of the radar cross-section is based on vector subtraction (both phase and amplitude).

The receiver is designed to provide precise measurement of change in the amplitudes and relative phases of two CW signals that are applied to the signal input terminals. The receiver's local oscillator

can be tuned from 2 to 4.1 GHz in order to convert the input signal to the 45 MHz IF. With X-band operating frequencies an external crystal mixer is required to convert the input signal to a signal below 2 GHz. The Scientific-Atlanta Model 14-3 mixer is employed in AFIT's chamber. It is important the the "xtal current" be adjusted on the receiver not to exceed 10 milliamperes can indicated on the receiver panel meter. Fortunately the diode in the mixer is field repairable. It is recommended that a supply of Sylvania D5506 replacement diodes (or equivalent) be kept on hand to reduce any unnecessary downtime.

Crystal-Bolometer Amplifier. The amplitude and phase data will be acquired by a DC digital voltmeter in the HP 3497A Data Acquisition system. The DVM measures the DC analog signal and transfers this data to the controller. Because of this only the phase data (DC) is input from the receiver to the 3497A. The amplitude information is obtained from the Scientific-Atlanta Model 1586 Crystal Bolometer Amplifier.

Pattern Recorder. An automated measurement facility operates on the principal that the data can be stored and later retrieved for calculations in order to present this data to the operator. The disadvantage, of course, is the lack of real-time monitoring of the results. An addition to provide this real-time capability is a Scientific-Atlanta Model 1581 Pattern Recorder. The previously mentioned 1566 Crystal-Bolometer Amplifier is an accessory unit intended for use as a preamplifier with the pattern recorder. The 1586 is a sensitive amplifier which can accept inputs for either a crystal detector or bolometer detector. Fortunately one output of the 1586 is

an isolated BNC-type output provided for monitoring the resulting DC equivalent of the amplified input signal. This provides the necessary DC analog signal of the amplitude for the 3497A Data Acquisition unit.

Positioning of Target

The radar cross-section of a target is usually dependent on the aspect angle. Therefore it is desirable to be able to move the target 360 degrees in azimuth to obtain the radar cross-section at every aspect in azimuth. In addition it is required to correlate the phase and amplitude data with aspect angle to enable the operator to evaluate the radar cross-section data. This translates into two requirements: First, an ability to rotate the target a full 360 degrees inside the chamber. Second, an ability to correlate the position data with the phase and amplitude data.

Positioning the target is accomplished with three pieces of equipment. The first piece is the actual positioner itself. AFIT's chamber utilizes a Scientific-Atlanta Model 5021 Azimuth Positioner. This is a single axis positioner designed to support and rotate the target in azimuth. For most applications a single axis positioner is adequate. Since the target must be in the chamber to be measured it is necessary to try and reduce the backscattering from the positioner and support assembly. To accomplish this an aluminum shield was fabricated in the shape of an ogive. This shape minimizes the specular backscattering and reduces the contributions of the support structure to the radar cross-section. In addition, the ogive is covered with a magnetic radar absorbing material (RAM). Every effort is made to

reduce the backscattering from the empty chamber (including the positioner) to obtain better radar cross-section measurements.

The positioner is controlled by a Scientific-Atlanta Model 4116B Remote Control Unit. This unit provides a means to manually start the positioner traveling in a forward or reverse direction. The rate of rotation is also controlled by the 4116B.

The actual real-time position of the target in degrees is visually displayed on the Scientific-Atlanta Series 1844 Digital Position Indicator. The indicator is electrically connected to the positioner to obtain the synchro voltages. The indicator then processes this information to obtain the position data. The processed data in turn is displayed on the six decade LED display. The position is also supplied to the pattern recorder, in BCD format, over an interface cable between the indicator and the recorder.

To correlate the phase and amplitude information with the appropriate aspect angle a means must be provided to establish the position each time the phase and amplitude data is measured. One way to accomplish this would be to build a digital to analog converter (DAC) that samples the BCD data on the interface cable between the indicator and recorder. The analog output could then be measured and later translated into degrees.

Another technique would be to purchase a BCD interface for the controller that would sample the BCD data directly. Such an interface has been ordered for the HP 9836 in AFIT's chamber but will not arrive in time for completion of this thesis effort.

A simpler technique was implemented to prove the concept behind

automating the facility. Every time the phase and amplitude data is sampled a clock is also sampled and stored in the data matrix. The rate of rotation is determined by dividing the total number of degrees rotated by the total time in seconds.

$$\text{Total \# of deg / Total \# of sec} = \text{Rotation rate (deg/sec)} \quad (34)$$

If the time of the sampling is made relative to the first sample and multiplied by the rotation rate the actual position of the target in degrees when the phase and amplitude data was taken will be determined.

$$\text{Time of sample / Rate of rotation} = \text{Actual position (deg)} \quad (35)$$

Since the positioner actually travels more than 360 degree (approximately 400 degrees) the data matrix must be truncated to include only the azimuth aspect angles from 0-360 degrees. This assumes a constant rotation rate. In addition the positioner must be rotated slow enough to ensure that 360 data points are achieved. This will provide the necessary resolution. In reality each data point will be the average of 9 or more samples of phase data and 9 or more samples of amplitude data. This will be explained under Data Acquisition.

To obtain the total number of degrees the positioner rotates, the operator is instructed by the software to rotate the positioner to one of its limits. The operator must enter the displayed degrees on the indicator. The positioner is then rotated until it reaches the other limit. The operator is again queried for the displayed degrees. From this the software determines the total number of degrees rotated.

The total time of rotation is determined from the start and stop times. The limit lamp circuits are utilized since the positioner will start from one of its limits and stop at the other limit (Fig. 11).

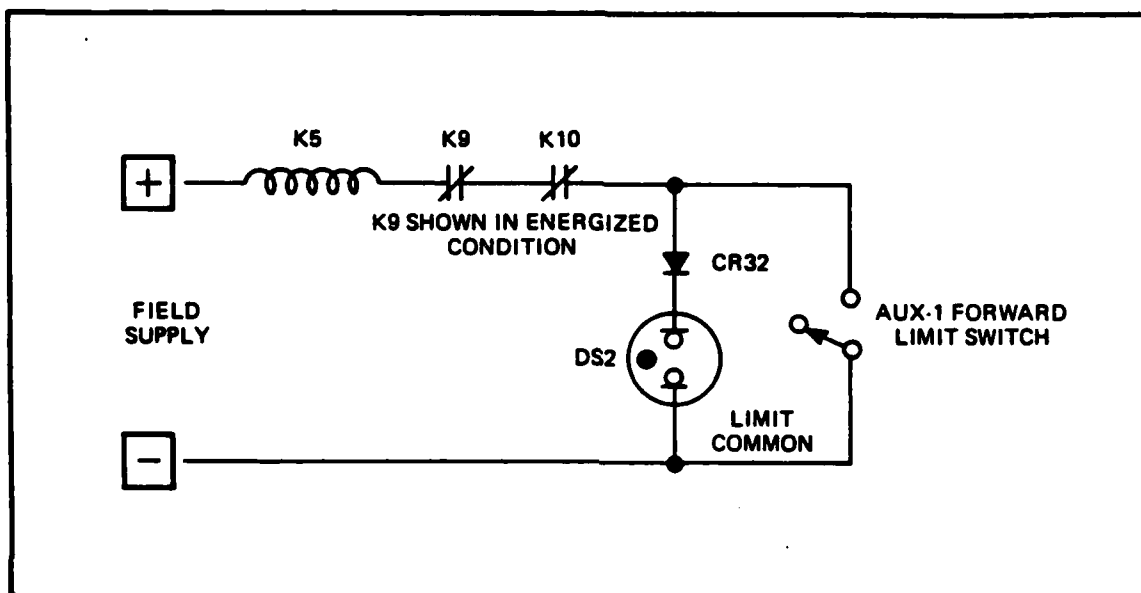


Fig. 11. Limit Light Circuit

The two limit switches are normally closed switches. When the positioner is not at the corresponding limit the indicator lamp is shorted out (not lit). The voltage across the lamp and the diode would be zero. When the positioner reaches the limit the switch opens causing the voltage measured to be nonzero. Since DS2 is a neon glow lamp and its illuminating current is very small, the voltage measured is effectively the voltage of the field supply, 117 VDC. Therefore, by sampling the voltage across the diode and the neon glow lamp it can be determined when the positioner starts (leaves the reverse limit) and

stops (arrives at the forward limit). The algorithm for this will be explained in the following chapter.

Data Acquisition

With an automated measurement facility a method must be provided to acquire the data and transfer it to the controller. In AFIT's chamber this is accomplished by using a Hewlett-Packard Model 3497A Data Acquisition/Control unit. The 3497A is designed to perform two tasks: data acquisition and control. In AFIT's chamber the function of the 3497A is to measure data points from the system and transfer this data to the computer (i.e. data acquisition). On command from the computer, the 3497A samples and measures the input data and then outputs these measurements over a communications interface (HP-IB) to the HP 9836.

Data acquisition measurements can be divided into five categories, depending on the system parameters to be determined: voltage, temperature, resistance, frequency or pressure. Since the data is available as DC signals, voltage measurement will be utilized to acquire the data. The 3497A's digital voltmeter (DVM) assembly (option 001) is a 5 1/2 digit, 1 microvolt sensitive DC voltmeter which can measure voltages up to 119.999 volts. The DVM assembly is fully guarded and uses an integrating A/D conversion technique which provides excellent common and normal mode noise rejection.

In addition the 3497A also has a 20 Channel Relay Multiplexer Assembly (Option 010). The 20 channel analog signal multiplexer assembly is used to switch (multiplex) signals from up to 20 channels

to the 3497A DVM. The 20 channels divided accordingly:

- 0-16 (even channels)--phase
- 1-17 (odd channels)--amplitude
- 18 Reverse limit switch
- 19 Forward limit switch

The 3497A is instructed by the computer to take 20 readings, storing each reading internally before downloading the entire array to the computer. Once in the computer, channels 18 and 19 are checked by the software for a high voltage output (>50 VDC) to establish start and stop times.

The terminal card from the multiplexer assembly is configured as follows (Fig. 12):

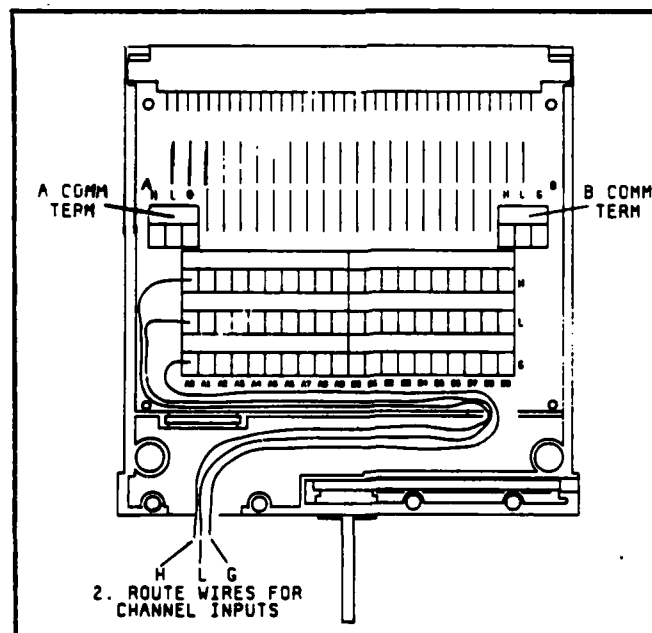


Fig. 12. Multiplexer Terminal Card

The even channels from 0-16 are connected in parallel. Likewise for the odd channels 1-17. The G terminal in Fig. 12 is the Guard terminal and is connected to the Low (L) terminal. The purpose of the Guard terminal is to reduce the effect of common mode voltages. These are the errors caused when the grounds of the voltmeter and device are at different potentials. Although both the voltmeter ground and device ground in this system are on the same line the ground voltage differs at each point along the line. The voltmeter is eventually grounded back to the same ground as the rest of the system, so the voltmeter contains a common mode whenever its referenced to any point but the one where it's actually grounded. Connecting the Guard to the Low terminal makes both terminals at almost the same voltages. This configuration provides common mode rejection when the leads are kept to a minimum.

The amplitude lead is connected to the BNC connector behind the crystal/bolometer amplifier that provides a DC output. The phase lead is connected the BNC phase output on the back of the receiver. The leads from channel 18 are attached across the diode and indicator lamp in the reverse limit circuit (Fig. 11). Similarly the leads from channel 19 are attached in the forward limit circuit.

Interface/Bus Structures

The interface provides the means by which the computer can communicate with the test equipment. The IEEE standard 488-1978, "Standard Digital Interface for Programmable Instrumentation", was chosen for AFIT's facility. The Hewlett-Packard Interface Bus (HP-IB) which is an IEEE 488 bus, provides the communication between

the HP 9836 desktop computer and the other HP equipment.

The HP-IB is an interface system which uses a party-line bus structure so that up to 15 devices can be placed on a single bus. Each of these devices can be classified into one of three categories: Talkers, Listeners or Controllers.

Talkers: These are devices which are capable of transmitting data over the bus to other devices. A device becomes an active talker when addressed by the controller. There can be only one active talker on the interface bus at a time.

Listeners: These are devices which are capable of receiving data over the bus. A device becomes an active listener when addressed by the controller. There can be up to 14 active listeners on the bus at any one time.

Controllers: These are devices which can designate active listeners and talkers for data transfer. There are two types of controllers, active and system. The Active controller is the current controlling device. The system controller can take control of the bus even when it is not the active controller. There can only be one controller on the bus at any one time.

In AFIT's chamber the HP 9836 desktop computer, acting as system controller, controls five devices. Refer to Appendix B for listing of capabilities and addresses of each device.

The HP-IB cables can be ordered in a variety of lengths. The cables come with identical "piggy-back" connectors on both ends so that several cables can be connected to a single source (Fig. 13).

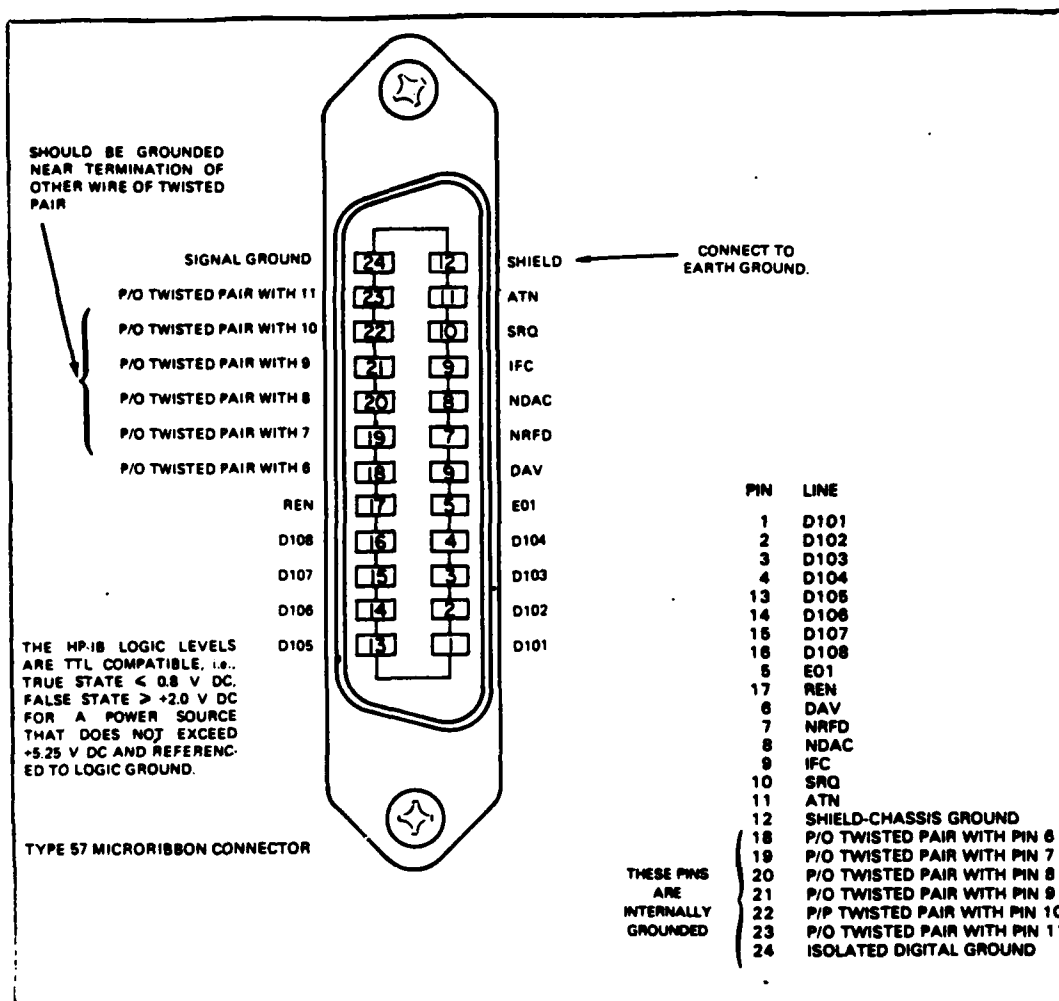


Fig. 13. HP-IB Connector Pin Designators

A good rule of thumb is not to stack more than two cables on any one connector. If the stack becomes too large and is "bumped" the force may cause the connectors to break and interfere with the HP-IB operation. In addition, the total cable length should not exceed 20 meters. A Hewlett-Packard recommendation is to take the number of devices connected to the HP-IB and multiply by 2 meters to arrive at

the maximum total length of cable.

The HP-IB bus structure consists of a parallel bus of 16 active signal lines, grouped into three functional sets (Fig. 14).

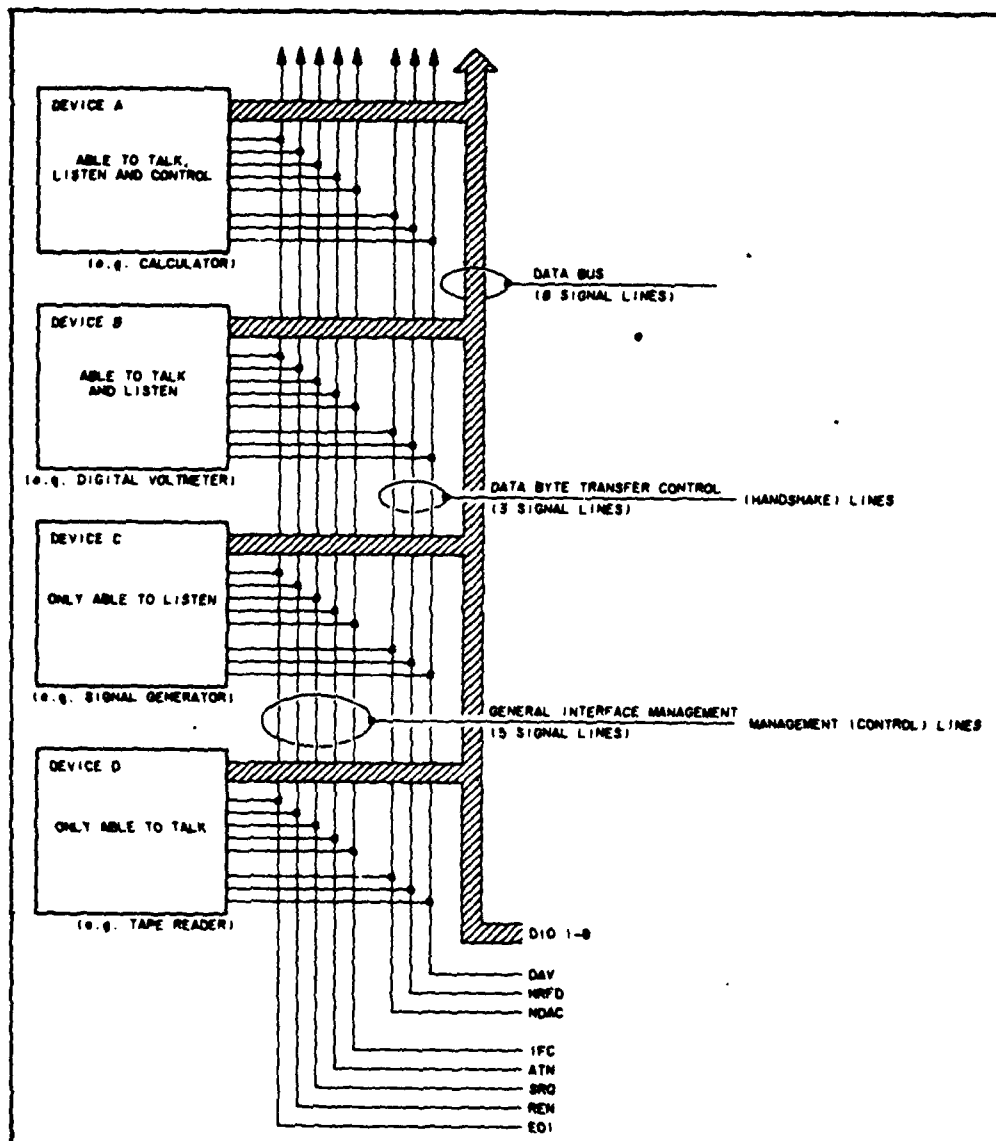


Fig. 14. HP-IB Structure

The DATA lines consist of eight signal lines used to transmit data in the form of coded messages. This data can be used to program devices on the bus, transfer measured data, coordinate instrument operation and manage the system. The DATA BYTE TRANSFER control lines are three signal lines that permit the proper coordination (handshaking) required between devices. These lines permit asynchronous data transfer at the rate of the slowest active device used in that transfer. The remaining five GENERAL INTERFACE MANAGEMENT lines are used to perform "household chores" in managing the bus. This includes activating all connected devices at once, clearing the interface and others.

Several types of information may be transferred over the bus, the most common being in the form of Bus Messages. Each bus message can be divided into three parts: Operation, Address, and Information (Fig. 15)

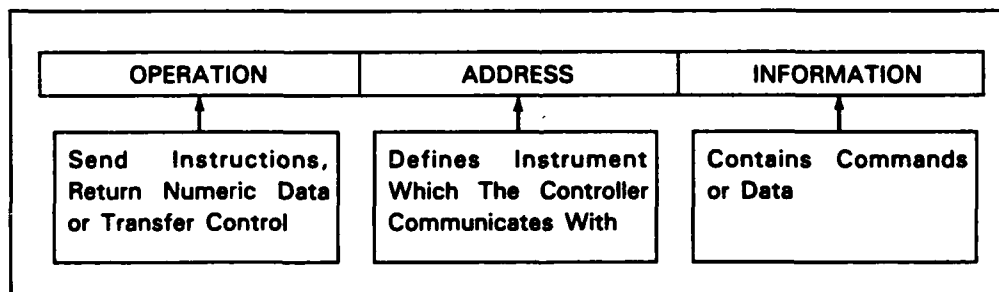


Fig. 15. HP-IB Message Format

The operation portion of the bus message specifies the type of bus message. The syntax is controller dependent for the operation portion of the bus message. Each device on the bus must have a unique address. The address consists of a Interface Select Code (7 for HP-IB) and

Device Code (eg., 09 for HP 3497A). The final portion of the bus message contains the commands for the devices or data that is being transferred. The transferred data may consist of measured data or the status of the device.

In summary, the HP-IB was chosen because it allows computer control of the properly equipped test equipment and provides an avenue for data input and output. Other standard busses could be selected but the HP-IB control language is simple, yet powerful, allowing extensive control of the external devices.

Controller

As discussed earlier the controller manages the operation of the bus primarily by designating which devices are to send and receive data. It may also command specific actions within the devices themselves. The controller chosen for AFIT's facility is the Hewlett-Packard 9836 Desktop Computer. The 9836 was chosen because it contains many features that make the measurement process very quick and easy.

The 9836 contains a powerful 16 Bit Motorola MC68000 CPU with a built in 8 MHz clock, 912 Kbytes of internal memory and two 133 mm (5 1/4 inch) flexible disk drives with 260 Kbyte capacity each. To help in the programming, the 9836 contains a rotary control knob for cursor control, interrupt generation, a 120 character ASCII keyboard with ten (20 with shift) softkeys, and special function keys for program editing, cursor control and system control.

Output Devices

The man-machine interface is a key aspect of any automated operation. With an automated scattering measurement facility several separate output devices are used to effectively and efficiently interact with the user.

As previously mentioned the SA series 1580 pattern recorder provides a real time output for the user. The pattern recorder plots the radar-cross section as a function of target position angle in either polar or rectangular chart format.

The CRT of the HP 9836 provides a volatile means of presenting data for the user to verify. The resolution of the CRT plot is less than that of the plotter but does provide a quick means of viewing the data.

The HP 7470A plotter and HP 2671A printer provide the user with hard copy plots of the measurement data. The plotter provides a higher resolution two color plot of the measured data whereas the printer essentially dumps the CRT plot onto the paper.

And finally the disk drive of the HP 9836 provides the means of storing the measurement data for archival purposes on 5 1/4 inch floppy disks. In addition the disks can be used to conveniently transfer the data to other organizations.

IV. Software

Objective

The main objective of the software for AFIT's automated facility is to provide a capability for the user to measure the radar cross-section of a variety of targets in a rapid, repeatable manner. The user of AFIT's facility will consist mainly of graduate students participating in AFIT's graduate program.

The anechoic chamber allows the student to observe first hand the impact the physical characteristic of a target has on its radar cross-section and to explore different techniques to reduce the radar cross-section.

Since the main usage will be in a non-production mode the software must be extremely user friendly. That is, the student must be able to sit down at the computer and conduct a meaningful radar cross-section measurement and obtain a plot with minimum background in the actual operation of the facility. In addition, the chamber's accuracy must be at a level such that it may be used in a research capacity. Since each student is required to prepare a thesis, it is conceivable that several individuals will want to use the facility in their research efforts.

Another user group that will find the facility useful are the participants of the short courses presented by AFIT. Again, because of their limited background in radar cross-section measurement, the software must be extremely user friendly. In essence, the software must lead the user from turn on to turn off.

System

As discussed in Chapter III, the controller used is a Hewlett-Packard 9836 Desktop Computer. The 9836 comes with nearly one megabyte of RAM before loading one of three possible languages: BASIC, HPL or Pascal. The software for this paper was written with BASIC 3.0. There are several versions (other than 3.0) of BASIC in use today. BASIC 3.0 is HP's latest version and contains many powerful commands that enhance the ease of programming. BASIC 3.0 was chosen over Pascal because of the author's familiarity with BASIC and time constraints prevented the learning and subsequent usage of Pascal for this thesis effort. To assist in the plotting routines Hewlett-Packard Graphics Language (HP-GL) was utilized. HP-GL consists of two-letter mnemonic instructions which activate the plotter.

Every attempt was made to present a software package that is not only user friendly but also programmer friendly. This allows future modifications to the program to be made as painlessly as possible. The use of Basic and HP-GL were chosen to assist the programmer but had no real impact on the output to the user. There is no reason why another language (i.e. Pascal) could not be used instead.

Applications

Keeping the pedagogical purposes of AFIT's facility in mind, the desired features of the software can be listed as:

- 1) Provide easy start up procedures.
- 2) Allow a student/user unfamiliar with radar cross-section measurements to sit down and be able to make, store and plot a radar cross-section measurement.

- 3) Be menu driven.
- 4) Minimize data entry through the use of soft keys and with common default values.
- 5) Be capable of viewing data on a cathode ray tube (CRT).
- 6) Provide a means of quickly outputting data (dump to printer) or outputting a finished product (dump to plotter).
- 7) Be capable of plotting up to four sets of data on one plot.
- 8) Provide error trapping whenever possible.
- 9) Provide the user an graceful exit from the program.

The rest of this chapter describes implementations of these key features and the reasons why they were implemented as such. The reader is directed to Appendix B for a more detailed explanation of the software.

Easy Start Up. The student loads the computer with the necessary language and program by simply inserting the two appropriately marked disks into the two disk drives and then turn the computer on. First, all the BINS (portions of BASIC needed for this program) are loaded, then the actual program is loaded and automatically run.

User Friendliness. Every attempt is made to ensure user friendliness throughout the program. The first message seen will introduce the user to the protocol of the program (i.e. types of queries/responses). The program will also instruct the user to turn on all equipment and initiate the program with date and time information. This allows the data to be identified not only with a file name but also with the date and time of the measurement.

To further assist, the user is prompted and the program is paused while a required interaction with the chamber takes place (i.e.

placement of standard or target in the chamber, adjustment and rotation of the positioner, ensuring plotter has paper and pen installed, etc.).

Menu Driven. The use of menu's are employed throughout the program. This allows the user an easily understandable format for making decisions concerning program structure. Each decision is explained on the screen with relevant information also displayed. In addition the heading of the menu describes what portion of program the user is currently at. Whenever practical the user has the capability of returning back to the main menu. This allows the user to "change direction in midstream" if desired.

Soft Keys/Default Values. To minimize data entry, default values are used whenever possible. This reduces the possibility of error in input and speeds the measurement process. As an example, a default value of 5" is used for the diameter of the standard sphere. This is the diameter of the sphere fabricated by AFIT's Model Fabrication Shop. But the user still has the capability to input another diameter if another size standard sphere is used.

Soft keys allow decision inputs to be made with a single key. The use of soft keys speeds up the measurement process and reduce the possibility of incorrect inputs. The actual soft key assignments reduce the possibility of striking the wrong key by placing idle soft keys between active keys.

CRT Viewing. After taking a radar cross-section measurement the data is displayed on the CRT for viewing. This allows the user the opportunity to observe the data for any obvious errors that occurred during the measurement process (i.e. receiver lost lock). After

viewing the data the user can dump to the printer, store the data on the storage disk or dump to the plotter. Likewise when retrieving stored data the plot is displayed on the CRT. Again the user can quickly observe an incorrect choice of a file name. Of course this check cannot distinguish files that have radar cross-sections that are similar, but it does provide the user the capability to detect obvious mistakes (ex. viewing a flat plate versus a corner reflector).

Data Output. The user should be capable of obtaining a hard copy of the data when finished. This is accomplished in two formats. The quick way, but with less resolution, is to dump the data to the printer. The user can do this when a data set is in place in the program. This can be right after a measurement or after recalling a data set from memory. As can be seen in Fig. 16 the data is presented in a graphical format with minimal information. Still, the major features of the radar cross-section can be observed along with the maximum and minimum radar cross-section values (dBsm) and file name. To produce a more complete product the user can output the data to the plotter. The plotter provides a larger, better resolution, two colored plot of the data (Fig. 17). The legend contains all the important information about that particular measurement: file name, frequency, polarity, date and time taken.

Plotting Multiple Data Sets. The program has the capability of plotting up to two sets of data on the same graph. This allows the user to compare the radar cross-section of a variety of targets or a single target that has been modified several times. The user then gets a chance to gain an insight into the major contributors to the radar

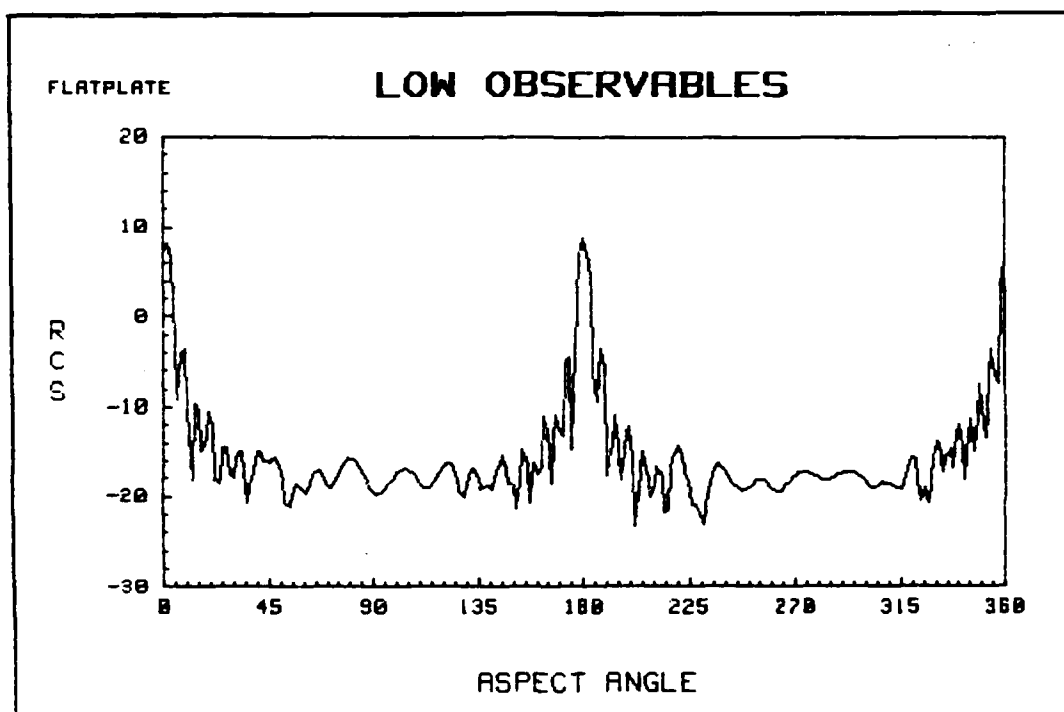


Fig. 16. Printer Output

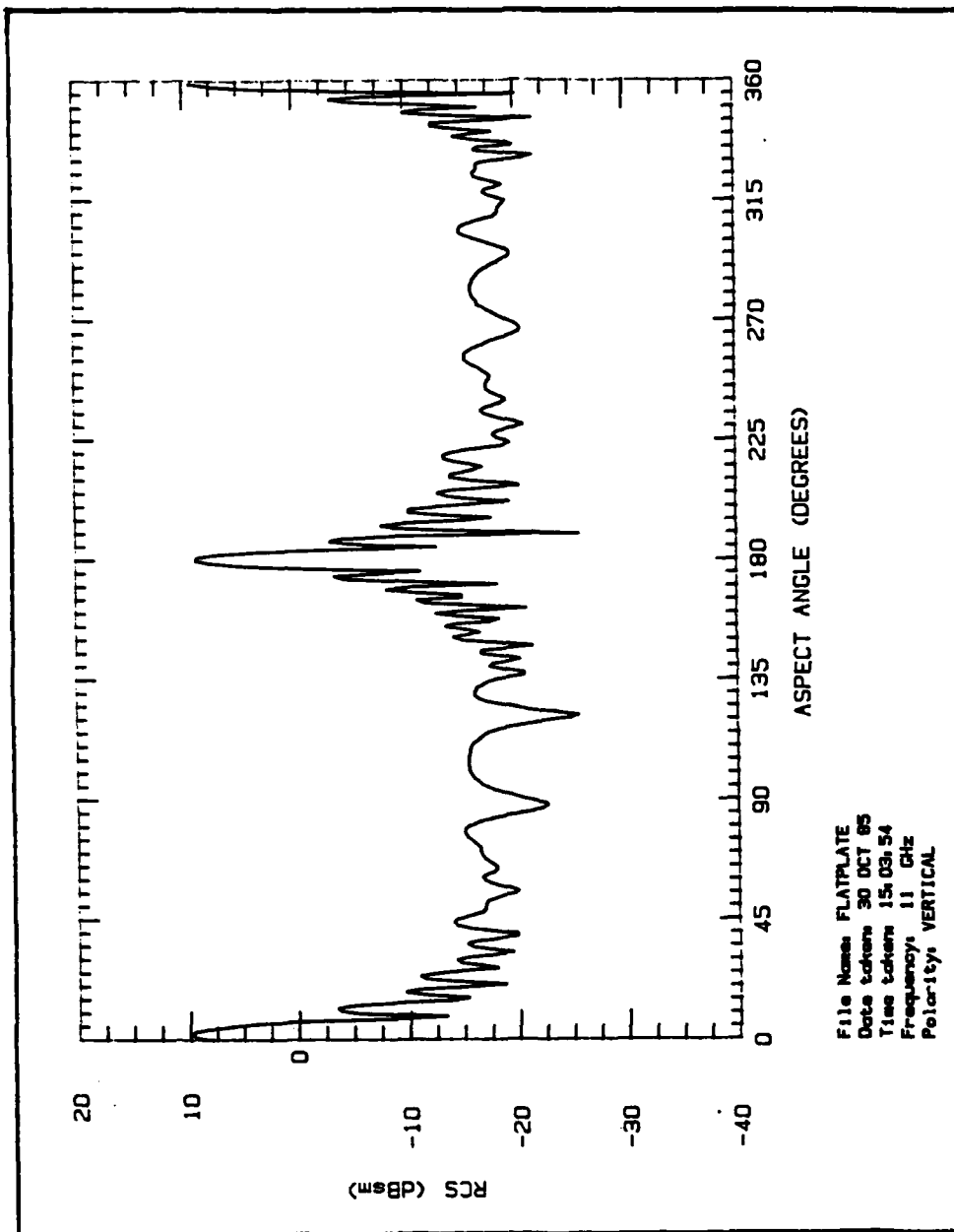


Fig. 17. Plotter Output

cross-section of a particular target.

Error Trapping. To avoid the possibility of a user induced error causing the program to "crash", error trapping is used whenever possible. The most common error will occur when loading or storing data from the storage disk. If the user request a file that does not exist or tries to store a file that has a duplicate file name an error message is displayed and the user is prompted again for the proper file names. To further reduce these types of errors the user can view the names of the files already stored on the disk. This will help ensure the student chooses the correct file name. Other error trapping involves the user defined RCS (dBsm) scale of the RCS (dBsm) of the plots. If the maximum value of the scale inputted is equal to or less than the minimum value the user is notified of the condition and prompted for the correct inputs.

Graceful Exit. After finishing the desired operations with the facility the user can exit the program by pressing the "EXIT" soft key in the main menu. The program prompts the student in shutting down the system and displays a HP provided space shuttle picture before exiting back to BASIC.

V. Results and Discussion

A design methodology for an automated scattering measurement facility has been described in this thesis. Test equipment from various manufacturers was interfaced and a software package was written. The menu-driven program provides easy start up procedures for users unfamiliar with the operation of the HP computer. The program also allows a user with limited background to make, store and output a meaningful radar cross-section measurement. These features were verified during a demonstration of the facility to a group of students (i.e. future users). The group was capable of conducting a RCS measurement and outputting the data with minimum assistance. The user's reaction was very positive as to the potential of facility to provide a "hands-on" environment to reinforce classroom lectures.

The major by-product of this thesis is the automation of AFIT's scattering measurement facility. To further improve the credibility of the facility some work remains to be done. These tasks, though trivial in appearance, will impact any measurements taken. These include investigating the placement of absorber on the floor to securing absorber on the door on the back wall of the chamber. Most importantly, however, the chamber must go through a calibration process to ensure that the accuracy of the measurements achieve the highest level possible. Tasks such as these were not undertaken in this thesis because of time constraints.

Finally, the inherent shortcoming of the measurement process must be pointed out. As is discussed in Appendix C, there is some interpolation of data if the rotation rate of the positioner exceeds one degree of azimuth per sample set. Any RCS fluctuations resulting from real or resultant point sources may go unmeasured in this circumstance. Therefore it is important to keep this "smoothing" error in mind when analyzing the data.

VI. Recommendations

A years worth of work can not be done on a project such as this thesis without acquiring a "wish list" of items that could enhance the operation of the facility. Most of these suggestions were not undertaken because of time or money constraints, but are listed here as a reference.

- 1) The RF plumbing for this thesis is accomplished with waveguides and their associated devices (directional couplers, attenuators, etc.). By using SMC type devices the size of the RF system can be reduced from 20 square feet down to under four square feet. This should enhance the accuracy of the system since it would be less susceptible to vibration. Also this would give more room to move around the test equipment area.
- 2) To enhance the stability of the RF system it is recommended that the system be rigidly mounted on a 1/4 inch thick aluminum plate. By firmly affixing the waveguides or SMC devices to this plate the measurements will be less affected by vibration. These errors will show up in the accuracy of the measurement.
- 3) When measuring low radar cross-section targets all available power must find its way from the oscillator to the transmit antenna, back into the receive antenna and into the receiver. The power transfer can be enhanced by minimizing the length of the coaxial cables. This can be accomplished by placing the RF system as close as possible to the

antennas. With SMC devices the aluminum plate can be hung on the wall under the antennas.

- 4) Most RF sources are not built with shielding in mind. When measuring low radar cross-section targets any leakage from the RF source will limit the minimum cross-section that can be measured. Therefore it is recommended that a box lined with metal sheets be constructed (with proper ventilation) to enclose the RF source.
- 5) The leakage of RF at waveguide connections raises the minimum cross-section that can be measured. By using RF gaskets this extraneous signal can be greatly reduced.

The next recommendation, albeit a more expensive one, could greatly enhance the capability and accuracy of the facility. Utilizing a HP 8510 Network Analyzer, a HP 8340 Synthesized Sweep Oscillator and a HP 8511A Frequency Converter very highly accurate swept frequency radar cross-section measurements can be automatically made [15].

One drawback of the current system used in AFIT's facility is the rate at which data can be obtained. A complete sample set (20 measurements) takes approximately .9 seconds to measure and store in the computer. Although this process can be shortened by using a packed BCD format for the data, only about .15 seconds will be gained. With a synthesized sweeper, the 8510 takes about .7 seconds to take 401 measurement points. In addition the 8510 provides:

A) Measurement accuracies that are ten to a hundred times more precise than previously attainable with commercially available instrumentation.

B) 45 MHz to 26.5 GHz vector testing with no change of connections.

C) Optional transformation (using Fast Fourier techniques) of error-corrected data between the frequency and time domains at speeds permitting real-time adjustments.

Perhaps the most powerful feature of the 8510 is its time domain gating capability. This is the ability to isolate a gate in time (i.e. a specific length within the chamber) and look only at the frequency response due to the item located in this gate. In effect the 8510 will look only at the area of the target and eliminate unwanted signals from the back and side walls. This can all be accomplished by utilizing the internal calibration capabilities of the 8510. The error models contained in the 8510 have been optimized for network measurements but several are more than adequate for radar cross-section measurements.

The HP 8340A Synthesized Sweeper combines a high performance synthesizer and broadband sweep oscillator into one instrument. The HP 8511A frequency converter should be used because of the large dynamic range usually associated with radar cross-section measurements.

The HP 8510 recommendation comes about as a result of a thesis written by an AFIT student comparing the characteristics of a RCS measurement range using CW nulling technique and pulse gating technique [16]. Simpson writes that RCS measurements can be enhanced utilizing a time gating technique. But in a chamber such as AFIT's, where the side walls are relatively close to the target, there is still a significant level of background interference in the gated "window". By utilizing a hybrid configuration, where both time gating and CW nulling techniques are employed, this background signal can be eliminated.

These recommendations, although varying in price, will all enhance the capability of an educational/research automated scattering measurement facility. Still, the current configuration provides a user friendly system that will give the user insight to the electromagnetic phenomenon surrounding radar cross-section measurements.

Appendix A

The following is a list of equipment used for this thesis:

Hewlett-Packard

- | | |
|-------------|-------------------------------|
| 1) HP 9836 | Desktop Computer |
| 2) HP 8350B | Sweep Oscillator |
| 3) HP 5344S | Microwave Source Synchronizer |
| 4) HP 495A | Microwave TWT Amplifier |
| 5) HP 3497A | Data Acquisition/Control Unit |
| 6) HP 7470A | 2-pen Graphics Plotter |
| 7) HP 2671A | Alphanumeric Thermal Printer |

Scientific-Atlanta

- | | |
|-------------|-----------------------------|
| 1) SA 1750 | Phase/Amplitude Receiver |
| 2) SA 1586 | Crystal-Bolometer Amplifier |
| 3) SA 1580 | Pattern Recorder |
| 4) SA 1844 | Digital Position Indicator |
| 5) SA 4116B | Remote Control Unit |
| 6) SA 5021 | High Accuracy Positioner |

Appendix B

In AFIT's chamber the HP 9836 Desktop Computer, acting as system controller, controls five devices. Each device is capable of being a Listener, Talker and/or Controller. These devices are listed below with their appropriate capabilities and HP-IB addresses.

<u>Device</u>	<u>Capabilities</u>	<u>Address.</u>
HP 9836 Desktop Computer	Listener, Talker Controller	N/A
HP 8350B Sweep Oscillator	Listener	719
HP 5344A Source Synchronizer	Listener, Talker	704
HP 3497A Data Acquisition	Listener, Talker	709
HP 2671A Thermal Printer	Listener	701
HP 7470A Graphics Plotter	Listener	705

Appendix C

This appendix describes in greater detail the flow and structure of the software program written for AFIT's facility. The program can be broken into two main subroutines: Begin and Main_menu. As shown in Fig. 18 after the user enters Main_menu, two paths may be taken depending on the user's needs (i.e. to plot data already stored or to make a new measurement). The reader is advised to reference the listing in Appendix D to better follow this appendix.

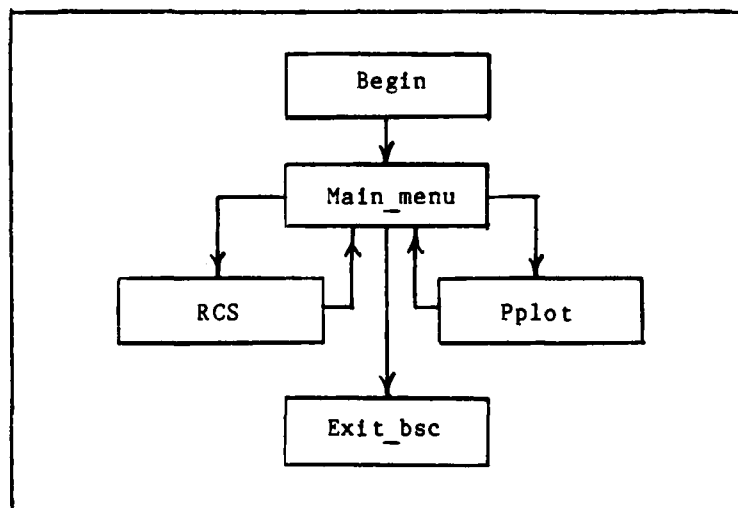


Fig. 18 Main Program

Begin

The first subroutine, Begin, introduces the user to AFIT's facility. The user is instructed on the three types of queries the computer generates: 1) type the appropriate answer followed by depressing the ENTER key, 2) press the appropriate soft key or 3) press

the CONTINUE key. The routine also tells the user what equipment should be on (namely all) and asks for the date and time. The date and time information is stored with the data when a radar cross-section measurement is made. This allows the information to be included in the legend when a plot is made.

Main menu

This subroutine allows the student to choose between the two main purposes of the program, i.e. to plot data previously stored on disk or to make, store and plot a new radar cross-section measurement. In addition it provides the user a way to exit back to BASIC.

Pplot. If the student requires a plot of data that was previously stored on a disk the "PLOT" soft key would be pressed as instructed by the main menu. This would get the user into Pplot. The passed parameters of this subroutine are:

Plot_dt (2,365).....A 2 x 365 array containing two dat sets, one in each row. There are 360 data sets stored corresponding to 0-359 degrees aspect angle (one data set per degree). The data stored is in dBsm.

View (365).....An array used to retrieve data from the disk and transfer to Plot_dt (*) (note: a variable with (*) signifies an array). Also used to view the data on the CRT. Included in View (*) are also the frequency and polarity information of that particular data set.

Frl.....Frequency of data set 1 (GHz).

Polarity1.....Polarity of data set 1 (vertical=0, horizontal=1)

Dtel\$.....Date data set 1 was taken.

Timel\$.....Time data set 1 was taken (ex. 13:23:10).

Fr2.....Frequency of data set 2.
 Polarity2.....Polarity of data set 2.
 Dte2\$.....Date data set 2 was taken.
 Time2\$.....Time data set 2 was taken.
 Ymax.....The maximum value of the radar cross-section data
 set(s). Used for scaling of plot.
 Ymin.....The minimum value of the radar cross-section data
 set(s). Used for scaling of plot.
 Dbl_flag.....Flag to indicate a double set of data will be
 plotted.
 Help.....Flag to get user back to Main_menu.

As seen in Fig. 19 the first subroutine called in Pplot is
 Plt_sgl_dbl. This routine allows the user to choose between a single
 or double set of data to be plotted. The user is also given the chance
 to escape back to the main menu. After choosing between "Single" or
 "Double" by soft key the Dbl_flag is set to either 1 or 2. The user is
 then instructed to insert the disk containing the data into disk drive
 0 (right-hand drive). The user is queried to see if he wishes a
 listing of the disk (default being no).

After viewing the listing the student is prompted for the name of
 the first file. If the user enters a file name that does not exist on
 the disk an error message is generated and the user is prompted again
 for the first file name. When a good file name is input the radar
 cross-section, frequency and polarity data is transferred to View(*).
 From there the radar cross-section data is transferred to the first
 column in Plot_dt (*), the frequency data to Fr1 and polarity data to
 Polarity1. In addition the time and date information is retrieved from

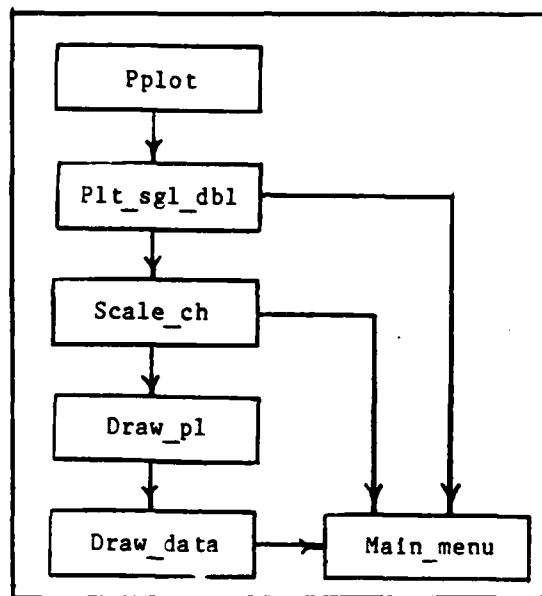


Fig. 19. Pplot Subroutine

the disk and stored in the appropriate string variables.

At this point View_crt is called. View_crt takes the radar cross-section data passed in View (*) and plots this information on the CRT. The user can then visually inspect the data, dump the data to the printer for a quick copy and/or continue. If this is not the data set the user really wanted to use he may then re-choose and begin the process over again by pressing the soft key "RE-DO". After viewing the data on the CRT, control is passed back to Plt_sgl_dbl. If the "Double" key was pressed (Dbl_flag=2) then the whole process is repeated for the second set of data. The only difference is that the radar cross-section data is now stored in the second column of Plot_dt(*).

After the radar cross-section data set(s) are stored in Plot_dt(*), Scale_ch is called. This subroutine, common to both Pplot and RCS, allows the student to select a computer generated scale or a user generated scale for the plot. The maximum and minimum values of the radar cross-section data are displayed on the CRT. The student must press the "Auto Scale" or "User" soft key. If "Auto Scale" is pressed the software adds 10 dB to the maximum value and subtracts 10 dB from the minimum value. It then rounds these new values to the nearest ten. This establishes a scale where the data fills the majority of the plot and the range of radar cross-section axes is divisible by 10. If the "User" soft key is pressed the student is queried to enter the maximum and minimum value for the radar cross-section scale. If the maximum is less than or equal to the minimum the student is notified and asked again for the appropriate values. In both cases (Auto Scale

and User) the maximum and minimum values of the axis are passed in the Ymax and Ymin variables for the next subroutine, Draw_pl.

Draw_pl is a subroutine common to both RCS and Pplot. After pausing to ensure that paper and pens are in the plotter, the subroutine draws the basic grid of the plot on the HP plotter. Next the aspect angles in degrees are drawn on the abscissa with 180 degrees at the center. The major tick marks are drawn at 45 degree intervals with minor ticks drawn every five degrees. Using Ymax and Ymin the RCS (dBsm) ordinate axis is drawn to scale. The major and minor tick marks are dependent on the range of Ymax and Ymin. If the computer generated Ymax and Ymin a major tick mark is drawn every 10 dB. If the user generated the scale the major tick marks are at every tenth of the range.

The data itself is drawn using the common subroutine Draw_data. If only one data set is being plotted (Dbl_flag=1) then the data and legend are drawn in a different color than the plot grid. The legend contains the file name, date and time the measurement was taken, the frequency of the oscillator during the measurement and the polarity of the electric field.

If two data sets are being plotted the first data set and legend are drawn in the same color as the grid with the second data set and legend drawn in the remaining color. After the complete plot is drawn the paper is positioned towards the user for easy removal.

At this point Pplot is completed and the user is returned back to the main menu.

Rcs. To make a radar cross-section measurement the user must press the "RCS" soft key while on the main menu. This calls the other major subroutine Rcs. The passed parameters include:

Dt (750,23).....A 750 x 23 array that contains the raw data voltage measurements) that the data acquisition unit takes in. The actual values of the columns will be explained with the Target subroutine

Dummy (750,3).....A 750 x 3 array that contains the data from Dt(*) after being averaged and reduced. The first column contains the time (in sec) of sampling. The second column contains amplitude measurements and the third column contains the phase measurement.

Good (361,2).....A 361 x 2 array that contains the data from Dummy(*) in a truncated version. Since the positioner actually travels more than 360 degrees Good(*) starts when the target crosses 0 degrees and ends when the target crosses 360 degrees at one data set (amplitude and phase) per degree.

Plot_dt(*).....Same array as in Pplot. Contains the actual radar cross-section data in dBsm that will be plotted.

Frl.....Frequency of measured data.

Polarity1.....Polarity of electric field used in measured data.

Timel\$.....Time target measurement was started.

Dtel\$.....Date target measurement was taken.

Fr2.....Frequency of data set 2.

Polarity2.....Polarity of electric field of data set 2.

Dte2\$.....Date of data set 2.

Timel\$.....Time of data set 1.

Ec_amp.....Amplitude (volts) of the backscatter signal from the empty chamber.

Ec_phase.....Phase (volts converted to degrees) of the
backscatter signal from the empty chamber.

Std_ec_amp.....Amplitude of the backscatter signal from the
standard target and chamber.

Std_ec_phase.....Phase of the backscatter signal from the
standard target and chamber.

Degf.....The degree the positioner is on at beginning
of revolution (full reverse limit).

Degl.....The degree the positioner is on at the end
of the revolution (full forward limit).

Rcs_stndrd.....The mathematical prediction of the radar
cross-section of the standard target (dBsm).

I.....The number of data samples taken (i.e.
length of Dt(*)).

Dt_lgth.....The number of data samples between 0 and 360
degrees.

Referring to Fig. 20 the first subroutine called in RCS is Configure. Configure allows the user to remotely program the sweep oscillator and synchronizer to the user supplied frequency. This frequency is loaded into the variable Frl for transfer to other subprograms. The student is also queried for the polarity (Polarity1) of the antennas with default being vertical. The software continues on after receiving a response from the synchronizer that it has locked onto the desired frequency and calls Empty_chamber.

Empty_chmbr measures the phase and amplitude of the backscatter signal from the empty chamber. The program is paused while the user ensures that the chamber is empty, the receiver is locked on the signal and the backscatter signal is cancelled as much as possible. The cancellation is achieved by adjusting the coupled signal in phase and

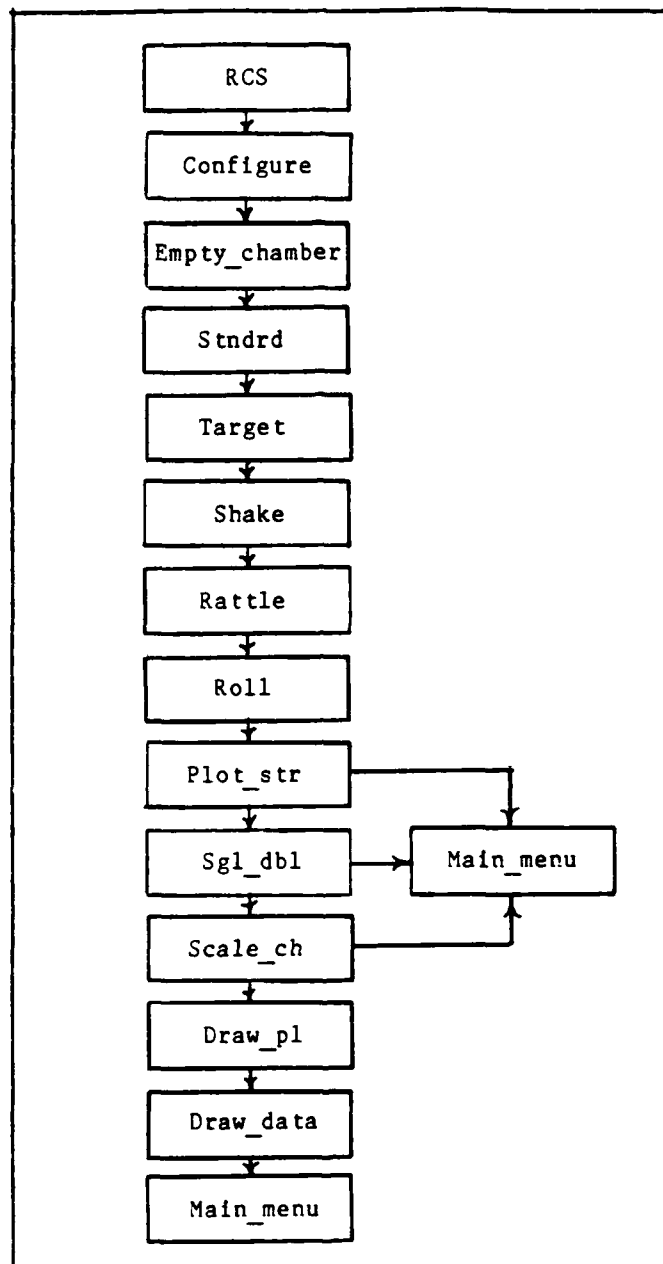


Fig. 20. Rcs Subroutine

amplitude to be 180 degrees out of phase and equal in amplitude to the backscattered signal. When this is accomplished the software directs the Data Acquisition unit to take 90 measurements each of the amplitude and phase. The average amplitude and phase of the signal are stored in the variables Ec_amp and Ec_phase respectively.

The subroutine Standard measures the amplitude and phase of the backscatter signal from the chamber with the standard target in place. The program is paused while the student places the standard (assumed to be a sphere) target on the positioner inside the chamber. The student is then prompted for the diameter of the standard sphere to compute the mathematical radar cross-section to be placed into Rcs_stdnd. The default value for the diameter is 5 inches (diameter of the sphere fabricated by the model shop). At this point the Data Acquisition unit again takes 90 samples each of the amplitude and phase output and places the average value into Std_ec_amp and Std_ec_phase.

The next subroutine called is Target. This subroutine measures the amplitude and phase of the backscattered signal from the chamber and target. The program is paused while the student places the target on the positioner. After rotating the positioner to the reverse limit (reverse limit light on) the user enters the degree reading from the position indicator into the variable Degf. The Data Acquisition unit then continuously samples the reverse limit light circuit. When the user begins to rotate the positioner the light will go off and a voltage appears across the circuit. At that point the internal clock of the computer is sampled and this start time is stored in Time\$. The Data Acquisition unit then begins taking 9 samples each of the

amplitude and phase outputs. In addition the forward limit light circuit is sampled. After unloading the 20 samples (9 amplitude, 9 phase, reverse light circuit, forward light circuit) into an intermediate array the information is placed into Dt(*). The amplitude samples are put into the even columns for 4 to 20, the phase samples into the odd columns 5 to 21, the reverse limit circuit voltage into column 22 and the forward limit circuit voltage in column 23. The time of each set of samples is placed into the first column. This whole procedure is repeated until a voltage appears accross the forward limit circuit. This indicates that the positioner has finished rotating.

The user must then enter the final setting of the positioner in the degrees indicated on the positioner indicator. This variable, Degl, is used with Degf to compute the total degrees that the positioner has traveled. If the rotation rate of the positioner is too slow, Dt(*) array size will be exceeded. When this occurs the user will be required to restart the rotation process but at a faster rotation rate.

To complete the subroutine the nine samples of amplitude and the nine samples of phase for each sample set are averaged and placed into the second and third column respectively of Dt(*). The end result is that the time of the measured sample set is in column one with the average amplitude and average phase in columns two and three respectively.

The next three subroutines, Shake, Rattle and Roll perform the actual "number-crunching" of the data. Shake takes the time of each sample set (first column is Dt(*)) and translates this to the actual

position of the positioner in degrees. This is accomplished by computing the total number of degrees rotated ($\text{Total_deg} = 720 + \text{Degl} - \text{Degf}$), dividing this by the total time of rotation to arrive at the rotation rate. By multiplying the rotation rate with the time elapsed from the initial measurement, the degrees rotated since the initial measurement will be obtained. By adding Degf to this, the actual position of the positioner at each sample set will be derived. These values are then rounded to the nearest degree. Since the only measurements of interest are those when the positioner was between 0 and 360 degrees, Dt(*) is truncated to include only the degrees of interest and placed into Dummy(*)).

The length of Dummy(*) will reflect one of three conditions: 1) more than one sample set per degree ($\text{Dt_lgth} > 361$), 2) one sample set per degree ($\text{Dt_lgth} = 361$) and 3) less than one sample set per degree ($\text{Dt_lgth} < 361$).

When Dt_lgth is greater than 361 some of the degrees will be repeated. If this condition exists Rattle goes through Dummy(*) and finds which degrees are repeated. The routine then finds the average measured values for that degree of position and translates that information to the array Good(*). This array is 361 rows long (0 to 360 degrees) with each row containing the measured or average of the amplitude and phase value.

If Dt_lgth is equal to 361 then Dummy(*) is transferred directly to Good(*) since the sample rate was exactly one sample set per degree.

Finally if Dt_lgth is less than 361 some position values will be missed. Rattle establishes which and how many degrees are missing. It

then creates a value for the missing degree that is proportional to the known value surrounding the missed values. For example if the phase measurements at 90 and 93 degrees were 1 and 4 VDC respectively the software would assign values of 2 and 3 VDC to 91 and 92 degrees respectively. The final result is that at the end of Rattle Good(*) will have 361 amplitude values and 361 phase values, one set for each degree of position.

The final "number-crunching" subroutine is called Roll. Roll takes the values of amplitude and phase from Good(*) and combines them with Ec_amp, Ec_phase, Std_ec_amp, Std_ec_phase and Rcs_stndr to arrive at the value for the radar cross-section of the target at the respective aspect angle in dBsm. This is accomplished through the use of vector subtraction as explained in Chapter 4. All this information is transferred to the array Plot_dt(*). This array contains the plot data for a particular target and is used when preparing a plot for the CRT or plotter.

The next subroutine the user encounters is Plot_str. In this routine the user must assign a file name to the measured data. Once the file name is entered into Dt_fill\$, View_crt is called to display the file on the CRT for verification. From that point a decision to store the data on disk, plot the data or return to the main menu must be made. If the decision to store the data is made the user will be prompted to insert the storage disk into drive 0 (right-hand drive). After this is completed two files are created. In order to conserve space on the disk one BDAT file is created to contain the plot data, frequency and polarity with respect to the measured target. Since this

information will be accessed as a whole unit only one record is created 2960 bytes long. This gives the room necessary for 362 real numbers (360 radar cross-section values, frequency in GHz and a polarity value of 0 or 1). To store the string variables, Dtel\$ and Timel\$, a second BDAT file is created two records long, 30 bytes/record. This allows the two string variables to be up to 26 characters long apiece. The file name of this file is the lower case version of the original file name in Dt_filel\$. For this reason Dt_filel\$ must contain at least one upper case character. After the storage is completed the "Plot/Store" menu is returned to the CRT.

If a decision is made to plot the data ("Plot" soft key is pressed) the user will no longer be able to store the data previously measured. If the user does press "Plot" the next menu will be from the subroutine Rcs_sgl_dbl. In this menu the user must decide to have either one data set plotted or two data sets plotted. This routine is very similar to Plot_sgl_dbl with the following exception. Since the current radar cross-section data is already in Plot_dt(*)'s first column (from subroutine Roll). A decision to plot a single data set results in Dbl_flag being set to one and then an exit from subroutine Plot_sgl_dbl. A decision to plot two data sets results in Dbl_flag being set to 2 and a query for the file name of the second data set. Just as in Plot_sgl_dbl the data is loaded from the storage disk and the subroutine is exited.

The remaining subroutines Scale_ch, Draw_pl and Draw_dt are common to both Rcs and Pplot. Since these routines were previously discussed earlier the reader is directed to review the appropriate section under

Pplot for the description of those subroutines.

As with Pplot, control of the program is returned to Main_menu when the plot is completed. From that point the user may exit the program by depressing "Exit" or continue on to RCS or PLOT. If the user exits the program he will be reminded to shut off all equipment before the program is scratched and returned to BASIC.

Appendix D

The following listing is the software written for this thesis for AFIT's scattering measurement facility. The reader is directed to Appendix C for a detailed description of the flow and structure of the program.

```
10  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
20  !
30  !       Software for AFIT's
40  !       Automated Scattering
50  !       Measurement Facility
60  !
70  !       written by
80  !       David G. Mazur
90  !
100 !       Revision Record
110 !       26 Nov 85
120 !
130 !       Consult thesis, Appendix C,
140 !       for description of structure
150 !       and flow.
160 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
170 MASS STORAGE IS ":INTERNAL,4,0"
180 ABORT 7
190 GRAPHICS OFF
200 OPTION BASE 1
210 CLEAR 7
220 CALL Begin(Dtel$)
230 CALL Main_menu(Dtel$)
240 PRINT "You are now back in BASIC."
250 END
260 !
270 !
280 SUB Begin(Dtel$)
290   CALL Heading
300   PRINT "      ";CHR$(129);"*
      *";CHR$(128)

310   PRINT "      ";CHR$(129);"*
      Welcome to AFIT's Automated Scatteri
ng Measurement      *";CHR$(128)
320   PRINT "      ";CHR$(129);"* F
      acility. Please answer the computer gen
erated queries      *";CHR$(128)
330   PRINT "      ";CHR$(129);"* u
      sing the three types of protocol: 1) Ty
pe in appropriate      *";CHR$(128)
340   PRINT "      ";CHR$(129);"* a
      nswer followed by depressing the ENTER k
ey, 2) Press      *";CHR$(128)
350   PRINT "      ";CHR$(129);"* t
      he appropriate soft key or 3) Press CONT
INUE.      *";CHR$(128)
360   PRINT "      ";CHR$(129);"*
      *";CHR$(128)
370   PRINT "      ";CHR$(129);"*
      At this time ensure that ALL equipme
nt is turned on.      *";CHR$(128)
380   PRINT "      ";CHR$(129);"* P
      ay close attention to equipment on HP-IB
      (i.e. printer,      *";CHR$(128)
390   PRINT "      ";CHR$(129);"* p
      lotter, sweep osc. synchronizer and data
      acquisition.      *";CHR$(128)
400   PRINT "      ";CHR$(129);"* I
      f the program 'crashes', verify that all
      equipment is      *";CHR$(128)
410   PRINT "      ";CHR$(129);"* t
```

```

turned on before RESETting and RUNNING th
e program.      *";CHRS(128)
420 PRINT "      ";CHRS(129);"-----"
*****";CHRS(128)
430 INPUT "Enter today's date.",Dte1$
440 INPUT "Enter present hour (milit
ary time).",Hours
450 INPUT "Enter present minutes.",M
inutes
460 SET TIME Hours*3600+Minutes*60
470 SUBEND
480 !
490 !
500 SUB Main_menu(Dte1$)
510 DIM Dt(750,23),Dummy(750,3),Good
(361,3),Plot_dt(370,3)
520 Begin:Flag_rcs_plt=0
530 Help=0
540 OFF KEY
550 CALL Clear_crt
560 CALL Heading
570 PRINT "      "
580 PRINT "      "
MAIN MENU
590 PRINT "      "
600 PRINT "      "
*****
610 PRINT ""
620 PRINT ""
630 PRINT ""
640 PRINT ""
650 PRINT "      ";CHRS(129);"RCS";
CHRS(128);".....Take RCS measuremen
t."
660 PRINT ""
670 PRINT "      ";CHRS(129);"PLOT"
;CHRS(128);".....Plot data already
stored on disc."
680 PRINT ""
690 PRINT "      ";CHRS(129);"EXIT"
;CHRS(128);".....Exit back to BASIC
."
700 ON KEY 5 LABEL "      RCS" GOTO C_
rcs
710 ON KEY 7 LABEL "      PLOT" GOTO C
_pplot
720 ON KEY 9 LABEL "      EXIT" GOTO C
_exit
730 ON KEY 0 GOTO Idle
740 ON KEY 1 GOTO Idle
750 ON KEY 2 GOTO Idle
760 ON KEY 3 GOTO Idle
770 ON KEY 4 GOTO Idle
780 ON KEY 6 GOTO Idle
790 ON KEY 8 GOTO Idle

```

```

800 Idle:DISP "Enter appropriate soft ke
y."
810 GOTO Idle
820 C_rcs:OFF KEY
830 CALL Rcs(Dt(*),Dummy(*),Good(*),
Plot_dt(*),Dte1$)
840 GOTO Begin
850 C_pplot:OFF KEY
860 CALL Pplot(Plot_dt(*),Good(*))
870 GOTO Begin
880 C_exit:OFF KEY
890 CALL Exit_bsc
900 SUBEND
910 !
920 !
930 SUB Rcs(Dt(*),Dummy(*),Good(*),Plo
t_dt(*),Dte1$)
940 ABORT 7
950 CALL Clear_crt
960 CALL Configure(Fr1,Polarity1)
970 CALL Empty_chmbr(Ec_amp,Ec_phase)
980 CALL Stndrd(Std_ec_amp,Std_ec_ph
ase,Rcs_stndrd)
990 CALL Target(Dt(*),Degf,Degl,I,Ti
me1$)
1000 CALL Shake(Dt(*),Dummy(*),Degf,D
egl,I,Dt_lgth)
1010 CALL Rattle(Dummy(*),Good(*),Dt_
lgth)
1020 CALL Roll(Plot_dt(*),Good(*),Ec_
amp,Ec_phase,Std_ec_amp,Std_ec_phase,Rcs
_stndrd,Help)
1030 IF Help=1 THEN SUBEXIT
1040 CALL Plot_str(Plot_dt(*),Fr1,Poi
arity1,Time1$,Dte1$,Dt_file1$,Help)
1050 IF Help=1 THEN SUBEXIT
1060 CALL Sgl_dbl(Dbl_flag,Plot_dt(*),
Dte2$,Dt_file2$,Fr2,Polarity2,Time2$,He
lp)
1070 IF Help=1 THEN SUBEXIT
1080 CALL Scale_ch(Ymax,Ymin,Dbl_flag
,Plot_dt(*),Help)
1090 IF Help=1 THEN SUBEXIT
1100 CALL Draw_pl(Ymax,Ymin)
1110 CALL Draw_data(Plot_dt(*),Ymax,Y
min,Dte1$,Dt_file1$,Fr1,Polarity1,Time1$
,Dt_file2$,Dte2$,Dbl_flag,Fr2,Polarity2,
Time2$)
1120 SUBEND
1130 !
1140 !
1150 SUB Heading
1160 CALL Clear_crt
1170 PRINT "      ";CHRS(129);"-----"
*****";CHRS(128)
1180 PRINT "      ";CHRS(129);"
";CHRS(128)
1190 PRINT "      ";CHRS(129);"
AFIT'S AUTOMATED SCATTERING MEASUREMENT

```

```

ENT FACILITY      *":CHRS(128)
1200 PRINT "      ";CHRS(129);" "
      *":CHRS(128)
1210 PRINT "      ";CHRS(129);"*****"
      *":CHRS(128)
1220 SUBEND
1230 !
1240 !
1250 SUB Configure(Fr1,Polarity1)
1260 CALL Clear_crt
1270 CALL Heading
1280 PRINT "      "
      *":CHRS(128)
1290 PRINT "      "
      RCS SYSTEM CONFIGURATION
1300 PRINT "      "
      *":CHRS(128)
1310 PRINT "      *****"
      *":CHRS(128)
1320 Polarity1=0
1330 INPUT "CW Frequency (GHz) = ?","Fr1
1340 OUTPUT 719;"CW";Fr1;"GZ RF1"
1350 OUTPUT 704;"SR08 PF";Fr1;"G PL"
      REPLACE WITH "CW";Fr1;"GZLK1
" WITH HP CNTR/SYNC
1360 ON INTR 7 GOTO 1390
1370 ENABLE INTR 7:2
1380 GOTO 1380
1390 INPUT "Enter polarity of antenna
s: 0 = vert, 1 = horz (default is vert).
",Polarity1
1400 SUBEND
1410 !
1420 !
1430 SUB Empty_chmbr(Ec_amp,Ec_phase)
1440 OPTION BASE 1
1450 DIM A(18)
1460 DIM M(10,18)
1470 Amp_sum=0
1480 Phase_sum=0
1490 CLEAR 709
1500 CALL Clear_crt
1510 CALL Empty_hdg
1520 PRINT "      "
      Ensure th
at the receiver is locked on the signal.
1530 PRINT "      "
      Adjust ph
ase shifter and attenuator at this time.
1540 PRINT ""
1550 PRINT "      "
      Pr
ess ";CHRS(131);"CONTINUE";CHRS(128);" "
hen chamber is empty."
1560 PAUSE
1570 CALL Clear_crt
1580 CALL Empty_hdg
1590 ON INTR 7 GOTO 1620

1600 ENABLE INTR 7:2
1610 GOTO 1610
1620 PRINT "
      Please wait."
1630 PRINT "      "
      The
system is taking measurements."
1640 OUTPUT 709;"VT4 VS1 SD0 VR4 VF1"
1650 FOR I=1 TO 10
1660 OUTPUT 709;"AF00 AL17 AE1 VS1
VN18 AC00 SD1 VT3 VS"
1670 ENTER 709:A(=)
1680 FOR J=1 TO 18
1690 M(I,J)=A(J)
1700 NEXT J
1710 NEXT I
1720 CALL Clear_crt
1730 CALL Empty_hdg
1740 PRINT "
      Thank you."
1750 WAIT .75
1760 FOR I=1 TO 10
1770 FOR J=1 TO 17 STEP 2
1780 Amp_sum=Amp_sum+M(I,J)
1790 Phase_sum=Phase_sum+M(I,J+1)
1800 NEXT J
1810 NEXT I
1820 Ec_amp=Amp_sum/90
1830 Ec_phase=Phase_sum*(-100/90)
1840 CALL Clear_crt
1850 SUBEND
1860 !
1870 !
1880 SUB Empty_hdg
1890 CALL Heading
1900 PRINT "      "
      *":CHRS(128)
1910 PRINT "      "
      CALIBRATION OF EMPTY CHAMBER
1920 PRINT "      "
      *":CHRS(128)
1930 PRINT "      *****"
      *":CHRS(128)
1940 PRINT ""
1950 PRINT ""
1960 SUBEND
1970 !
1980 !
1990 SUB Stndrd(Std_ec_amp,Std_ec_phase
,Rcs_stndrd)
2000 Amp_sum=0
2010 Phase_sum=0
2020 Diam=0
2030 OPTION BASE 1
2040 DIM A(18)
2050 DIM M(10,18)
2060 CLEAR 709
2070 CALL Clear_crt
2080 CALL Stndrd_hdg
2090 PRINT "      "
      Press ";C

```

```

HRS(131);"CONTINUE";CHRS(128);" when sta
ndard target is in chamber."
2100 PAUSE
2110 CALL Clear_crt
2120 CALL Stndrd_hdg
2130 INPUT "Enter the diameter (inch)
of the standard sphere used (default =
5 inch)",Diam
2140 IF Diam=0 THEN Diam=5
2150 Rcs_stndrd=10*LGT(PI*(Diam*.0254
/2)^2)
2160 CALL Clear_crt
2170 CALL Stndrd_hdg
2180 ON INTR 7 GOTO 2210
2190 ENABLE INTR 7;2
2200 GOTO 2200
2210 PRINT "
PLEASE WAIT."
2220 PRINT " THE
SYSTEM IS TAKING MEASUREMENTS."
2230 OUTPUT 709;"VT4 VS1 SDO VR4 VF1"
2240 FOR I=1 TO 10
2250 OUTPUT 709;"AF00 AL17 AE1 VS1
VN18 AC00 S01 VT3 VS"
2260 ENTER 709:A(*)
2270 FOR J=1 TO 18
2280 M(I,J)=A(J)
2290 NEXT J
2300 NEXT I
2310 CALL Clear_crt
2320 CALL Stndrd_hdg
2330 PRINT "
THANK YOU."
2340 WAIT .75
2350 FOR I=1 TO 10
2360 FOR J=1 TO 17 STEP 2
2370 Amp_sum=Amp_sum+M(I,J)
2380 Phase_sum=Phase_sum+M(I,J+1)
2390 NEXT J
2400 NEXT I
2410 Std_ec_amp=Amp_sum/90
2420 Std_ec_phase=Phase_sum*(-100/90)
2430 SUBEND
2440 !
2450 !
2460 SUB Stndrd_hdg
2470 CALL Heading
2480 PRINT "
"
2490 PRINT " CA
LIBRATION WITH STANDARD TARGET
"
2500 PRINT "
"
2510 PRINT "
=====
=====
2520 PRINT ""
2530 PRINT ""
2540 SUBEND
2550 !

2560 !
2570 SUB Target(Dt(*),Degf,Degl,I,Time1
s)
2580 Amp_sum=0
2590 Phase_sum=0
2600 OPTION BASE 1
2610 DIM A(20)
2620 CALL Clear_crt
2630 CALL Target_hdg
2640 PRINT " Pres
s ";CHRS(131);"CONTINUE";CHRS(128);" whe
n target is in place."
2650 PAUSE
2660 CALL Clear_crt
2670 CALL Target_hdg
2680 PRINT " Adj
ust positioner to the reverse limit."
2690 INPUT "What degree is positioner
on?",Degf
2700 CALL Clear_crt
2710 CALL Target_hdg
2720 ON INTR 7 GOTO Start
2730 ENABLE INTR 7;2
2740 GOTO 2740
2750 Start:OUTPUT 709;"VT4 AE0 VS0 SDO V
R3 VF1"
2760 PRINT "
Begin rotating positioner."
2770 PRINT ""
2780 PRINT ""
2790 Lloop:OUTPUT 709;"AC19 S01 VT3"
2800 ENTER 709:R
2810 IF R<50 AND R>-50 THEN GOTO Pl_w
ait
2820 GOTO Lloop
2830 Pl_wait:PRINT " Pleas
e wait. The system is taking measuremen
ts."
2840 FOR I=1 TO 750
2850 Time1S=TIMES(TIMEDATE)
2860 Dt(I,1)=TIMEDATE MOD 86400
2870 OUTPUT 709;"VT4 AF00 AL19 AE1
VS1 VN20 AC00 S01 VT3 VS"
2880 ENTER 709:A(*)
2890 FOR J=1 TO 20
2900 Dt(I,J+3)=A(J)
2910 NEXT J
2920 IF Dt(I,22)>50 OR Dt(I,22)<-50
THEN GOTO 2990
2930 NEXT I
2940 CALL Clear_crt
2950 CALL Target_hdg
2960 PRINT "You have exceeded the arr
ay size. You must increase the speed.
Press 'CONTINUE'."
2970 PAUSE
2980 GOTO 2580
2990 CALL Clear_crt
3000 BEEP
3010 CALL Target_hdg
3020 INPUT "Enter final position of p

```

```

ositioner (DEG).".Degl
3030   FOR K=1 TO I
3040     Amp_sum=0
3050     Phase_sum=0
3060     FOR J=4 TO 20 STEP 2
3070       Amp_sum=Amp_sum+Dt(K,J)
3080       Phase_sum=Phase_sum+Dt(K,J+1)
3090     NEXT J
3100     Dt(K,2)=Amp_sum/9
3110     Dt(K,3)=Phase_sum/9
3120   NEXT K
3130 SUBEND
3140 !
3150 !
3160 SUB Target_hdg
3170   CALL Heading
3180   PRINT "
3190   PRINT "
3200   PRINT "
3210   PRINT "
3220   PRINT ""
3230   PRINT ""
3240 SUBEND
3250 !
3260 !
3270 SUB Shake(Dt(*),Dummy(*),Degf,Degl
,I,Dt_lgth)
3280   PRINT ""
3290   PRINT ""
3300   PRINT "
LOW OBSERVABLES"
3310   PRINT ""
3320   Flag=0
3330   K=0
3340   Total_deg=720+Degl-Degf
3350   Total_time=Dt(I,1)-Dt(1,1)
3360   Rot_rate=Total_deg/Total_time
3370   Time1=Dt(1,1)
3380   FOR J=1 TO I
3390     Dt(J,1)=(Dt(J,1)-Time1)*Rot_r
ate)+Degf
3400     Dt(J,1)=PROUND(Dt(J,1),0)
3410     Dt(J,3)=Dt(J,3)*(-100)
3420     IF Dt(J,1)>360 OR Dt(J,1)<360
THEN Dt(J,1)=Dt(J,1)-360
3430   NEXT J
3440   FOR J=1 TO I
3450     IF Flag>0 THEN GOTO Test
3460     IF Dt(J,1)<10 THEN GOTO Set_flg
ag
3470     GOTO Next_J
3480   Set_flg:Flag=J
3490   Test:IF Dt(J,1)>360 THEN GOTO Set_l
gth

3500     K=K+1
3510   Next_J:NEXT J
3520   Set_lgth:Dt_lgth=K
3530   FOR J=1 TO K
3540     FOR L=1 TO 3
3550       Dummy(J,L)=Dt(J+Flag-1,L)
3560     NEXT L
3570   NEXT J
3580 SUBEND
3590 !
3600 !
3610 SUB Rattle(Dummy(*),Good(*),Dt_lgt
h)
362   PRINT "
The less you see"
3630   FOR J=1 TO 361
3640     Good(J,1)=J-1
3650   NEXT J
3660   IF Dt_lgth>361 THEN GOTO Repeats
!REPEATS
3670   IF Dt_lgth<361 THEN GOTO Misses
!MISSES
3680   FOR J=1 TO Dt_lgth-1
3690     Good(J,2)=Dummy(J,2)
3700     Good(J,3)=Dummy(J,3)
3710   NEXT J
3720 SUBEXIT
3730 Repeats:K=1
! REPEATS
3740   FOR J=1 TO Dt_lgth-1
3750     Amp=0
3760     Phase=0
3770     L=1
3780     IF Dummy(J,1)=Dummy(J+L,1) THE
N
L=L+1
3790   ELSE
3800     IF L>1 THEN GOTO 3880
3810     Good(K,2)=Dummy(J,2)
3820     Good(K,3)=Dummy(J,3)
3830     K=K+1
3840     GOTO 3990
3850   END IF
3860   GOTO 3780
3870   FOR M=0 TO L-1
3880     Amp=Amp+Dummy(J+M,2)
3890     Phase=Phase+Dummy(J+M,3)
3900   NEXT M
3910   Good(K,2)=Amp/L
3920   Good(K,3)=Phase/L
3930   FOR M=1 TO L-1
3940     J=J+1
3950   NEXT M
3960   K=K+1
3970   L=1
3980   NEXT J
3990

```

```

4000 GOTO Bottom
4010 Misses:IF Dummy(1,1)=0 THEN
      ! MISSES
4020 Good(1,2)=Dummy(1,2)
4030 Good(1,3)=Dummy(1,3)
4040 K=2
4050 ELSE
4060 K=1
4070 FOR L=1 TO Dummy(1,1)+1
      Good(L,2)=Dummy(1,2)
4080 Good(L,3)=Dummy(1,3)
4090 K=K+1
4100 NEXT L
4110 END IF
4120 FOR J=2 TO Dt_lgth
      Test=Dummy(J,1)-Dummy(J-1,1)
4140 IF Test=1 THEN GOTO 4240
4150 Amp=Dummy(J,2)-Dummy(J-1,2)
4160 Phase=Dummy(J,3)-Dummy(J-1,3)
4170 FOR M=1 TO Test
      Good(K,2)=Dummy(J-1,2)+(Amp*
M/Test)
4200 Good(K,3)=Dummy(J-1,3)+(Phas
e=M/Test)
4210 K=K+1
4220 NEXT M
4230 GOTO 4270
4240 Good(K,2)=Dummy(J,2)
4250 Good(K,3)=Dummy(J,3)
4260 K=K+1
4270 NEXT J
4280 Bottom:SUBEND
4290 !
4300 !
4310 SUB Roil(Plot_dt(*),Good(*),Ec_amp
,Ec_phase,Std_ec_amp,Std_ec_phase,Rcs_st
ndrd,Help)
4320 PRINT "
the more it hurts!"
4330 ON ERROR GOTO Bottom
4340 Ec_x=Ec_amp*COS(Ec_phase)
4350 Ec_y=Ec_amp*SIN(Ec_phase)
4360 Std_ec_x=Std_ec_amp*COS(Std_ec_p
hase)
4370 Std_ec_y=Std_ec_amp*SIN(Std_ec_p
hase)
4380 Std_x=Std_ec_x-Ec_x
4390 Std_y=Std_ec_y-Ec_y
4400 Std_amp=(Std_x^2+Std_y^2)`.5
4410 FOR I=1 TO 360
      Trgt_ec_x=Good(I,2)*COS(Good(I
,3))
4430 Trgt_ec_y=Good(I,2)*SIN(Good(I
,3))
4440 Trgt_x=Trgt_ec_x-Ec_x
4450 Trgt_y=Trgt_ec_y-Ec_y
4460 Trgt_amp=(Trgt_x^2+Trgt_y^2)`.
5
4470 Rcs_trgt=Rcs_stndrd-(20*LGT(St
d_amp))+(20*LGT(Trgt_amp))
4480 Plot_dt(I,2)=Rcs_trgt
4490 Plot_dt(I,1)=I-1
4500 NEXT I
4510 OFF ERROR
4520 SUBEXIT
4530 Bottom:BEEP
4540 Help=1
4550 PRINT " The program has enco
ntered a problem. Verify that"
4560 PRINT " the receiver is stil
l in lock. You will need to "
4570 PRINT " start the measuremen
t again. Press ";CHR$(13);"CONTINUE";C
HRS(128);" when "
4580 PRINT " ready. Thank you."
4590 OFF ERROR
4600 PAUSE
4610 SUBEND
4620 !
4630 !
4640 SUB Plot_str(Plot_dt(*),Fri,Polari
ty1,Time1$,Dte1$,Dt_file1$,Help)
4650 DIM View(365)
4660 CALL Clear_crt
4670 CALL Heading
4680 CALL Plot_str_hdg
4690 PRINT ""
4700 PRINT ""
4710 PRINT ""
4720 PRINT ""
4730 Name:PRINT " The file name
must have at least one UPPER CASE lette
r in it."
4740 INPUT "Enter the filename for th
e current set of data.",Dt_file1$
4750 File_name1$=LWCS(Dt_file1$)
4760 FOR I=1 TO 360
      View(I)=Plot_dt(I,2)
4770 NEXT I
4780 CALL View_crt(View(*),Dt_file1$,
Help)
4800 CALL Clear_crt
4810 CALL Heading
4820 PRINT "
"
4830 PRINT "
DATA STORAGE OR PLOT
"
4840 PRINT "
"
4850 PRINT "
*****"
4860 PRINT ""
4870 PRINT ""
4880 PRINT " ";CHR$(129);"STORE
";CHR$(128);".....Store current dat
a."
4890 PRINT ""
4900 PRINT " ";CHR$(129);"PLOT"
";CHR$(128);".....Plot current data
"

```

```

4910 PRINT ""
4920 PRINT " ";CHR$(129);"MAIN
MENU";CHR$(128);".....Exit back to main
menu."
4930 ON KEY 5 LABEL " STORE" GOTO S
tr
4940 ON KEY 7 LABEL " PLOT" GOTO Pl
t
4950 ON KEY 0 GOTO Idle
4960 ON KEY 1 GOTO Idle
4970 ON KEY 2 GOTO Idle
4980 ON KEY 3 GOTO Idle
4990 ON KEY 4 GOTO Idle
5000 ON KEY 6 GOTO Idle
5010 ON KEY 8 GOTO Idle
5020 ON KEY 9 LABEL " MAIN MENU" GO
TO Mm
5030 Idle:DISP "Enter appropriate soft k
ey."
5040 GOTO Idle
5050 Mm:OFF KEY
5060 Help=1
5070 SUBEXIT
5080 Str:OFF KEY
5090 CALL Clear_crt
5100 CALL Heading
5110 PRINT ""
5120 PRINT ""
5130 PRINT ""
5140 PRINT ""
5150 PRINT "Insert storage disk into
right hand disk drive. Press ";CHR$(129
);"CONTINUE";CHR$(128);" when ready."
5160 PAUSE
5170 ON ERROR GOTO Err
5180 GOTO Disk
5190 Err:PRINT ERRMS
5200 GOTO Name
5210 Disk:CREATE BDAT Dt_file1$,1,2960
5220 View(361)=Fr1
5230 View(362)=Polarity1
5240 ASSIGN @Dt_file1 TO Dt_file1$
5250 OUTPUT @Dt_file1;View(=)
5260 ASSIGN @Dt_file1 TO *
5270 CREATE BDAT File_name1$,2,30
5280 ASSIGN @File_name1 TO File_name1
$
5290 OUTPUT @File_name1,1;Dt1$
5300 OUTPUT @File_name1,2;Time1$
5310 ASSIGN @File_name1 TO *
5320 SUBEXIT
5330 Plt:OFF KEY
5340 SUBEND
5350 !
5360 !
5370 SUB Plot_str_hdg
5380 PRINT "
"
5390 PRINT "
DATA STORAGE
"

```

```

5400 PRINT "
"
5410 PRINT "
*****"
5420 SUBEND
5430 !
5440 !
5450 SUB Sgl_dbl(Dbl_flag,Plot_dt(=),Dt
e2$,Dt_file2$,Fr2,Polarity2,Time2$,Help)
5460 DIM View(365)
5470 CALL Clear_crt
5480 CALL Heading
5490 CALL Sgl_dbl_hdg
5500 PRINT ""
5510 PRINT ""
5520 PRINT " ";CHR$(129);"SINGL
E";CHR$(128);".....Plot single data
set (current)."
5530 PRINT ""
5540 PRINT " ";CHR$(129);"DOUBL
E";CHR$(128);".....Plot two data se
ts (current and stored)."
5550 PRINT ""
5560 PRINT " ";CHR$(129);"MAIN
MENU";CHR$(128);".....Exit back to mai
n menu."
5570 ON KEY 5 LABEL " SINGLE" GOTO S
gl
5580 ON KEY 7 LABEL " DOUBLE" GOTO D
bl
5590 ON KEY 0 GOTO Idle
5600 ON KEY 1 GOTO Idle
5610 ON KEY 2 GOTO Idle
5620 ON KEY 3 GOTO Idle
5630 ON KEY 4 GOTO Idle
5640 ON KEY 6 GOTO Idle
5650 ON KEY 8 GOTO Idle
5660 ON KEY 9 LABEL " MAIN MENU" GO
TO Mm
5670 Idle:DISP "Enter the appropriate so
ft key."
5680 GOTO Idle
5690 Mm:OFF KEY
5700 Help=1
5710 SUBEXIT
5720 Sgl:Dbl_flag=1
5730 OFF KEY
5740 SUBEXIT
5750 Dbl:Dbl_flag=2
5760 OFF KEY
5770 CALL Clear_crt
5780 CALL Heading
5790 CALL Sgl_dbl_hdg
5800 Start:PRINT ""
5810 PRINT ""
5820 PRINT " Insert disc con
taining data file into right hand disk d
rive."
5830 PRINT ""
5840 PRINT "

```

```

Press ":CHRS(131);"CONTINUE";CHRS(128);
" when ready."
5850 PAUSE
5860 ON ERROR GOTO Err2
5870 CALL Clear_crt
5880 CALL Heading
5890 CALL Sgl_dbl_hdg
5900 INPUT "Do you wish to see listing of disk (Y or N)? Default is NO.",Llist$
5910 IF Llist$="Y" THEN
5920 CAT
5930 ON KBD GOTO Again
5940 DISP CHRS(131);"Press space bar when ready.":CHRS(128)
5950 Loop:GOTO Lloop
5960 ELSE
5970 GOTO Again
5980 END IF
5990 Again:CALL Clear_crt
6000 OFF KBD
6010 OFF ERROR
6020 CALL Heading
6030 CALL Sgl_dbl_hdg
6040 Name:INPUT "Enter the file name of the stored file.",Dt_file2$
6050 ON ERROR GOTO Err1
6060 GOTO Inbound
6070 Err1:PRINT ERRMS
6080 GOTO Name
6090 Inbound:ASSIGN @File2 TO Dt_file2$
6100 ENTER @File2:View(*)
6110 ASSIGN @File2 TO *
6120 FOR I=1 TO 360
6130 Plot_dt(I,3)=View(I)
6140 NEXT I
6150 Fr2=View(361)
6160 Polarity2=View(362)
6170 Dte_file2$=LWCS(Dt_file2$)
6180 ASSIGN @Dte_file2 TO Dte_file2$
6190 ENTER @Dte_file2,1:Dte2$
6200 ENTER @Dte_file2,2:Time2$
6210 ASSIGN @Dte_file2 TO *
6220 CALL View_crt(View(*),Dt_file2$,Help)
6230 SUBEXIT
6240 Err2:CALL Clear_crt
6250 DISP ERRMS
6260 BEEP
6270 OFF ERROR
6280 GOTO Start
6290 SUBEND
6300 !
6310 !
6320 SUB Sgl_dbl_hdg
6330 PRINT "
"
6340 PRINT "
"
F NUMBER OF DATA SETS DESIRED
6350 PRINT "
"

```

```

6360 PRINT "
*****
*****"
6370 PRINT ""
6380 PRINT ""
6390 SUBEND
6400 !
6410 !
6420 SUB Scale_ch(Ymax,Ymin,Dbl_flag,Plot_dt(*),Help)
6430 Ymin=Plot_dt(1,2)
6440 ! INITIALIZE
6450 Ymax=Ymin
6460 FOR I=2 TO Dbl_flag+1
6470 FOR J=1 TO 360
6480 IF Plot_dt(J,I)<Ymin THEN Ymin=Plot_dt(J,I)
6490 IF Plot_dt(J,I)>Ymax THEN Ymax=Plot_dt(J,I)
6500 NEXT J
6510 NEXT I
6520 CALL Clear_crt
6530 CALL Heading
6540 PRINT "
"
SCALING CHOICES
6550 PRINT "
"
6560 PRINT "
*****
*****"
6570 PRINT ""
6580 PRINT " The maximum value of the current data is ":Ymax;" (dBsm)."
6590 PRINT " The minimum value of the current data is ":Ymin;" (dBsm)."
6600 PRINT ""
6610 PRINT " ";CHRS(129);"AUTO SCALE";CHRS(128);".....Computer generates scale."
6620 PRINT ""
6630 PRINT " ";CHRS(129);"USER";CHRS(128);".....User defines scale."
6640 PRINT ""
6650 PRINT " ";CHRS(129);"MAIN MENU";CHRS(128);".....Exit back to main menu."
6660 ON KEY 5 LABEL " AUTO SCALE" GOTO Auto
6670 ON KEY 7 LABEL " USER" GOTO User
6680 ON KEY 9 LABEL " MAIN MENU" GOTO Mm
6690 ON KEY 0 GOTO Idle
6700 ON KEY 1 GOTO Idle
6710 ON KEY 2 GOTO Idle
6720 ON KEY 3 GOTO Idle

```

AD-A163 896

DESIGN METHODOLOGY OF AN AUTOMATED SCATTERING
MEASUREMENT FACILITY(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING
D G MAZUR DEC 85 AFIT/GE/ENG/85D-26

2/2

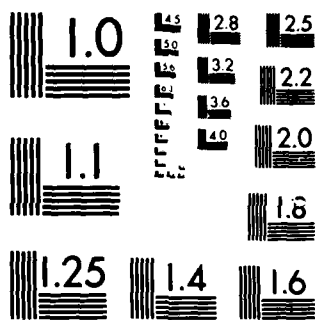
UNCLASSIFIED

F/G 17/9

NL



END
FILED
DEC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

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6730 ON KEY 4 GOTO Idle
6740 ON KEY 6 GOTO Idle
6750 ON KEY 8 GOTO Idle
6760 Idle:DISP "Enter appropriate soft key."
6770 GOTO Idle
6780 Mn:OFF KEY
6790 Help=1
6800 SUBEXIT
6810 User:CALL Clear_crt
6820 CALL Heading
6830 PRINT " "
6840 PRINT " "
      USER DEFINED SCALE
6850 PRINT " "
6860 PRINT " "
-----
6870 PRINT ""
6880 PRINT ""
6890 INPUT "Enter the maximum value of RCS scale desired.",Ymax
6900 INPUT "Enter the minimum value of RCS scale desired.",Ymin
6910 Range=Ymax-Ymin
6920 IF Range>0 THEN GOTO Good_rge
6930 BEEP
6940 IF Range=0 THEN PRINT "
      You have entered the same value for Ymin and Ymax."
6950 IF Range<0 THEN PRINT "
      Your Ymin is greater than your Ymax."
6960 PRINT ""
6970 PRINT "
      Try again!"
6980 GOTO 6890
6990 Good_rge:CALL Clear_crt
7000 OFF KEY
7010 SUBEXIT
7020 Auto:CALL Clear_crt
7030 Ymax=Ymax+10
7040 Ymax=PROUND(Ymax,1)
7050 Ymin=Ymin-10
7060 Ymin=PROUND(Ymin,1)
7070 OFF KEY
7080 SUBEND
7090 !
7100 !
7110 SUB Draw_pl(Ymax,Ymin)
7120 CALL Clear_crt
7130 CALL Heading
7140 PRINT ""
7150 PRINT ""
7160 PRINT ""
7170 PRINT "      Ensure that paper and two pens are in the plotter at this time."

7180 PRINT ""
7190 PRINT "
      Press ";CHR$(129);"CONTINUE";CHR$(128)";" when ready."
7200 PAUSE
7210 CALL Clear_crt
7220 CALL Heading
7230 PRINTER IS 705
7240 Es=CHR$(3)
7250 PRINT "IN;SP1:IP 1500,2000,9500,7500;"
7260 PRINT "SC0,360,0,100;"
7270 PRINT "PU 0,0 PD 360,0,360,100,0,100,0,0 PU;"
7280 PRINT "SI .2,.3;TL 3,0;"
7290 FOR X=45 TO 315 STEP 45
7300 PRINT "PA",X,"0,XT;"
7310 NEXT X
7320 PRINT "TL 1.5,0"
7330 FOR X=5 TO 355 STEP 5
7340 PRINT "PA",X,"0,XT"
7350 NEXT X
7360 PRINT "TL 0,3;"
7370 FOR X=45 TO 315 STEP 45
7380 PRINT "PA",X,"100,XT;"
7390 NEXT X
7400 PRINT "TL 0,1.5"
7410 FOR X=5 TO 355 STEP 5
7420 PRINT "PA",X,"100,XT"
7430 NEXT X
7440 FOR X=0 TO 360 STEP 45
7450 PRINT "PA",X,"0"
7460 IF X<10 THEN PRINT "CP -1.5,-1;LB";X;Es
7470 IF X>9 AND X<100 THEN PRINT "CP -2,-1;LB";X;Es
7480 IF X>99 THEN PRINT "CP -2.5,-1;LB";X;Es
7490 NEXT X
7500 PRINT "PA 180,0;CP -11,-2.5; LBA SPECT ANGLE (DEGREES);Es
7510 PRINT "SC0,360",Ymin,Ymax;"TL 3,0"
7520 Range=Ymax-Ymin
7530 FOR Y=Ymin+10 TO Ymax-10 STEP 10
7540 PRINT "PA0",Y,"YT"
7550 NEXT Y
7560 PRINT "TL 1.5,0"
7570 IF Range>49 THEN Little_tick=2.5
7580 IF Range<51 THEN Little_tick=2
7590 IF Range<31 THEN Little_tick=1
7600 FOR Y=Ymin+Little_tick TO Ymax-Little_tick STEP Little_tick
7610 PRINT "PA 0",Y,"YT"
7620 NEXT Y
7630 PRINT "TL 0,3"
7640 FOR Y=Ymin+10 TO Ymax-10 STEP 10
7650 PRINT "PA 360 ",Y,"YT"
7660 NEXT Y
7670 PRINT "TL 0,1.5"
7680 FOR Y=Ymin+Little_tick TO Ymax-L

```

```

little_tick STEP Little_tick
7690 PRINT "PA 360",Y,"YT"
7700 NEXT Y
7710 PRINT "TL 3.0"
7720 FOR Y=Ymin TO Ymax STEP 10
7730 PRINT "PA 0",Y;
7740 Ynum=Y
7750 Ynum=PROUND(Ynum,-2)
7760 IF Ynum<-99.99 THEN Offset=6
7770 IF Ynum>-100 AND Ynum<-9.99 TH
EN Offset=5
7780 IF Ynum>-10 AND Ynum<-9.99 THEN
Offset=4
7790 IF Ynum>-1 AND Ynum<0 THEN Off
set=3
7800 IF Ynum=0 THEN Offset=0
7810 IF Ynum>0 AND Ynum<1 THEN Offs
et=2
7820 IF Ynum>.99 AND Ynum<10 THEN O
ffset=3
7830 IF Ynum>9.99 AND Ynum<100 THEN
Offset=4
7840 IF Ynum>99.99 THEN Offset=5
7850 PRINT "CP",(-2.5)-Offset,"-.25
:LB";Ynum;ES
7860 NEXT Y
7870 PRINT "PA0",Ymin+Range/2;"DIO,1;
CP -5.5"
7880 PRINT "LBRCs (dBsm)";ES
7890 PRINT "DIO,0"
7900 PRINTER IS CRT
7910 SUBEND
7920 !
7930 !
7940 SUB Draw_data(Plot_dt(*),Ymax,Ymin
,Dte1$,Dt_file1$,Fr1,Polarity1,Time1$,Dt
_file2$,Dte2$,Dbl_flag,Fr2,Polarity2,Tim
e2$)
7950 PRINTER IS 705
7960 PRINT "SC0,360",Ymin,Ymax
7970 IF Dbl_flag=1 THEN PRINT "SP2:"
7980 PRINT "PU0",Plot_dt(1,2);
7990 FOR I=1 TO 360
8000 PRINT "PD",I-1,Plot_dt(I,2)
8010 NEXT I
8020 PRINT "PU;PA0",Ymin,";SI .15,.22
5;CP0,-5;"
8030 ES=CHRS(3)
8040 IF Polarity1=1 THEN
8050 Pol1$="HORIZONTAL"
8060 ELSE
8070 Pol1$="VERTICAL"
8080 END IF
8090 PRINT "LBFile Name: ";Dt_file1$;
ES
8100 PRINT "CP;LBDate taken: ";Dte1$;
ES
8110 PRINT "CP;LBTime taken: ";Time1$
;ES
8120 PRINT "CP;LBFrequency: ";Fr1;" G
Hz";ES
8130 PRINT "CP;LBPolarity: ";Pol1$;ES
8140 IF Dbl_flag=1 THEN GOTO Bottom
8150 PRINT "PU0",Plot_dt(1,3);
8160 PRINT "SP2:"
8170 FOR I=1 TO 360
8180 PRINT "PD",I-1,Plot_dt(I,3)
8190 NEXT I
8200 PRINT "PU;PA270",Ymin,"CP0,-5;"
8210 IF Polarity2=1 THEN
8220 Pol2$="HORIZONTAL"
8230 ELSE
8240 Pol2$="VERTICAL"
8250 END IF
8260 PRINT "LBFile Name: ";Dt_file2$;
ES
8270 PRINT "CP;LBDate taken: ";Dte2$;
ES
8280 PRINT "CP;LBTime taken: ";Time2$
;ES
8290 PRINT "CP;LBFrequency: ";Fr2;" G
Hz";ES
8300 PRINT "CP;LBPolarity: ";Pol2$;ES
8310 Bottom:PRINT "SI .2,.3;PU0",Ymin,"S
P;"
8320 PRINTER IS CRT
8330 SUBEND
8340 !
8350 !
8360 SUB Pplot(Plot_dt(*),Good(*))
8370 CALL Plt_sgl_dbl(Plot_dt(*),Fr1,
Polarity1,Time1$,Dte1$,Dt_file1$,Fr2,Pola
rity2,Time2$,Dte2$,Dt_file2$,Dbl_flag,Help)
8380 IF Help=1 THEN SUBEXIT
8390 CALL Scale_ch(Ymax,Ymin,Dbl_flag
,Plot_dt(*),Help)
8400 IF Help=1 THEN SUBEXIT
8410 CALL Draw_pl(Ymax,Ymin)
8420 CALL Draw_data(Plot_dt(*),Ymax,Y
min,Dte1$,Dt_file1$,Fr1,Polarity1,Time1$
,Dt_file2$,Dte2$,Dbl_flag,Fr2,Polarity2,
Time2$)
8430 SUBEND
8440 !
8450 !
8460 SUB Plt_sgl_dbl(Plot_dt(*),Fr1,Pola
rity1,Time1$,Dte1$,Dt_file1$,Fr2,Polarit
y2,Time2$,Dte2$,Dt_file2$,Dbl_flag,Help)
8470 DIM View(365)
8480 CALL Clear_crt
8490 CALL Heading
8500 CALL Sgl_dbl_hdg
8510 PRINT ""
8520 PRINT ""
8530 PRINT ""
8540 PRINT ""
8550 PRINT ""
8560 PRINT ""
8570 PRINT ""
8580 PRINT ""
8590 PRINT ""
8600 PRINT ""
8610 PRINT ""
8620 PRINT ""
8630 PRINT ""
8640 PRINT ""
8650 PRINT ""
8660 PRINT ""
8670 PRINT ""
8680 PRINT ""
8690 PRINT ""
8700 PRINT ""
8710 PRINT ""
8720 PRINT ""
8730 PRINT ""
8740 PRINT ""
8750 PRINT ""
8760 PRINT ""
8770 PRINT ""
8780 PRINT ""
8790 PRINT ""
8800 PRINT ""
8810 PRINT ""
8820 PRINT ""
8830 PRINT ""
8840 PRINT ""
8850 PRINT ""
8860 PRINT ""
8870 PRINT ""
8880 PRINT ""
8890 PRINT ""
8900 PRINT ""
8910 PRINT ""
8920 PRINT ""
8930 PRINT ""
8940 PRINT ""
8950 PRINT ""
8960 PRINT ""
8970 PRINT ""
8980 PRINT ""
8990 PRINT ""
9000 PRINT ""
9010 PRINT ""
9020 PRINT ""
9030 PRINT ""
9040 PRINT ""
9050 PRINT ""
9060 PRINT ""
9070 PRINT ""
9080 PRINT ""
9090 PRINT ""
9100 PRINT ""
9110 PRINT ""
9120 PRINT ""
9130 PRINT ""
9140 PRINT ""
9150 PRINT ""
9160 PRINT ""
9170 PRINT ""
9180 PRINT ""
9190 PRINT ""
9200 PRINT ""
9210 PRINT ""
9220 PRINT ""
9230 PRINT ""
9240 PRINT ""
9250 PRINT ""
9260 PRINT ""
9270 PRINT ""
9280 PRINT ""
9290 PRINT ""
9300 PRINT ""
9310 PRINT ""
9320 PRINT ""
9330 PRINT ""
9340 PRINT ""
9350 PRINT ""
9360 PRINT ""
9370 PRINT ""
9380 PRINT ""
9390 PRINT ""
9400 PRINT ""
9410 PRINT ""
9420 PRINT ""
9430 PRINT ""
9440 PRINT ""
9450 PRINT ""
9460 PRINT ""
9470 PRINT ""
9480 PRINT ""
9490 PRINT ""
9500 PRINT ""
9510 PRINT ""
9520 PRINT ""
9530 PRINT ""
9540 PRINT ""
9550 PRINT ""
9560 PRINT ""
9570 PRINT ""
9580 PRINT ""
9590 PRINT ""
9600 PRINT ""
9610 PRINT ""
9620 PRINT ""
9630 PRINT ""
9640 PRINT ""
9650 PRINT ""
9660 PRINT ""
9670 PRINT ""
9680 PRINT ""
9690 PRINT ""
9700 PRINT ""
9710 PRINT ""
9720 PRINT ""
9730 PRINT ""
9740 PRINT ""
9750 PRINT ""
9760 PRINT ""
9770 PRINT ""
9780 PRINT ""
9790 PRINT ""
9800 PRINT ""
9810 PRINT ""
9820 PRINT ""
9830 PRINT ""
9840 PRINT ""
9850 PRINT ""
9860 PRINT ""
9870 PRINT ""
9880 PRINT ""
9890 PRINT ""
9900 PRINT ""
9910 PRINT ""
9920 PRINT ""
9930 PRINT ""
9940 PRINT ""
9950 PRINT ""
9960 PRINT ""
9970 PRINT ""
9980 PRINT ""
9990 PRINT ""

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```

8550 PRINT ""
8560 PRINT " ";CHR$(129);"MAIN
MENU";CHR$(128);".....Exit back to mai
n menu."
8570 ON KEY 5 LABEL " SINGLE" GOTO S
gl
8580 ON KEY 7 LABEL " DOUBLE" GOTO D
bl
8590 ON KEY 0 GOTO Idle
8600 ON KEY 1 GOTO Idle
8610 ON KEY 2 GOTO Idle
8620 ON KEY 3 GOTO Idle
8630 ON KEY 4 GOTO Idle
8640 ON KEY 6 GOTO Idle
8650 ON KEY 8 GOTO Idle
8660 ON KEY 9 LABEL " MAIN MENU" GO
TO Mm
8670 Idle:DISP "Enter the appropriate so
ft key."
8680 GOTO Idle
8690 Mm:OFF KEY
8700 Help=1
8710 SUBEXIT
8720 Sgl:Dbl_flag=1
8730 OFF KEY
8740 GOTO Begin
8750 Dbl:Dbl_flag=2
8760 OFF KEY
8770 Begin:CALL Clear_crt
8780 CALL Heading
8790 CALL Sgl_dbl_hdg
8800 Start:PRINT ""
8810 PRINT ""
8820 PRINT "Insert disc containing da
ta file(s) into right hand disk drive."
8830 PRINT ""
8840 PRINT "Press ";CHR$(131);"CONTIN
UE";CHR$(128);" when ready."
8850 PAUSE
8860 CALL Clear_crt
8870 CALL Heading
8880 CALL Sgl_dbl_hdg
8890 ON ERROR GOTO Err3
8900 INPUT "Do you wish to see listin
g of disk (Y or N)? Default is NO.".Ll1
sts
8910 IF Ll1$="Y" THEN
8920 CAT
8930 ON KBD GOTO Again1
8940 DISP CHR$(131);"Press space ba
r when ready.";CHR$(128)
8950 Lloop:GOTO Lloop
8960 ELSE
8970 END IF
8980 CALL Clear_crt
8990 OFF KBD
9000 OFF ERROR
9010 CALL Heading
9020 CALL Sgl_dbl_hdg
9030 Again1:INPUT "Enter the file name o
f the first stored file.",Dt_file1$
9040 ON ERROR GOTO Err1
9050 GOTO Inbound1
9060 Err1:PRINT ERRMS
9070 GOTO Again1
9080 Inbound1:ASSIGN @File1 TO Dt_file1$
9090 ENTER @File1;View(=)
9100 ASSIGN @File1 TO *
9110 Dte_file1$=LWCS(Dt_file1$)
9120 ASSIGN @Dte_file1 TO Dte_file1$
9130 ENTER @Dte_file1.1:Dte1$
9140 ENTER @Dte_file1.2:Time1$
9150 ASSIGN @Dte_file1 TO *
9160 OFF ERROR
9170 FOR I=1 TO 360
9180 Plot_dt(I,2)=View(I)
9190 NEXT I
9200 Fr1=View(361)
9210 Polarity1=View(362)
9220 Time1=View(363)
9230 CALL View_crt(View(=),Dt_file1$,
Help)
9240 CALL Clear_crt
9250 IF Dbl_flag=1 THEN SUBEXIT
9260 CALL Heading
9270 CALL Sgl_dbl_hdg
9280 Again2:INPUT "Enter the file name o
f the second stored file.",Dt_file2$
9290 ON ERROR GOTO Err2
9300 GOTO Inbound2
9310 Err2:PRINT ERRMS
9320 GOTO Again2
9330 Inbound2:ASSIGN @File2 TO Dt_file2$
9340 ENTER @File2;View(=)
9350 ASSIGN @File2 TO *
9360 Dte_file2$=LWCS(Dt_file2$)
9370 ASSIGN @Dte_file2 TO Dte_file2$
9380 ENTER @Dte_file2.1:Dte2$
9390 ENTER @Dte_file2.2:Time2$
9400 ASSIGN @Dte_file2 TO *
9410 OFF ERROR
9420 FOR I=1 TO 360
9430 Plot_dt(I,3)=View(I)
9440 NEXT I
9450 Fr2=View(361)
9460 Polarity2=View(362)
9470 CALL View_crt(View(=),Dt_file2$,
Help)
9480 SUBEXIT
9490 Err3:BEEP
9500 CALL Clear_crt
9510 DISP ERRMS
9520 OFF ERROR
9530 GOTO Start
9540 SUBEND
9550 !
9560 !
9570 SUB View_crt(View(=),Name$,Help)
9580 CALL Clear_crt
9590 GINIT
9600 PLOTTER IS 3,"INTERNAL"
9610 Ymin=View(1)

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9620 Ymax=Ymin
9630 FOR I=1 TO 359
9640 IF View(I)<Ymin THEN Ymin=View
(I)
9650 IF View(I)>Ymax THEN Ymax=View
(I)
9660 NEXT I
9670 Ymax=Ymax+10
9680 Ymax=PROUND(Ymax,1)
9690 Ymin=Ymin-10
9700 Ymin=PROUND(Ymin,1)
9710 Range=Ymax-Ymin
9720 GRAPHICS ON
9730 MOVE 0,95
9740 CSIZE 3
9750 LABEL Names$
9760 CSIZE 6
9770 LORG 6
9780 FOR I=-.3 TO .3 STEP .1
9790 MOVE 70+I,100
9800 LABEL "LOW OBSERVABLES"
9810 NEXT I
9820 LORG 1
9830 CSIZE 4
9840 MOVE 0,62
9850 Labels="RCS"
9860 FOR I=1 TO 3
9870 LABEL Labels[I,I]
9880 NEXT I
9890 MOVE 56,15
9900 LABEL "ASPECT ANGLE"
9910 VIEWPORT 15,125,30,90
9920 FRAME
9930 WINDOW 0,360,Ymin,Ymax
9940 AXES 5,2.0,Ymin,9.5,2
9950 CSIZE 3
9960 LORG 6
9970 CLIP OFF
9980 FOR I=0 TO 360 STEP 45
9990 MOVE I,Ymin-1
10000 LABEL I
10010 NEXT I
10020 LORG 8
10030 FOR I=Ymin TO Ymax STEP 10
10040 MOVE -1,I
10050 LABEL I
10060 NEXT I
10070 FOR I=0 TO 359
10080 PLOT I,View(I+1)
10090 NEXT I
10100 ON KEY 5 LABEL "DUMP TO PRNTR" G
OTO Ddump
10110 ON KEY 0 GOTO Idle
10120 ON KEY 1 GOTO Idle
10130 ON KEY 2 GOTO Idle
10140 ON KEY 3 GOTO Idle
10150 ON KEY 4 GOTO Idle
10160 ON KEY 6 GOTO Idle
10170 ON KEY 7 GOTO Idle
10180 ON KEY 8 GOTO Idle
10190 ON KEY 9 GOTO Idle

10200 ON KBD GOTO Bottom
10210 Idle:DISP CHR$(131);"Press space b
ar.";CHR$(128);"
";TIMES(
TIMEDATE)
10220 WAIT 1
10230 GOTO Idle
10240 Ddump:PRINTER IS 701
10250 OUTPUT KBD;" N";
10260 PRINTER IS CRT
10270 GOTO Idle
10280 Bottom:GRAPHICS OFF
10290 CALL Clear_crt
10300 SUBEND
10310 !
10320 !
10330 SUB Clear_crt
10340 OUTPUT KBD;" K";
10350 SUBEND
10360 !
10370 !
10380 SUB Exit_bsc !SHUTTLE GRAPHICS PR
OVIDED BY HEWLETT-PACKARD
10390 CALL Heading
10400 PRINT " ";CHR$(129);"="
When finished with measurement and/or
plots ensure " ";CHR$(128)
10410 PRINT " ";CHR$(129);"="
that all equipment is turned off. Have
a nice day! " ";CHR$(128)
10420 PRINT " ";CHR$(129);"="
SEMPER FIDELIS!
" ";CHR$(128)
10430 PRINT " ";CHR$(129);"="
" ";CHR$(128)
10440 PRINT " ";CHR$(129);"="
*****";CHR$(128)
10450 ON KBD GOTO Start
10460 DISP "Press space bar when ready
"
10470 Idle:GOTO Idle
10480 Start:CALL Clear_crt
10490 OFF KBD
10500 OPTION BASE 0
10510 COM /Configuration/ Plotter,Prin
ter,Svm,Gen,Auto,Width
10520 INTEGER F(1392,2),B(518,2),Color
(17,1)
10530 ON ERROR GOTO Bottom
10540 GINIT
10550 GCLEAR
10560 PRINTER IS 1
10570 OUTPUT 2 USING "#,K";" K"
10580 IF Width=50 THEN Wd=15
10590 IF Width=80 THEN Wd=0
10600 MASS STORAGE IS ":INTERNAL,4,1"
10610 PRINT TAB(30-Wd);"** SPACE*SHUT
TLE **"
10620 ASSIGN @File TO "MATTE"
10630 ENTER @File;F(*),B(*)

```

```

10640 MASS STORAGE IS ":INTERNAL,4.0"
10650 GRAPHICS ON
10660 WINDOW -80.619,-50.482
10670 Re_plot: !
10680 PEN 1
10690 GCLEAR
10700 OUTPUT 2 USING "#.K";" K"
10710 RESTORE Star_data
10720 FOR I=1 TO 50
10730   READ X,Y
10740   MOVE X,Y
10750   DRAW X-.5,Y-.5
10760 NEXT I
10770 RESTORE F_color_data
10780 GOSUB Get_colors
10790 Mat_plot(F(*),1392,@File,Color(*)
)
10800 RESTORE B_color_data
10810 GOSUB Get_colors
10820 Mat_plot(B(*),518,@File,Color(*)
)
10830 BEEP 1500,.2
10840 PEN 1
10850 CSIZE 3
10860 PENUP
10870 ON KBD GOTO Bottom
10880 DISP "Press space bar when ready
to go back to BASIC or shut down."
10890 Stall:GOTO Stall
10900 Bottom:OFF KBD
10910 MASS STORAGE IS ":INTERNAL,4.0"
10920 GRAPHICS OFF
10930 CALL Clear_crt
10940 SUBEXIT
10950 Get_colors: !
10960 READ Color(*)
10970 RETURN
10980 F_color_data: !
10990 DATA 0.5,51.3,89.4,98.5,335.2,47
0.5,483.3,580.4,640.5,720.2,730.3,785.4
11000 DATA 832.7,940.5,1040.4,1130.5,1
303.2,1380.4
11010 B_color_data: !
11020 DATA 0.6,97.2,130.3,217.1,252.2,
256.2,272.3,279.1,293.2,350.6
11030 DATA 360.6,389.2,391.2,435.7,463
.1,492.3,499.2,519.1
11040 Star_data: !
11050 DATA 162.337,-48.469,90.399,232.
360.494,154.544,34.553,19.514,344.417
11060 DATA 29.9,9.-47.47,458.426,90.41
7.450,250.566,30.306,83.33,274.51,450
11070 DATA 32.429,462.475,454.472,21.1
64.391,35.-19.193,515.364,284.330,570
11080 DATA 139.210,73.-79.184,97.80,17
.7,368.290,49.427,192.28,239.473,-23
11090 DATA 473.348,80.-43.342,280.320,
403.449,322.65,69.161,340.60,261.370
11100 DATA 204.583,255.93,452.445,1.75
,70.236,405.300
11110 SUBEND

```

Appendix E

The following sample plots illustrate the format of the data that is outputted from the software for AFIT's facility. The targets are chosen because of their predictable peak radar cross-section. Fig. 21 is a plot of a square flat plate. The predicted RCS is 9.5 dBsm. The measured peak RCS is 9.8 dBsm. Fig. 22 is a plot of two data sets. The first data set is that of a 8" sphere. The actual plot has the data sets and their corresponding legends in different colors. In Fig. 22 the "flat" line is the sphere's RCS. The predicted RCS of the sphere is -14.8 dBsm where the measured RCS is -14.1 dBsm. The second data set is that of a trihedral corner reflector. Its predicted peak RCS is -2.1 dBsm and its peak measured RCS is -0.4 dBsm.

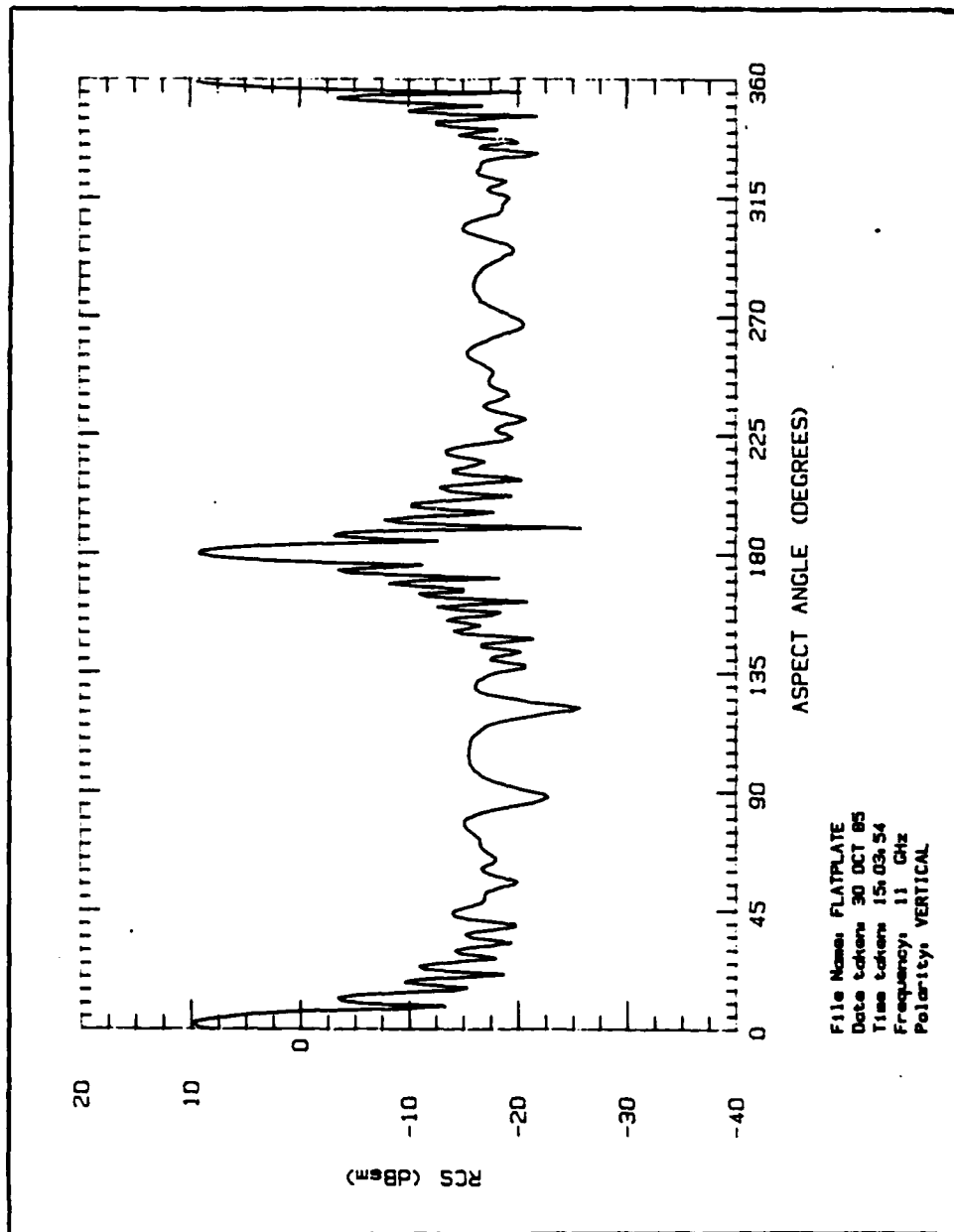


Fig. 21. Flat Plate RCS

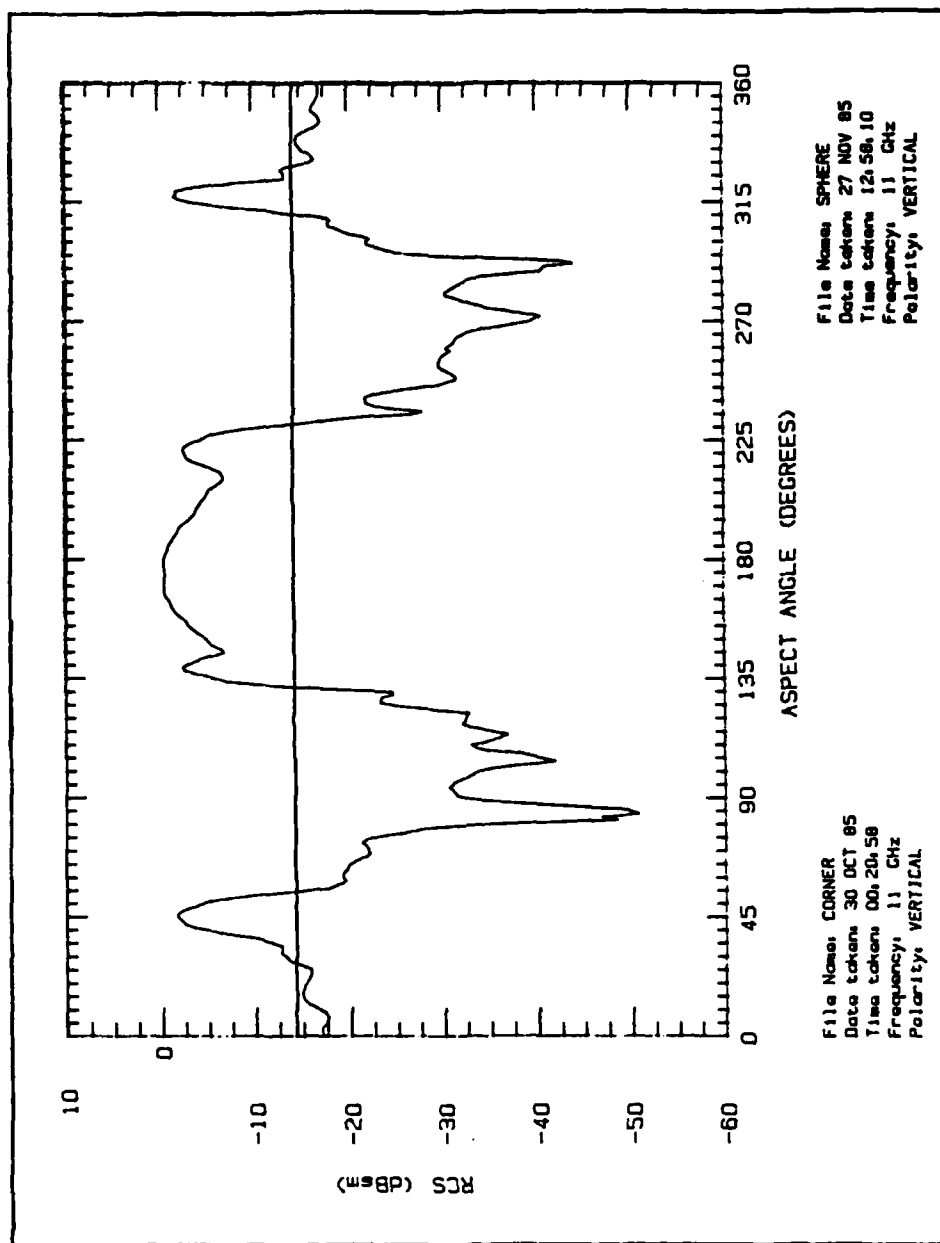


Fig. 22. Corner Reflector and Sphere RCS

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AN-A16-3 546

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS										
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited										
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE													
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GE/ENG/85D-26			5. MONITORING ORGANIZATION REPORT NUMBER(S)										
6a. NAME OF PERFORMING ORGANIZATION School of Engineering		6b. OFFICE SYMBOL (If applicable) AFIT/ENG		7a. NAME OF MONITORING ORGANIZATION									
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433			7b. ADDRESS (City, State and ZIP Code)										
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER									
8c. ADDRESS (City, State and ZIP Code)			10. SOURCE OF FUNDING NOS.										
			<table border="1"> <tr> <td>PROGRAM ELEMENT NO.</td> <td>PROJECT NO.</td> <td>TASK NO.</td> <td>WORK UNIT NO.</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.				
PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.										
11. TITLE (Include Security Classification) See box 19													
12. PERSONAL AUTHOR(S) David G. Mazur, 1Lt, USAF													
13a. TYPE OF REPORT MS Thesis		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Yr., Mo., Day) 1985 December									
				15. PAGE COUNT 107									
16. SUPPLEMENTARY NOTATION													
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)										
FIELD	GROUP	SUB. GR.											
20	14		Radar Waves Electromagnetic Wave Reflections Radar Cross Section										
19. ABSTRACT (Continue on reverse if necessary and identify by block number)													
Title: Design Methodology of an Automated Scattering Measurement Facility Thesis Chairman: Randy J. Jost, 1Lt, USAF Instructor of Electrical Engineering													
20. DISTRIBUTION AVAILABILITY OF ABSTRACT UNCLASSIFIED UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED										
22a. NAME OF RESPONSIBLE INDIVIDUAL Randy J. Jost, 1Lt, USAF			22b. TELEPHONE NUMBER (Include Area Code) 513-255-3576		22c. OFFICE SYMBOL AFIT/ENG								

Approved for public release: LAW AFR 190-1/
LYNN E. WOLAVE 16 JAN 86
Dean for Research and Professional Development
Air Force Institute of Technology (AFIT)
Wright-Patterson AFB OH 45433

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This thesis addresses the design methodology surrounding an automated scattering measurement facility. A brief historical survey of radar cross-section (RCS) measurements is presented. The electromagnetic theory associated with a continuous wave (CW) background cancellation technique for measuring RCS is discussed as background. In addition, problems associated with interfacing test equipment, data storage and output are addressed. The facility used as a model for this thesis is located at the Air Force Institute of Technology, WPAFB, OH. Even though this paper addresses a particular facility, the design methodology applies to any automated scattering measurement facility. A software package incorporating features that enhance the operation of AFIT's facility by students is presented. Finally, sample outputs from the software package illustrate formats for displaying RCS data. *Keywords: Electromagnetic wave scattering, Radar cross-section.*

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