Electromagnetic Coupling Reduction Techniques

First Quarterly Report
16 November 1965 - 15 February 1966

By

J. A. M Lyon, M. A. H. Ibrahim,
C.J.Digenis, A.Cha and Y.K.Kwon

15 March 1966

Contract No. AF33(615)-3371
Proj. 4357, Task 435709

Prepared for

Air Force Avionics Laboratory
United States Air Force, AFSC
Wright-Patterson AFB, Ohio 45433

FOREWORD

This report 7692-1-Q was prepared by The University of Michigan, Ann Arbor, Michigan, under the direction of Professor Ralph E Hiatt and Professor John A. M. Lyon and on Air Force Contract AF 33(615)-3371 under Task No. 435709 of Project 4357 (U) "Electromagnetic Coupling Reduction Techniques". The work was administered under the direction of the Air Force Avionics Laboratory, Electronic Warfare Division, Research and Technology Division, Wright-Patterson Air Force Base Ohio. The Task Engineer was Mr. Olin E. Horton, the Project Engineer Mr. Herbert Bartman.

This report covers the period 16 November 1965 through 15 February 1966.

TABLE OF CONTENTS

ABSTRACT

In this report, preliminary results are shown for relatively simple antenna coupling situations. In one series of measurements, rectangular slot antennas were used with absorbing obstacles between. Increase in isolation as high as 25 db has been obtained.

The use of specific absorbing materials is discussed. Extension of isolation techniques to various types of antennas is covered. A brief discussion of analysis now underway is given.

I

INTRODUCTION

In this work dealing with the increase of isolation between antennas, one analytical effort and two experimental efforts have been started. One of the experimental efforts deals with absorbing material used as an obstacle between two flush mounted antennas such as two rectangular slots. This effort has shown that substantial isolation can be obtained by such an obstacle. It is realized, however, that obstacles of this nature protruding above the ground plane would not be an acceptable solution, in many cases, for the increase of isolation. A next step in this experimental work is to have the absorbing material mounted flush between the two antennas.

A second experimental effort has dealt with the introduction of absorbing materials in rectangular horns. So far, during this report period, only H-plane sectoral horns have been involved. Small wedges of absorbing material have been inserted along the slant sides of such a horn. As can be expected, this insertion of material has resulted in comparatively little reduction in coupling or, in other words, has increased the isolation very little. Furthermore, the observed experimental results must be considered with due regard to the radiation pattern of such a horn with absorbing materials present. This part of the study remains to be done. More favorable situations, regarding rectangular horns and the use of absorbing material, are yet to be performed. It is anticipated that even better methods of reducing coupling between horns, can be used rather than having absorbing material inside the flare of the horn. It is recognized that other studies of rectangular horns dealing with sidelobe reduction have shown very clearly that absorbing materials have a limited usefulness in sidelobe reduction. It is observable in this work dealing with coupling, that coupling between two antennas can be reduced if the sidelobe level is reduced. The use of intervening trenches filled with lossy materials between horn antennas may be worthwhile in increasing the isolation. Coverage on isolation of horn antennas is not included in this First Quarterly Report. Ample coverage will be given in the next quarterly .

The analytical effort will not be described in this report since it is not sufficiently complete. The analysis underway considers a flush mounted slab interposed between two slot antennas for the E-plane coupling case. Tentative results of the analysis predict a substantial reduction in coupling. The analysis will be subjected to detailed verification before publication in the next quarterly.

Some study of absorbing materials has been made. Various selections of materials to date,have depended largely upon the availability of such materials. However, it is anticipated in the future that more specific selections will be made depending upon the electrical characteristics of the absorbing materials. The selection of materials will be coordinated with the needs of broadband isolation between antennas.

II
EXPERIMENTAL STUDIES

2.1 General

The bulk of the experimental effort during this period was devoted to the investigation of coupling reduction effects using a layer of absorbing material placed on the ground plane in the vicinity of the coupled antennas. A simple X-band apparatus was used to make experiments useful for guiding the further work on reduction of coupling. The following paragraphs indicate a number of these simple experiments. It is intended that these experiments be followed, where justified, by more detailed experiments, including the gathering of substantial data over a wide frequency range. The ones described here have been limited to a frequency range of 8.2 - 12.0 GHz. It is intended that such experiments will be amplified when they are performed in the anechoic chamber in the Radio Science Laboratory.

The first series of experiments involved slot antennas on a common ground plane. In view of current application requirements, as well as existing equipment, it was decided to conduct the experiments in the X-band region. A copper ground plane with four fixed slots and one rotatable slot was used (Fig. 2-1). To minimize the effect of reflections from scatterers in the vicinity of the ground plane a miniature anechoic chamber was used as a shield. This chamber was a cube of 2 feet on a side lined in the interior with microwave absorbing pyramids, VHP-2, 3" high, manufactured by B.F. Goodrich.

The microwave circuit used with the above ground plane and anechoic chamber is shown in Fig. 2-2. For a selected frequency the klystron was tuned and then both the transmitting and receiving antennas were tuned for maximum power indication on power meter (II). Then the transmitted power, W_t, was obtained from the reading of the power meter (I) and the calibration

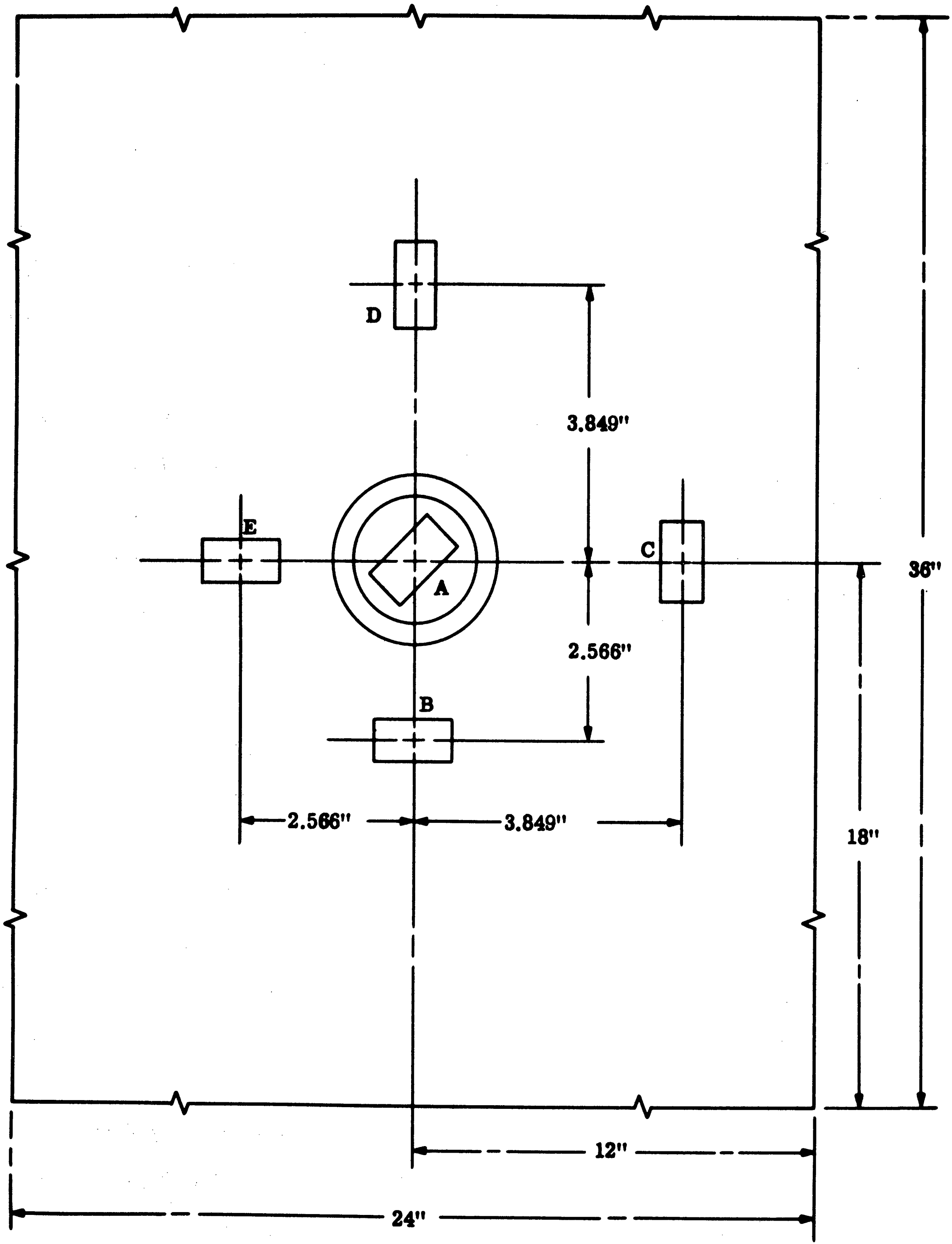


FIG. 2-1: COPPER GROUND PLANE USED IN THE SET OF EXPERIMENTS

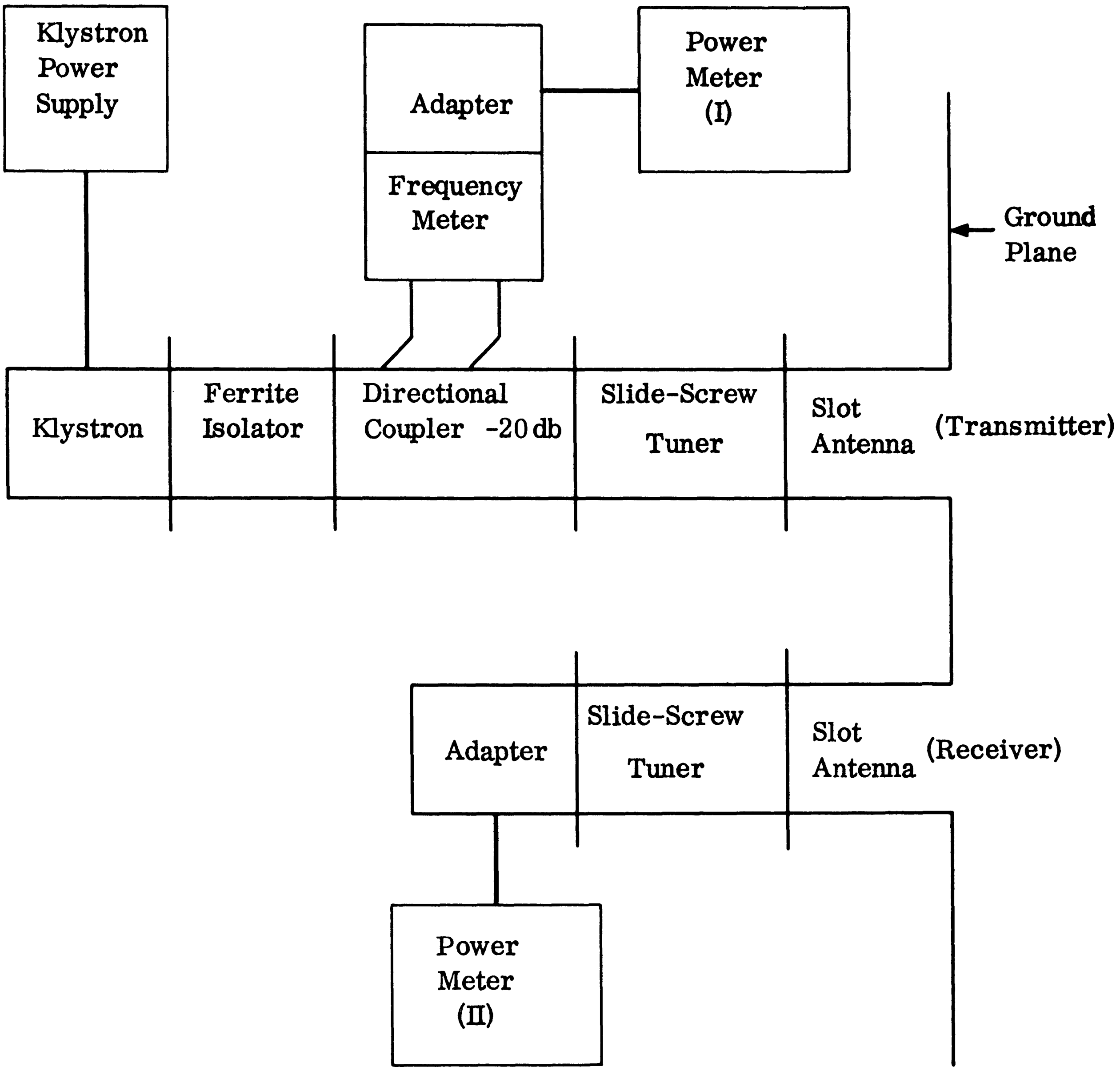


FIG. 2-2: MICROWAVE CIRCUIT

curve of the directional coupler while the power coupled into the receiving slot, W_r, was read directly on power meter (II). The coupling, C, is then

$$C(db)=W_r(dbm)-W_t(dbm) \quad \text{(yielding negative values)}$$

This point-by-point method consumes a fair amount of time. However, it has the advantage over a swept-frequency method of permitting tuning at every frequency and thus yielding the maximum possible coupling. A swept frequency method will be used in some of the future work for broadband studies. As expected, it was found that the coupling was most sensitive to tuning at the higher frequencies of the band.

The overall accuracy of the measurements is estimated at approximately 1 db for levels of coupling down to -45 db. For values of coupling between -45 db and -55 db the accuracy deterioriates to ± 3 db due to, a) readings near the end of the scale of power meter (II) and b) reflections from the chamber.

2.2 Barriers of B. F. Goodrich RF-X Material

Using two X-band rectangular slots in a metal plane, a series of experiments was made where B. F. Goodrich RF-X material with or without foil backing was used as a barrier. This material is a lightweight, flexible, resonant absorber. It is available tuned at any frequency in the S- through K-band regions and exhibits absorption in excess of 25 db at resonance. It has its maximum absorption for normal incidence, but versions designed for optimum absorption at other than normal incidence are available.

The following characteristics are typical of the standard version.

B. F. Goodrich Type:	RF-X	Guaranteed Minimum	
Thickness:	0.16"	Absorption:	25db
Radar Band:	X	Weight Sq. Ft.:	0.3

2.2.1: Experimental Data

This material was used for the purpose of reducing the coupling between two slots in the case of strong E-plane coupling. The dimension of the slots was 2.3 x 1cm; a separation of 6.5 cm center-to-center was used. A slab of the material was set vertically on the ground plane, between the two slots. The dimensions of the slab varied in length, height and number of layers of the material put next to each other.

It was found that the decoupling depends on the length, height, number of layers and also on the position of the slab between the two slots. It is expected also in this case that there would be a higher reduction in coupling if the slab was put next to either the receiver or the transmitter slot as was shown by the experiment using the Emerson and Cuming Eccosorb-CR material (Fig. 2-14).

A set of experiments was performed for coupling versus frequency from 8.2 to 11.7 GHz for the cases where the coupling between two slots was direct without any absorbing material between and also where the coupling between slots showed the effect of an intervening slab. For example, Fig. 2-6 shows a slab of dimension 7 cm long, 3.5 cm in height and with three, four or five layers

2.2.2: Experimental Deductions

From the numerous graphs the following deductions can be made.

a) The decoupling depends on the number of layers but decoupling does not increase in proportion to the number of layers. In the experiments four layers gave better results than three or five layers.

b) Some of the experimen ts were performed with the layers having foil backing and some of them without this backing. It is noticed, from comparison of Figs. 2-3 and 2-4 that for the same length and smaller height and same number of layers, higher decoupling results without foil backing.

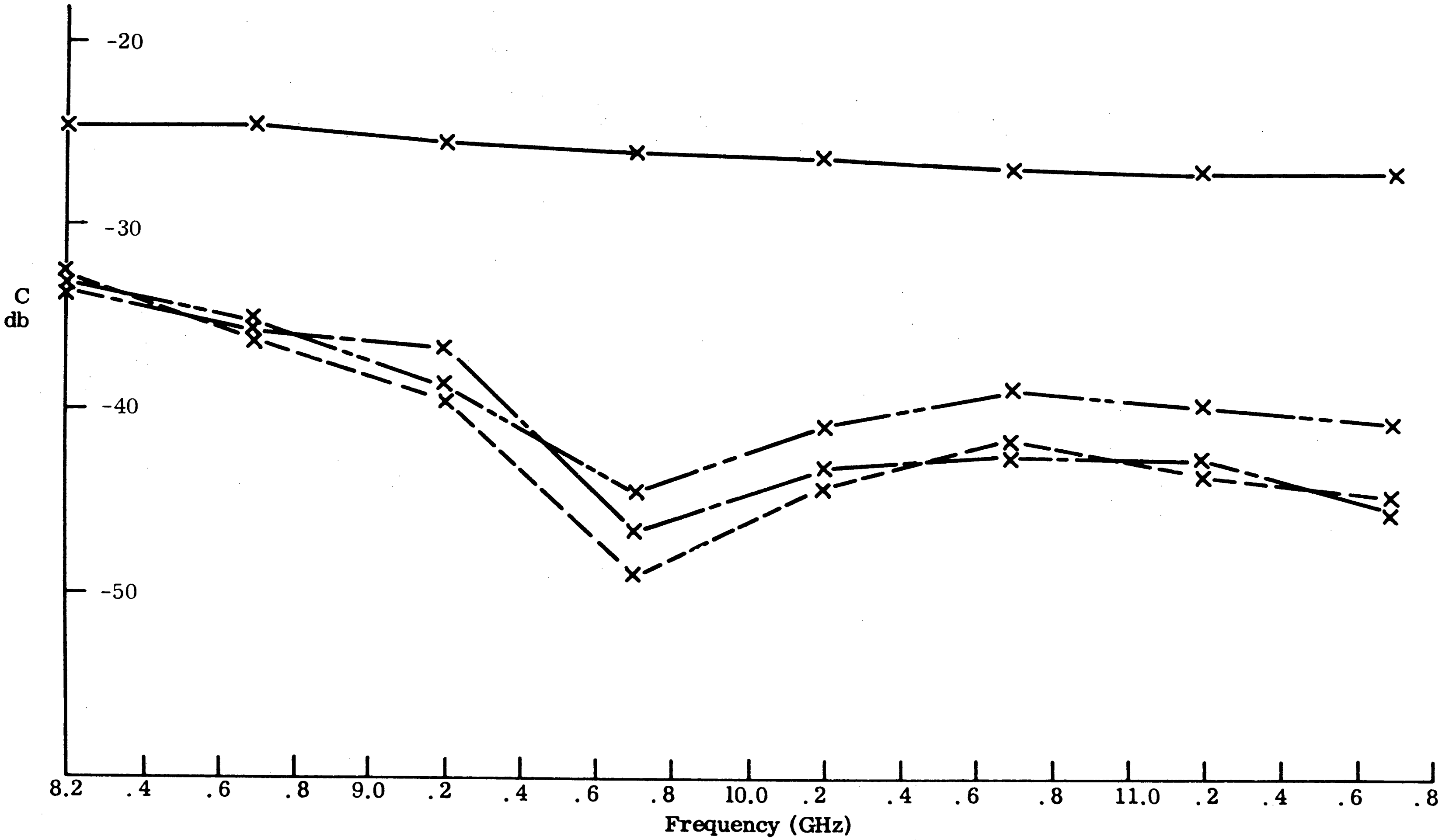


FIG 2-3: STRONG E-PLANE COUPLING VS FREQUENCY BETWEEN SLOTS OF 6.5 CM CENTER-TO-CENTER AND SLAB OF DIMENSIONS 6x2.5 x (n layers). B.F.GOODRICH RF-X MATERIAL WITH FOIL BACKING. (—) No Absorber (– - - –) Three Layers (– - –) Four Layers (— — —) Five Layers.

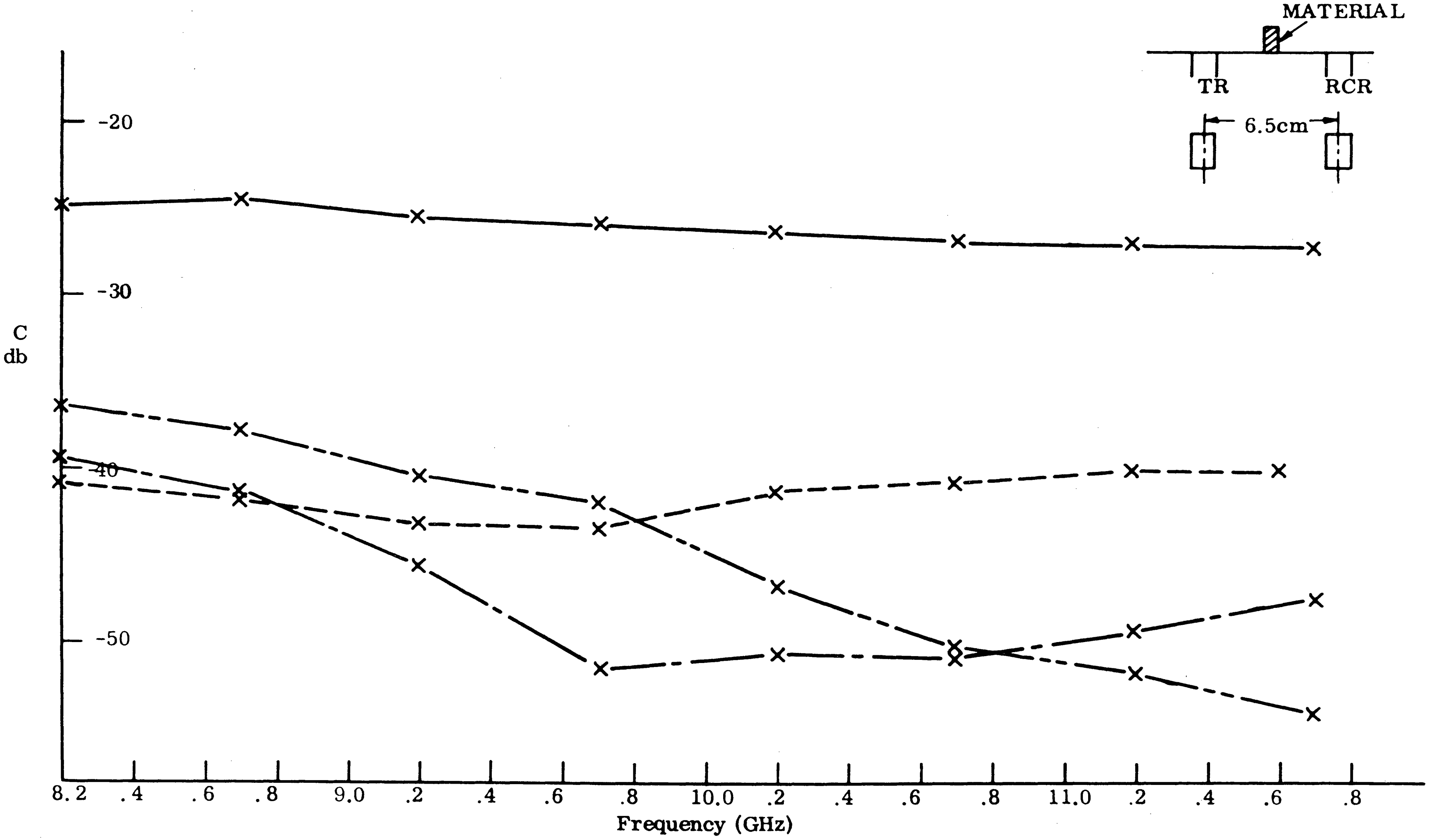


FIG. 2-4: STRONG E-PLANE COUPLING VS FREQUENCY BETWEEN SLOTS OF 6.5 CM CENTER-TO-CENTER AND SLAB OF DIMENSIONS 6 x 2.5 x (n layers). B.F.GOODRICH RF-X MATERIAL WITHOUT FOIL BACKING. (——)No Absorber (— - - - —)Three Layers (— - —)Four Layers (- - - -) Five Layers.

c) From the set of experiments performed for different slab lengths, it is noticed that the decoupling was higher in the case of the 6 cm length than for the 7 cm length. It is expected that there is an optimum length (see Figs. 2-5 and 2-6).

d) It is noted that in the case of no foil backing there is a minimum reduction of coupling of 15 db and it reaches about 27 db at approximately 9.7 GHz which is expected to be the resonance frequency of the absorption in the case of the four layers (Fig. 2-3).

e) From Figs. 2-3 and 2-5 it can be observed that greater isolation or more decoupling results from a higher absorbing barrier.

2.3 Barriers of Emerson and Cuming Eccosorb-CR Material

Experiments on Eccosorb-CR barriers concerned E-plane coupling of two slots at distances of 6.5 cm and 9.8 cm, center-to-center. A slab of absorbing material was placed on the ground plane between the two slots. The absorbing material used here is a casting resin absorber. The manufacturer gives the following data:

Density: 4.0 gr/cm^3
Flexural Strength: 10,000 psi (703 kg/cm^2)
Thermal Expansion Coef: 20x10^{-6} per °C
Temperature Range of Use: -70°F to +350°F (-57°C to +177°C)

Frequency	8.6 GHz	10 GHz
Attenuation db/cm	23	34
Dielectric Constant	21	21
Permeability	2.2	1.6
Dielectric Dissipation	0.08	0.08
Magnetic Dissipation	0.6	0.8

2.3.1: Experimental Arrangement

In most experiments the slab was symmetrically located on the ground plane with respect to the slots. The general geometry is shown in Fig. 2-7.

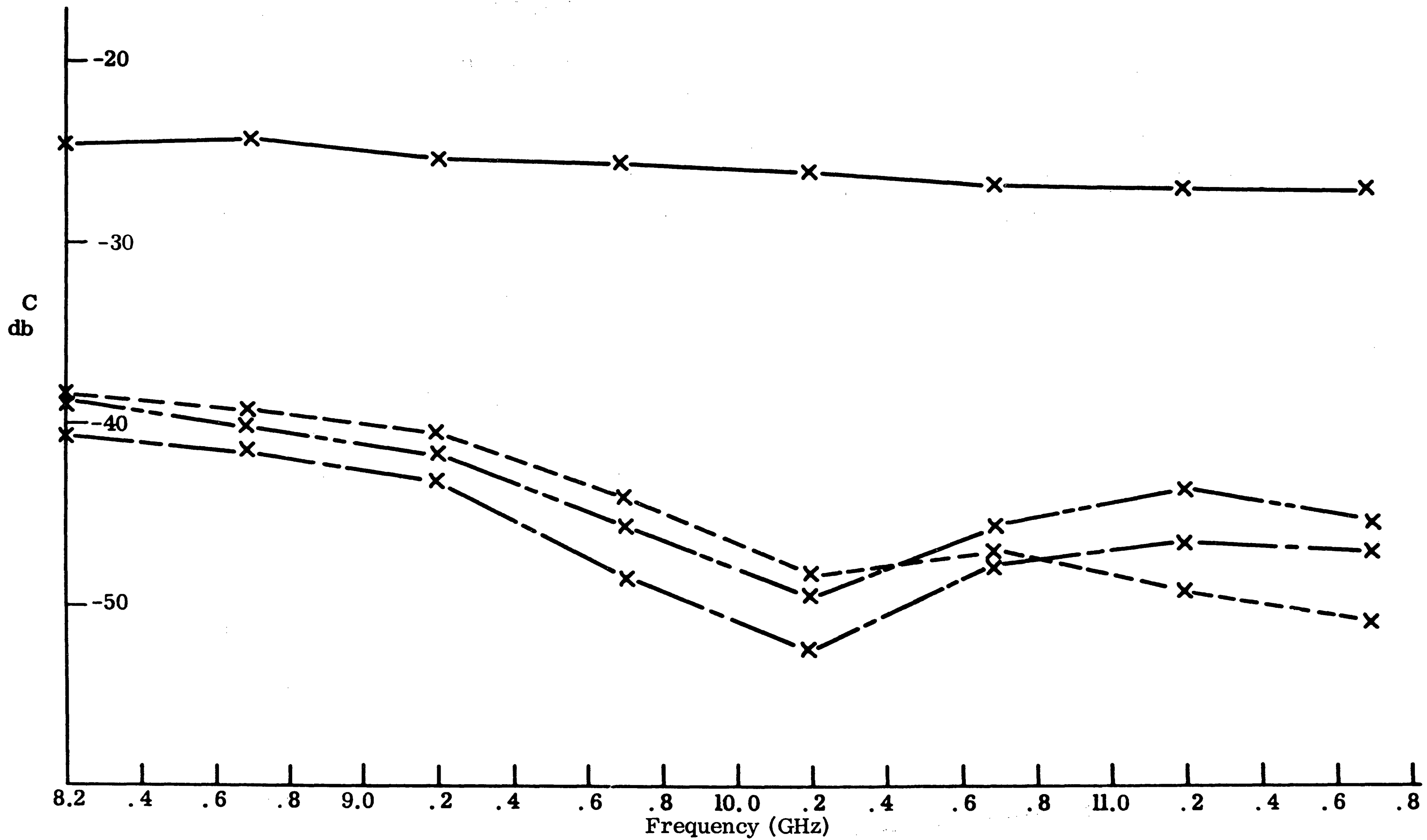


FIG. 2-5: STRONG E-PLANE COUPLING VS FREQUENCY BETWEEN SLOTS OF 6.5 CM CENTER-TO-CENTER AND SLAB OF DIMENSIONS 6 x 2.5 x (n layers). B.F.GOODRICH RF-X MATERIAL WITH FOIL BACKING (——)No Absorber (– – – –)Three Layers (— - —)Four Layers (– – –)Five Layers.

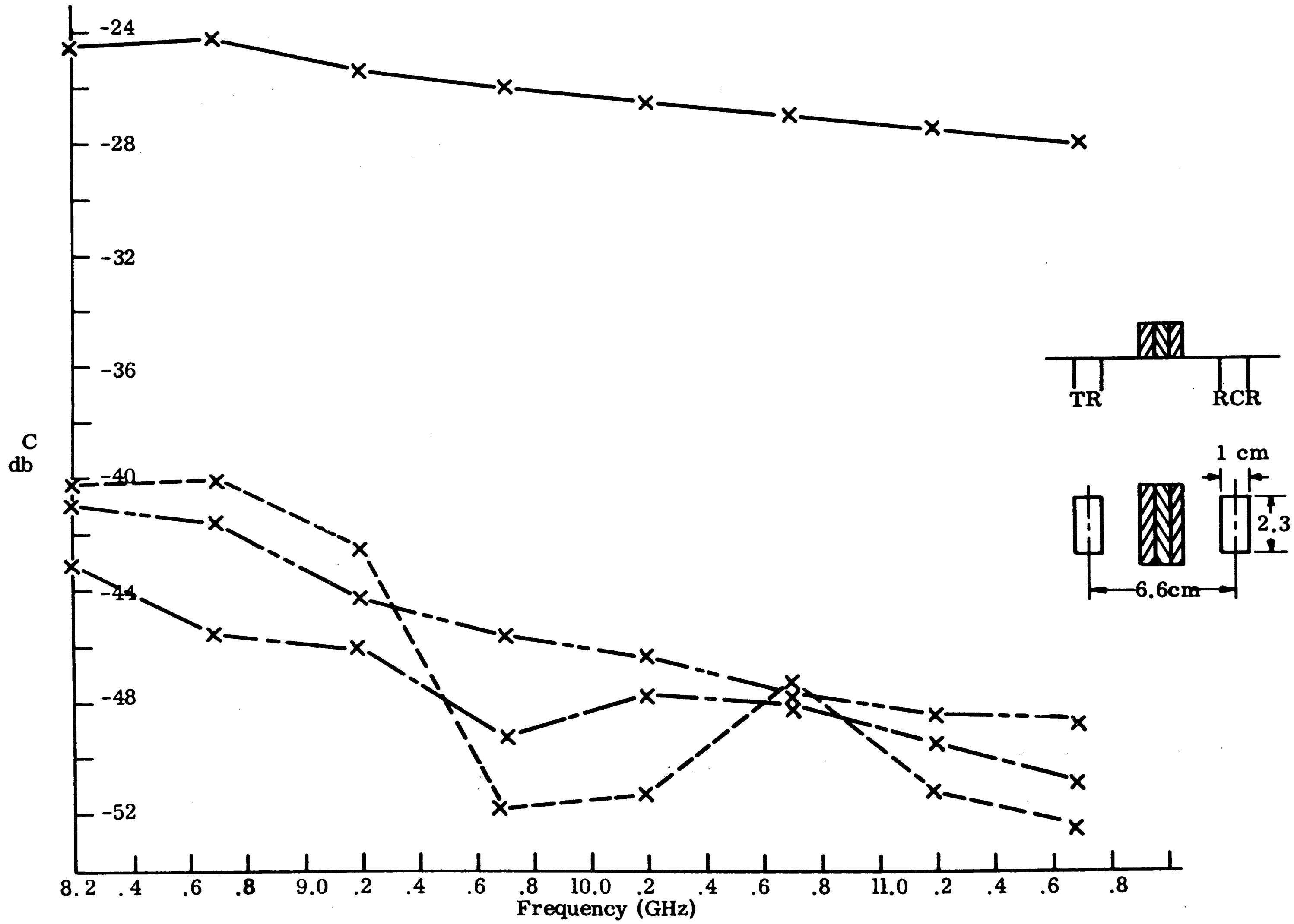
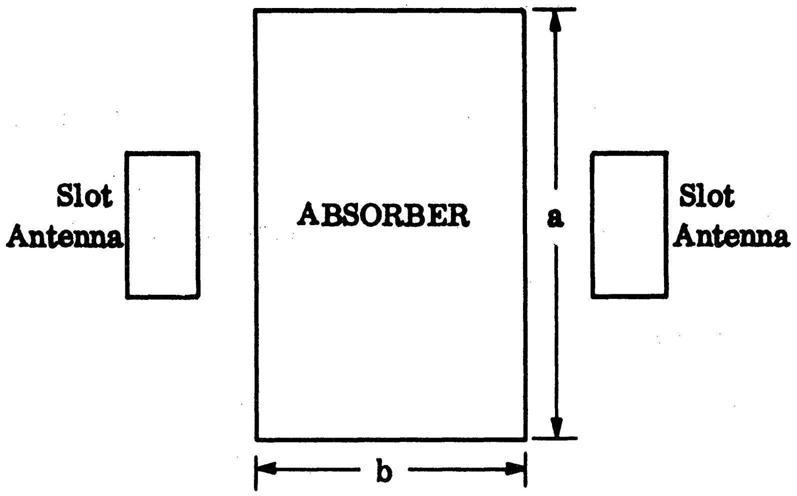
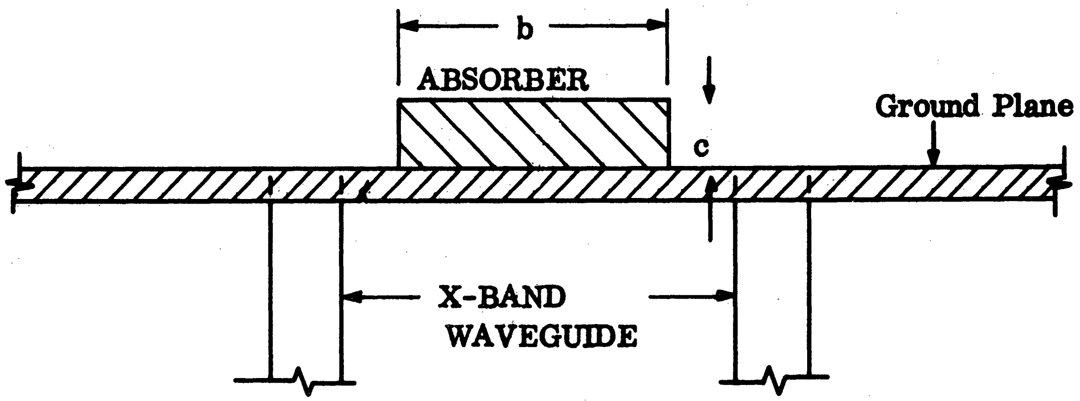


FIG. 2-6: STRONG E-PLANE COUPLING VS FREQUENCY BETWEEN SLOTS OF 6.5 CM CENTER-TO-CENTER AND SLAB OF DIMENSIONS 7 x 3.5 x (n layers). (——) No Absorber (— -- —)Three Layers (—— - ——)Four Layers (– – – –)Five Layers.



Top View.



Side View

FIG. 2-7: GENERAL GEOMETRY: E-PLANE COUPLING
a = length, b = width, c = height.

2.3.2: Experimental Deductions

The experiments showed that:

a) The greater the height of the absorber, the greater the coupling reduction. The maximum height used was 2 cm (Fig. 2-8).

b) There is an optimum length for a given slab width and an optimum width for a given slab length (Fig. 2-9).

c) There is an optimum cross section (width times height for constant length) to achieve maximum coupling reduction over the whole X-band under the constraint of using a constant amount of material (Fig. 2-10).

d) Metal strips properly placed can produce reflections and partial phase cancellation which further decrease the coupling (Fig. 2-11).

e) Without exceeding an absorber height of 2 cm above the ground plane, the maximum coupling over the entire X-band has been decreased by 24 db in the case of the 6.5 cm center-to-center distance and by 22 db in the case of the 9.8 cm center-to-center distance (Figs. 2-12 and 2-13).

f) Placing the absorber slab near either of the two slots instead of in a midposition decreases coupling (Fig. 2-14).

2.4 Agreement between Experiments

The deductions from experiments on Eccosorb -CR are in agreement with those experiments performed with B. F. Goodrich RF-X. The experiments are considered incomplete until radiation patterns are obtained for the antennas in the presence of the absorbing barriers.

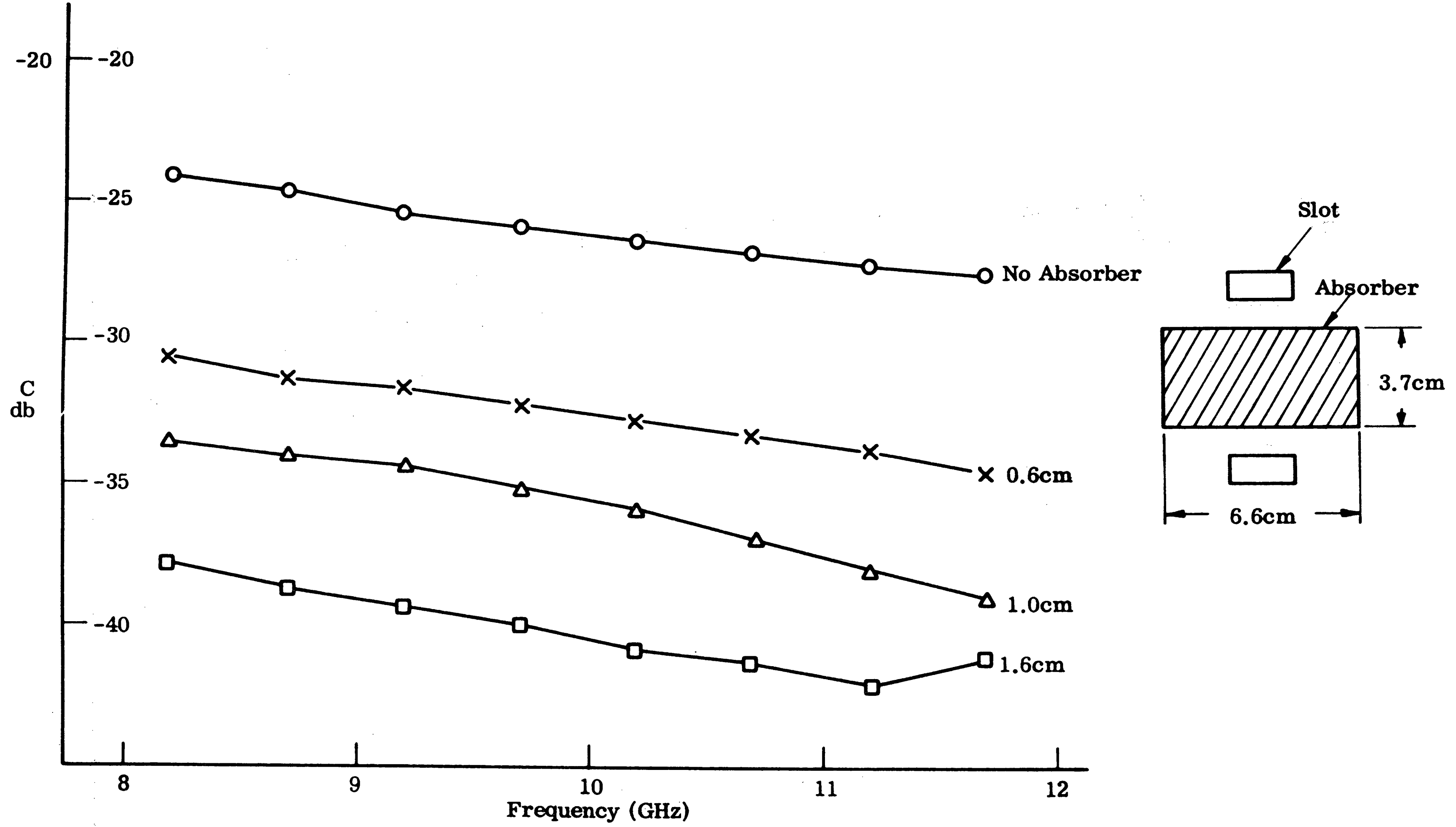


FIG. 2-8: E-PLANE COUPLING VS FREQUENCY FOR TWO SLOTS SPACED 6.5 CM CENTER-TO-CENTER. PARAMETER INDICATES ABSORBER SLAB HEIGHT. ABSORBER: EMERSON AND CUMING ECCOSORB-CR.

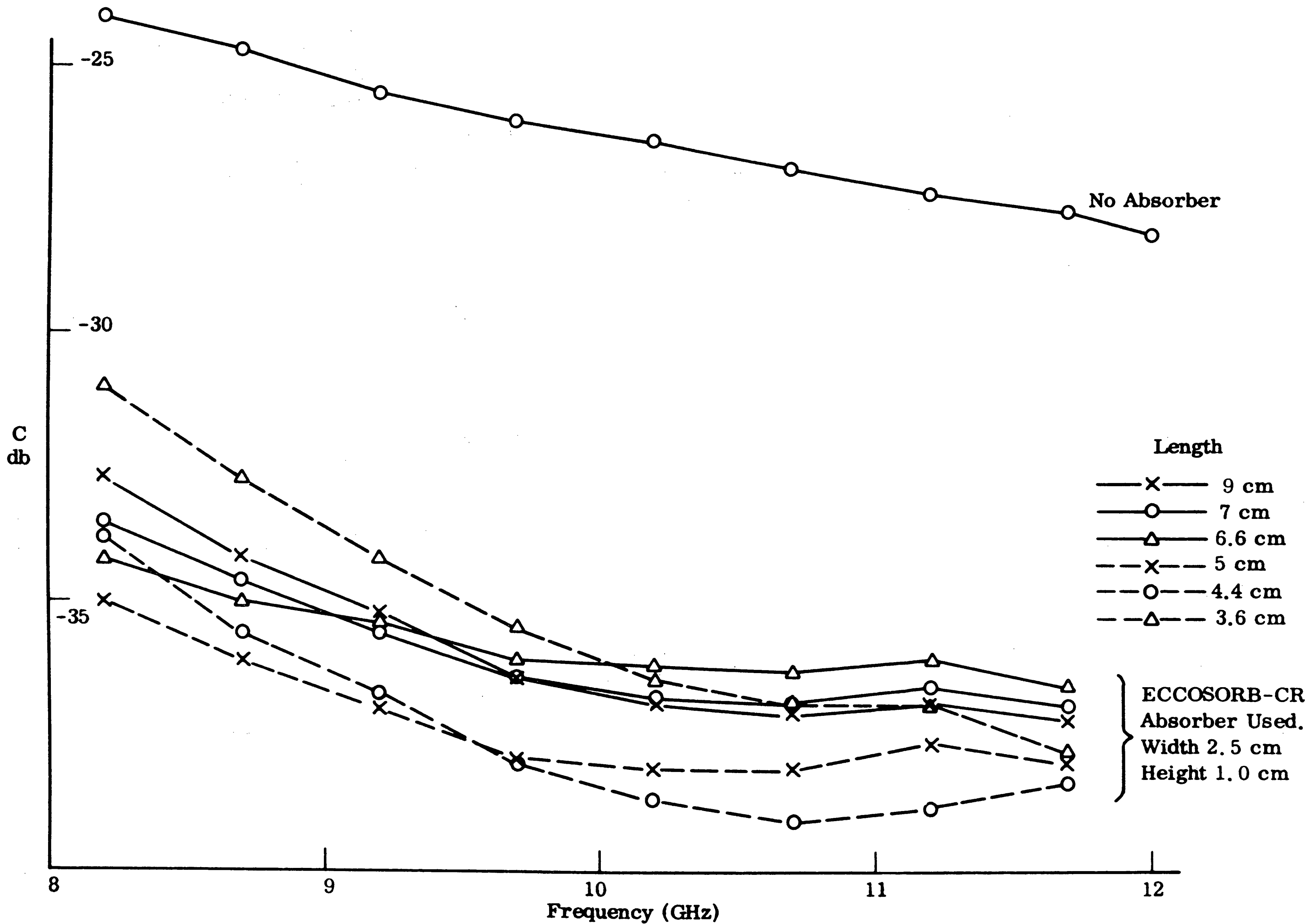


FIG. 2-9: E-PLANE COUPLING VS FREQUENCY FOR TWO SLOTS SPACED 6.5 CM CENTER-TO-CENTER.

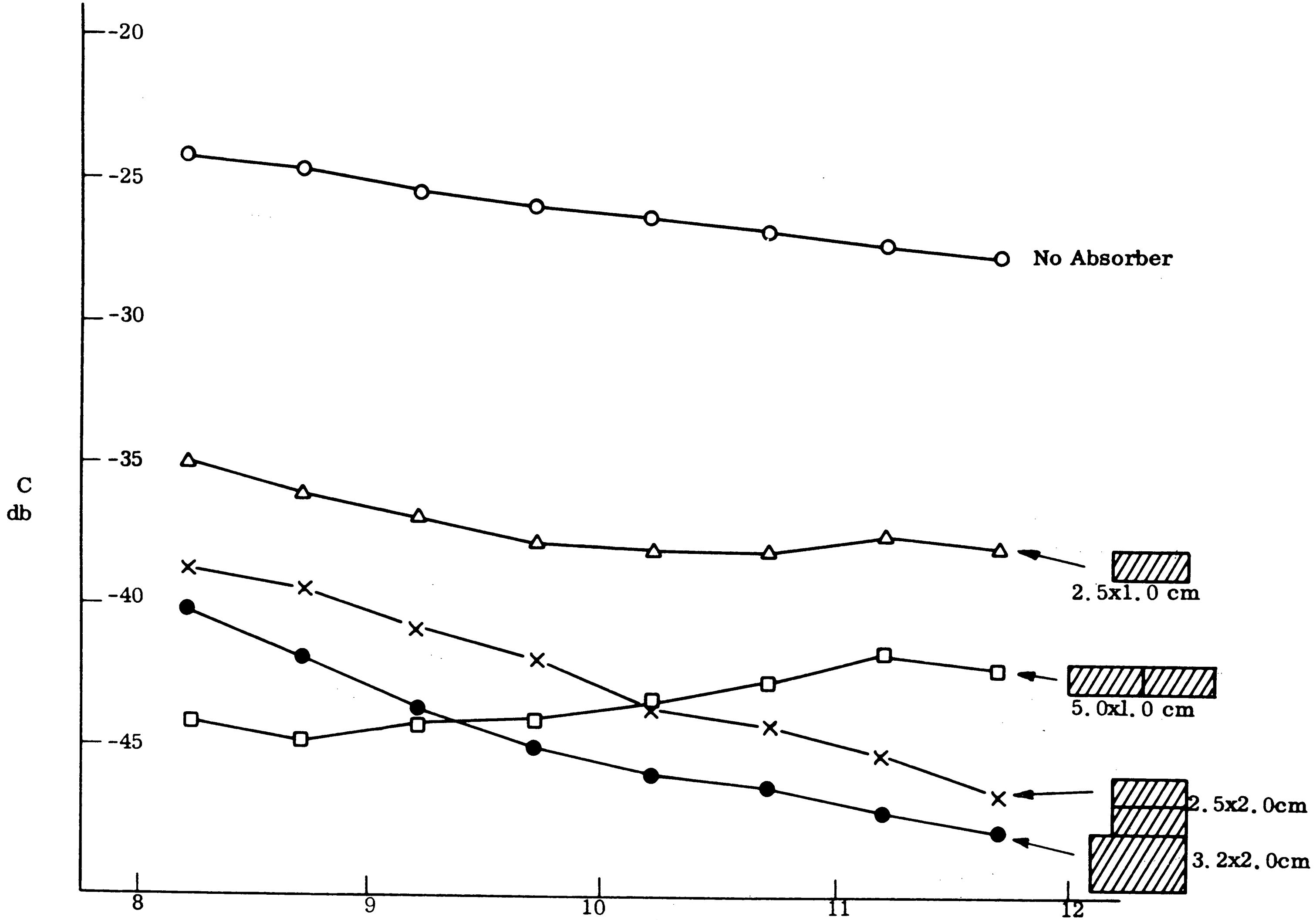


FIG 2-10: E-PLANE COUPLING VS FREQUENCY FOR TWO SLOTS SPACED 6.5 CM CENTER-TO-CENTER. ABSORBER: ECCOSORB-CR (LENGTH 5cm, WIDTH AND HEIGHT AS SHOWN).

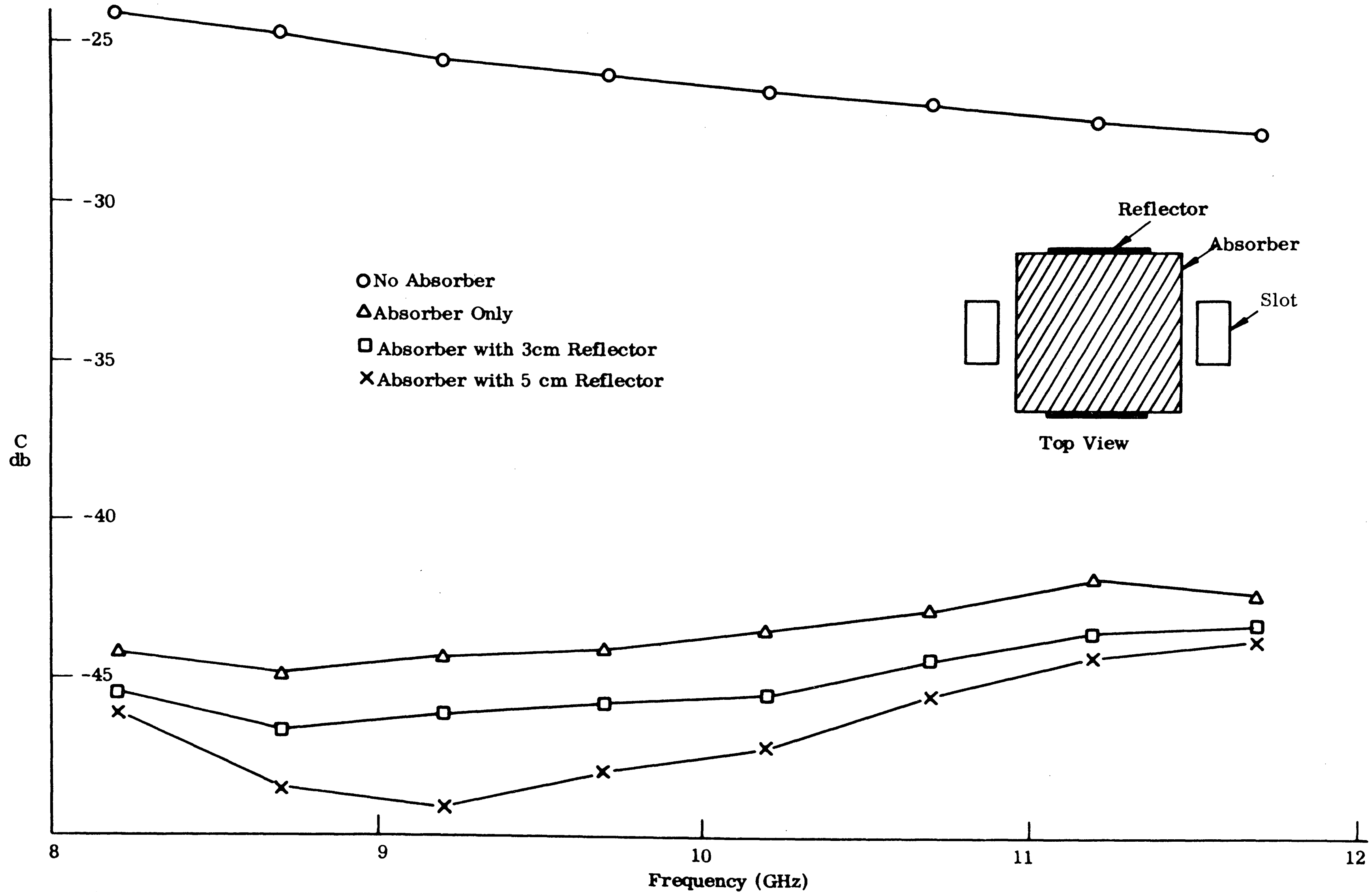


FIG. 2-11: E-PLANE COUPLING VS FREQUENCY FOR TWO SLOTS SPACED 6.5 CM CENTER-TO-CENTER. ABSORBER; ECCOSORB-CR (5 cm x 5 cm x 1 cm). REFLECTOR: STRIP OF ALUMINUM FOIL

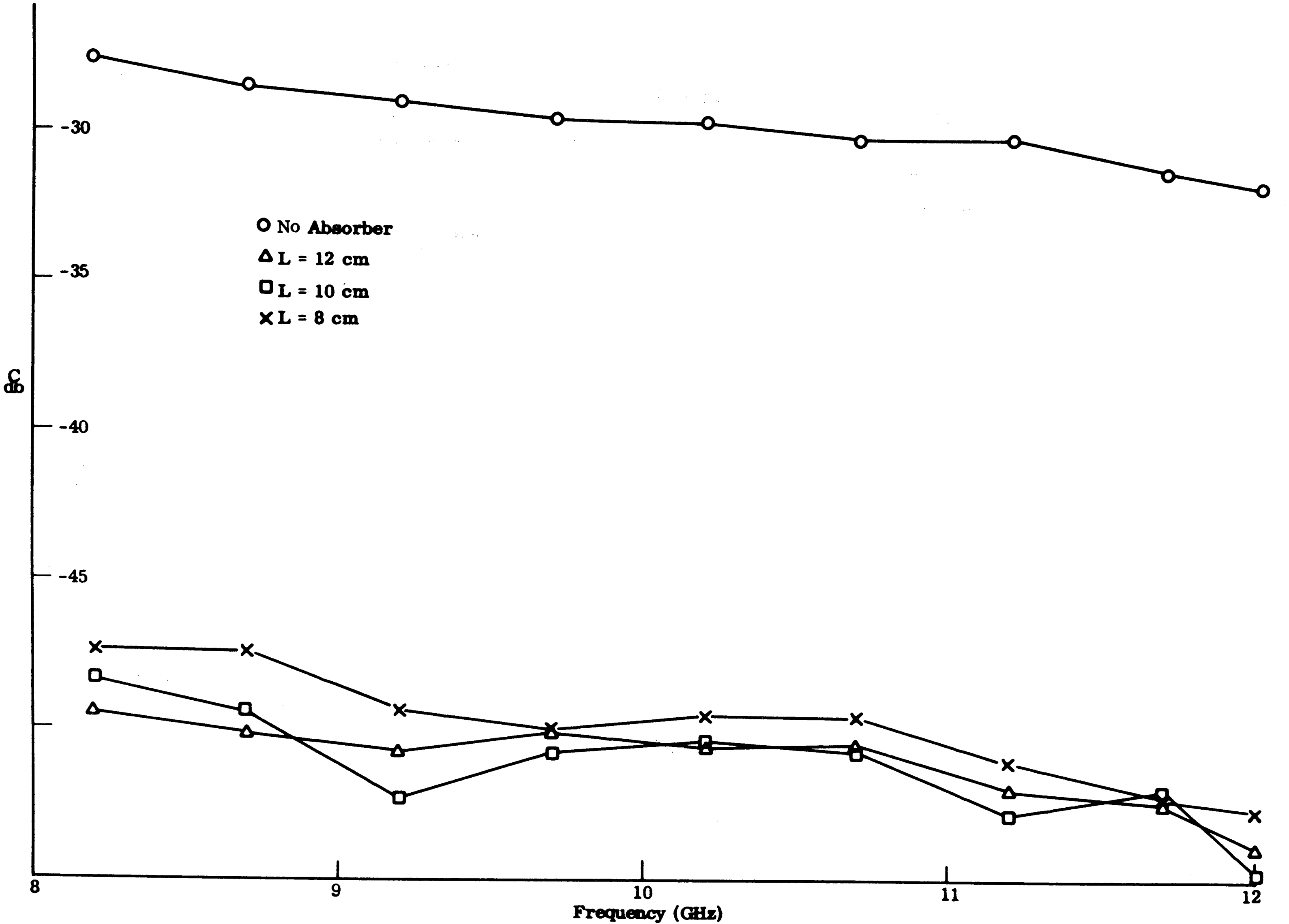


FIG. 2-12: E-PLANE COUPLING VS FREQUENCY FOR TWO SLOTS SPACED 9.8 CM CENTER-TO-CENTER. ABSORBER: ECCOSORB-CR (Width 8 cm, Height 1.7 cm, Length as shown).

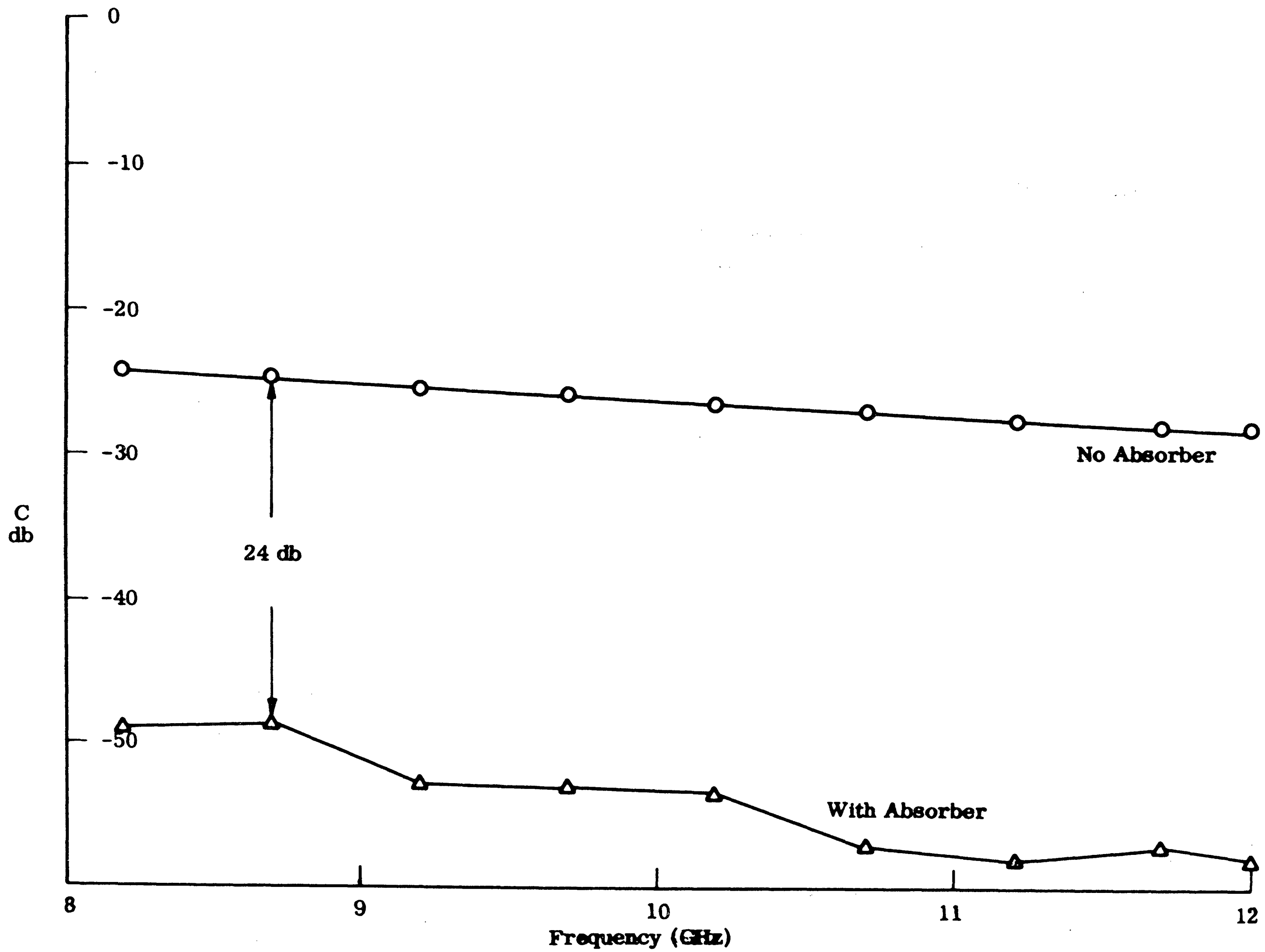


FIG. 2-13: E-PLANE COUPLING VS FREQUENCY FOR TWO SLOTS SPACED 6.5 CM CENTER-TO-CENTER . ABSORBER: ECCOSORB-CR (5cm x 5cm x 2cm)

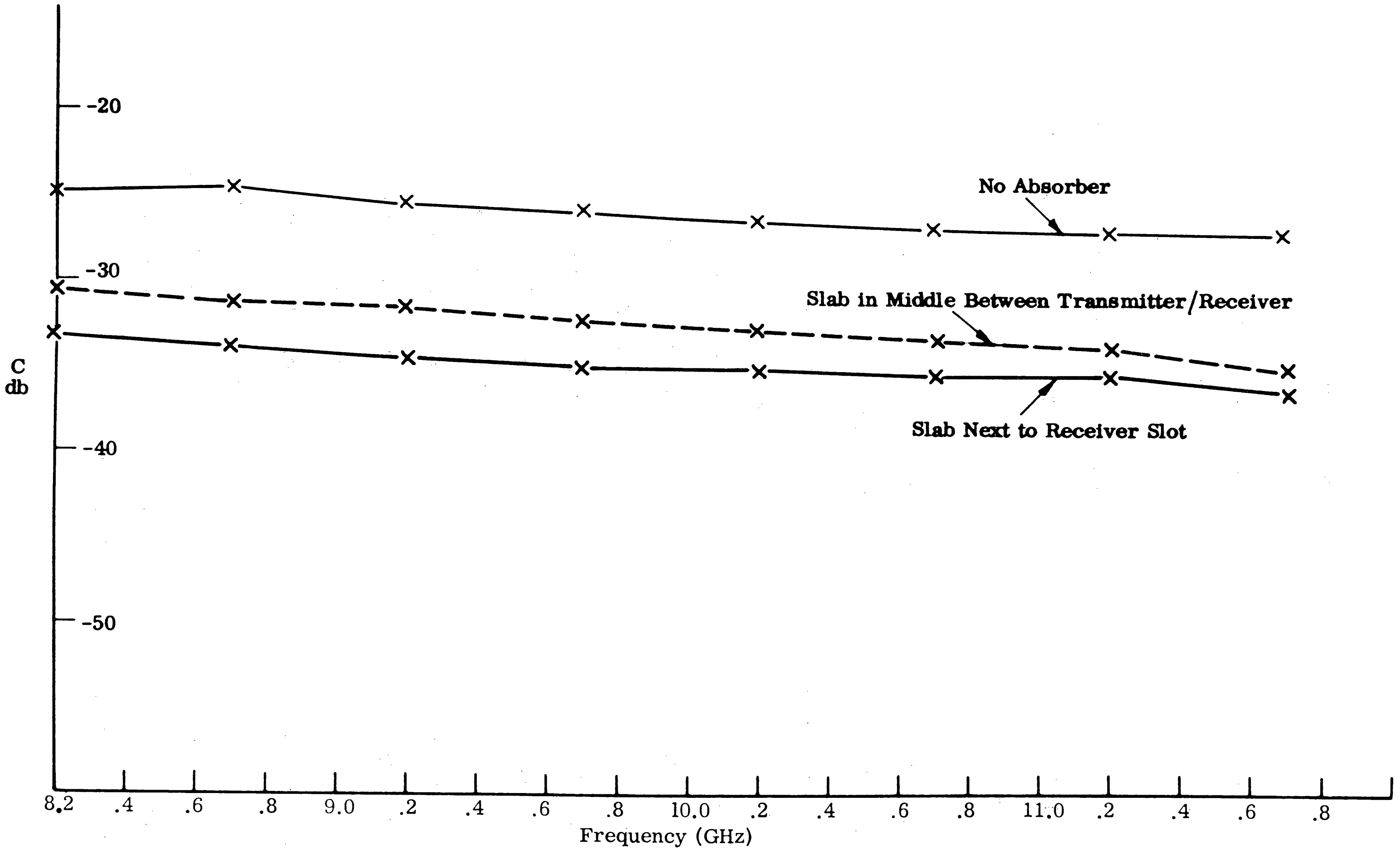


FIG. 2-14: E-PLANE COUPLING VS FREQUENCY FOR SLOTS OF SEPARATION OF 6.5 CM CENTER-TO-CENTER. ABSORBER: ECCOSORB-CR (6. 6 x 3. 7 x 0. 6 cm).

III
ABSORPTION MATERIALS

Study of the literature gives information on some of the possible sources of broadband absorption materials. The following information will serve as a guide to future efforts.

Except for materials with sharply resonant absorption, the loss tangent of a material is a good indication of its ability for power absorption. For resonant absorption material, the resonant frequency and bandwith (linewidth) of absorption are also of interest. It is often possible to shift the resonant frequency by varying one of the factors that determine the resonant frequency. This has been done by laboratories making absorption material.

Commercial ferrites having a small loss tangent, usually less than 0.002 often have resonant absorption which is also narrow-banded, ranging, for example, from a few tens of megahertz in the X-band to a few hundreds of megahertz . Some porous polycrystaline ferrites may have considerably larger loss tangents and greater bandwidth absorption. Such broadband absorption material is not readily available commercially at present.

So far, high loss dielectric material has been most promising for the needs of this contract. Some available dielectric materials are advertised to have loss tangent $\simeq$ 0.5 and measurements using some of them (Eccosorb-CR, etc) yield fairly good results. Increased isolation over the entire X-band is possible with the use of such material. It should also be mentioned that some of these dielectrics are resonant type materials whose absorption can be set at any frequency from S- through K-band according to composition and processing.

There are three general classifications of material which are useful for isolation purposes. One of these is a composite material consisting primarily of dielectric such as rubber, which is loaded by some conducting constituent such as carbon. The Goodrich RF-X material seems to be of this general type. Another material is an absorbing ferrite which is characterized by having a resonant frequency. At this frequency, a maximum of power absorption occurs. It is believed that the Eccosorb-CR material has a resonant frequency approximately in the center of the X-band. Depending upon the frequency used in coupling experiments, various selections of absorbing material will be made. A third class of material is one which may very well consist of a composition made in the laboratory from commonly available materials. This material could be made up of paraffin, carbon black and finely divided iron. Such a material is expected to be used in some of the experiments, since it will permit a wide latitude in arrangement. It will also minimize the need for machining work.

IV

CONCLUSIONS

During this quarter, both experimental and analytical results have been encouraging. Analytically, it has been shown that absorbing strips mounted flush between two antennas (if properly designed and placed) can substantially reduce the coupling from one antenna to another. Details of this analysis have been reserved for the next report.

Experimentally, a program of testing, using rectangular slots, has also proved that substantial reduction of coupling, or increased isolation can be accomplished through the use of absorbing barriers. The need for even greater reduction is apparent. Future efforts will be so directed.

V

FUTURE WORK

Work to be done in the next quarter includes a substantial experimental program in the S-band using Archemedean spiral antennas as well as rectangular slot antennas. It is believed that much should be accomplished in reducing coupling between two antennas, one of the spiral type and one of the rectangular slot type. Special emphasis will be placed upon the reduction of near-field coupling.

The analytical effort will be extended to a consideration of the type of absorbing material used in a strip barrier. This will include a study of the need for depth in such a strip, as well as the influence of the electrical characteristics of the material on the impedance offered to a bound wave traveling along such a surface.

Considerable experimental effort will be made upon rectangular slots with intervening panels or trenches with or without absorbing material (Fig. 5-1). It is planned to make extensive use of the anechoic chamber in order to obtain precise data on a large number of arrangements. Corrugated surfaces are to be included in this work. An attempt will be made to optimize slab design for absorption and cancellation effects when such a slab is mounted between two antennas.

A microwave compensating bridge is planned. This bridge will provide a properly phased and attenuated signal in a second antenna to compensate for the unwanted signal from the first antenna entering the second antenna due to coupling.

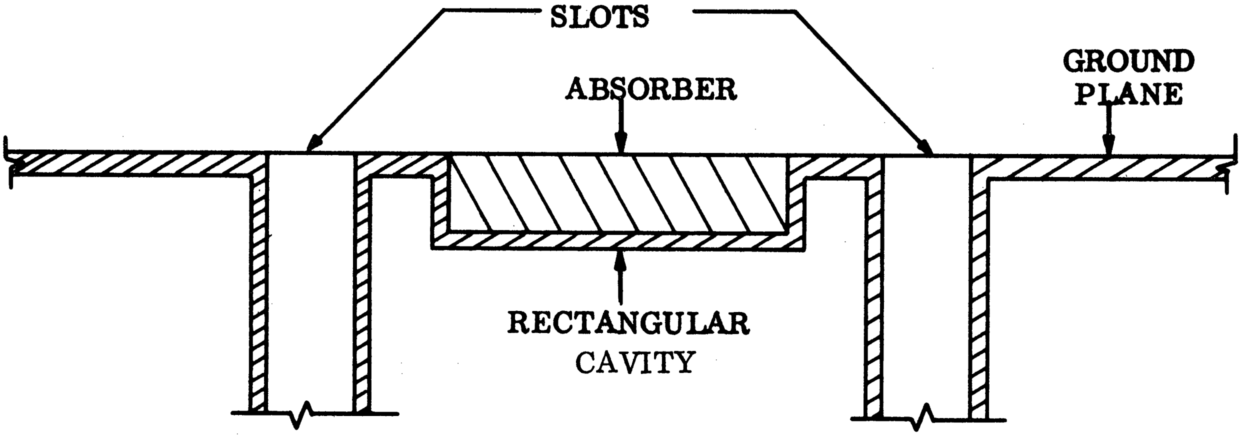


FIG. 5-1: ABSORBER PLACED IN SHALLOW CAVITY

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
The University of Michigan Radiation Laboratory
Department of Electrical Engineering

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
Electromagnetic Coupling Reduction Techniques

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
First Quarterly Report 1 November 1965 - 28 February 1966

5. AUTHOR(S) *(Last name, first name, initial)*
Lyon, John A. M. Ibrahim, Medhat, A. H., Digenis, Constantine, J.
Cha, Alan G. T. and Kwon, Yong-Kuk.

6. REPORT DATE
15 March 1966

7a. TOTAL NO. OF PAGES
26

7b. NO. OF REFS
--

8a. CONTRACT OR GRANT NO.
AF 33(615)-3371

b. PROJECT NO.
4357

c. Task 435709

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
7692-1-Q

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
Qualified requestors may obtain copies of this report from DDC

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Air Force Avionics Laboratory, USAF AFSC
Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

In this report, preliminary results are shown for relatively simple antenna coupling situations. In one series of measurements, rectangular slot antennas were used with absorbing obstacles between. Increase in isolation as high as 25 db has been obtained.

The use of specific absorbing materials is discussed. Extension of isolation techniques to various types of antennas is covered. A brief discussion of analysis now underway is given.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
DECOUPLING						
ABSORBING MATERIALS						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.