Activity Supply Officer, USAECOM  
Building 2504, Charles Wood Area  
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C, Institute of Exploratory Research  
ATTN: ANSEL-XL-C  
Mr. W. Czerwinski  
Inspect at Destination  
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER


Gentlemen:

A theoretical study and experimental investigation directed towards the establishment of techniques and procedures for simulating a free-space environment for RF testing of VHF whip antennas over the frequency range of 30 MHz to 75 MHz was initiated 1 July 1967.

Thus far, three sub-tasks have been initiated under this program. A measurement technique for measuring the reflectivity characteristics of absorbing materials over the frequency range from 30 MHz to 1 GHz has been developed and measurements have been performed on Eccosorb NZ-1 and Eccosorb HPY-72 absorbing materials.

A 10' x 10' ground plane is being constructed on the roof of the Electronics Research Building. This ground plane will be utilized for all open-field measurements on the twelve (12) AS-1729( )/VRC antennas.

An investigation of existing techniques for measuring the current distribution on antennas is being performed in an attempt to develop a technique for measuring the current distribution on the AS-1729( )/VRC antennas while operating (1) in the open-field, (2) in the open-field with absorbing material in close proximity and (3) in a compact anechoic chamber.

The measurement setup used to measure the reflectivity characteristics of absorbing materials is shown in Figure 1. The absorbing material to be measured is mounted on one side of a 3' x 2' aluminum plate. The plate with absorbing material attached is mounted on an antenna positioner, or rotator,
as shown in the figure. One tuned dipole antenna is used to radiate energy into the absorber-plate target and a second tuned dipole is used to receive the energy reflected from the target. The target is rotated through 360 degrees and reflection maximums are received when the plane of the absorbing material and the plane of the bare aluminum plate are normal to the bisector between the dipole antennas. The difference between the amplitudes of the two maximums is the reflectivity of the absorbing material.

During preliminary measurements, it became apparent that the direct coupling between the dipoles was so great that it overshadowed the reflected signal from the target. To overcome this problem a part of the signal from the signal generator was coupled over to the input of the receiver through a phase shifter and an attenuator. The phase shifter and attenuator are adjusted so that the phase and amplitude of the coupled signal is optimized to cancel the signal coupled directly between the dipole antennas, as well as reflected signals from arbitrary reflecting objects on and near the measurement range. This cancellation technique reduced the extraneous coupling between antennas and reflections to the extent that the desired reflectivity measurements could be made.

The reflectivity characteristics of Eccosorb NZ-1 absorbing material were measured over the frequency range from 50 to 1000 MHz. Between 350 and 1000 MHz the measured reflectivity of this material agreed quite well with the manufacturer's specified reflectivity, 15 to 19 dB below the flat metal plate. Below 350 MHz, however, the measured reflectivity rolled off quite rapidly with frequency and was down to approximately -5 dB at 200 MHz. At 75 MHz the reflectivity was -2 dB, and at 50 MHz was -1 dB.

We called Mr. E. F. Buckley at Emerson and Cuming, Inc. and discussed these results with him. We described our measurement procedure to him, and he indicated that he felt the measurements were valid. He admitted that they had never made measurements on the material below approximately 300 MHz and that the published reflectivity curve was based on calculations utilizing the characteristics of the ferrite material. Mr. Buckley said he would make some additional measurements and would call back.

Mr. Buckley called back and stated that our results were valid, that he had obtained essentially the same results, and that the reflectivity characteristics of NZ-1 were very poor below 300 MHz.

The reflectivity characteristics of Eccosorb HPY-72 absorbing material were also measured over the frequency range from 50 to 1000 MHz. The measured reflectivity of this material remained better than -10 dB over the entire frequency range. Additional measurements down to 30 MHz will be performed on this material. The HPY-72 material is six-feet thick and is not very attractive for application to compact anechoic chambers; however, it should be useful in experiments to determine the effects of absorbing material in the very near-fields of antennas.
Reflectivity measurements are presently being performed on Eccosorb FR-350 absorbing material.

The construction of an elevated 10' x 10' ground plane on the roof of the Electronics Research Building has been completed except for the installation of the expanded copper mesh. Delivery of the copper mesh is scheduled prior to August 15. It is anticipated that the ground plane will be completed by the time the twelve AS-1729( )/VRC antennas are received.

The AVCO anechoic chamber and Rohde and Schwarz Z-g Diagraph, type ZDU, have not been received as of this date.

Respectfully submitted:

William R. Free
Project Director

Approved: [Signature]

D. W. Robertson, Head
Communications Branch
Figure 1. Measurement setup for reflectivity measurements.
4 September 1967

Activity Supply Officer, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

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ATTN: AMSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

1 August 1967 to 1 September 1967, Contract DAAB07-67-C-0575,
"Compact Anechoic Chambers for Testing and Alignment of
VHF Whip Antennas."

Gentlemen:

A theoretical study and experimental investigation directed towards
the establishment of techniques and procedures for simulating a free-
space environment for RF testing of VHF whip antennas over the frequency
range of 30 MHz to 76 MHz was continued during this reporting period.

The AVCO anechoic chamber and the Rohde and Schwarz Z-g Diagraph,
type ZDU, were received 11 August 1967. A preliminary check of the
diagraph indicates that it is in good operating condition. The anechoic
chamber materials have been uncrated and everything appears to be in
reasonably good condition. It is not possible at this time to determine
the completeness of the shipment since a bill of materials was not included;
however, it is apparent that the toggle clamps and the 12" x 12" antenna
mounting plate were not included in the shipment.

The reflectivity characteristics of the B. F. Goodrich 48" wedge
absorbing material, used in the AVCO chamber, were measured over the
frequency range from 50 to 1000 MHz. Below 80 MHz the measured reflectivity
of this material was less than 1 dB below a flat metal plate of the same
size. Over the range from 100 to 600 MHz the reflectivity varied from
-1 dB to -9 dB. Above 600 MHz the reflectivity was better than -10 dB.

The reflectivity characteristics of Ecosorb FR 350 absorbing material
were also measured over the 50 to 1000 MHz frequency range. Below 200 MHz
the measured reflectivity was less than -1 dB. Over the range from 100 to
500 MHz the reflectivity gradually improved from -1 dB at 200 MHz to -9 dB
at 500 MHz. Above 500 MHz the reflectivity was better than -10 dB.
On 29 August 1967 notification was received from Mrs. S. McCashin of the ECOM Property Section that the twelve (12) AS-1729( )/VRC antennas would not be received before the middle of November.

The expanded copper mesh was received during this report period and is presently being installed on the elevated 10' x 10' ground plane frame.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
REPORT APPROVAL SHEET

Due Date: 10 Sept. 1967

Monthly Status Report No. 2

PROJECT NO. A-1031

REPORT TITLE (Unclassified) "Compact Anechoic Chambers for Testing and Alignment of VHF Whip Antennas"

REPORT AUTHOR(S) W. R. Free

PROJECT DIRECTOR W. R. Free

DIV./BR. Communications Br., Electronics

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MARKED FOR: DIVISION C, Institute of Exploratory Research
ATTN: AMSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

1 September 1967 to 1 October 1967, Contract DAAB07-67-C-0575,
"Compact Anechoic Chambers for Testing and Alignment of VHF
Whip Antennas".

Gentlemen:

A theoretical study and experimental investigation directed towards
the establishment of techniques and procedures for simulating a free-
space environment for RF testing of VHF whip antennas over the frequency
range of 50 MHz to 76 MHz was continued during this reporting period.

W. R. Free visited Mr. W. P. Czerwinski at Fort Monmouth on 13 Sep-
ember 1967 to discuss the current status of the project. The delay
in the delivery of the twelve AS-1729/VRC antennas, which are to be
furnished as GFE under the contract, was discussed. These antennas
were originally scheduled to be shipped by 1 August 1967. The latest
information indicates that the antennas will not be shipped before
November. Mr. Czerwinski agreed to loan Georgia Tech two antennas from
his lab until the 12 antennas are received. Two antennas were issued
to Mr. Free on a hand receipt and were hand carried to Georgia Tech.

Mr. Terry Louis of Conductron called W. R. Free on 6 September 1967.
He indicated that Conductron was very interested in working with Georgia
Tech and Mr. Czerwinski in the development of a compact anechoic chamber.
He stated that Conductron presently has a ferrite absorbing material
with -15 dB reflectivity at 50 MHz, however, this material presently
is classified. Mr. Louis plans to contact Mr. Baret and Mr. Kruger
at Wright-Patterson AFB to determine the possibility of removing the
security classification on the low-frequency absorbing materials. He
is to notify Mr. Czerwinski of the results of this contact.
Mr. Maddox, the local Emerson and Cumming representative, visited W. R. Free on 18 September 1967. Mr. Maddox was not aware of our communications with Mr. Buckley and Mr. Buckley's statement that the reflectivity characteristics of the Eccosorb NZ-1 material did not meet specifications below 300 MHz. Mr. Maddox contacted Mr. Emerson on the subject, and Mr. Emerson disagrees with Mr. Buckley's statements. He maintains that the material has been tested down to 50 MHz and meets the published specifications. Mr. Emerson requested information on the details of Georgia Tech's measurement technique and the resulting data. The requested information was furnished to Emerson and Cumming. It was suggested that Mr. Emerson and Mr. Buckley jointly reach a decision on the NZ-1 material and supply Georgia Tech with the necessary data to support the decision.

The fabrication of the 10' x 10' ground plane has been completed and the instrumentation necessary to make impedance measurements on the ground plane has been installed. Impedance measurements are currently being performed on the two AS-1729/VRC antennas. A 2' x 6' plane of Eccosorb NZ-1 absorbing material has been constructed. The next series of measurements will be performed to determine the effects on the input impedance of the antennas when the plane is placed in close proximity to the antenna.

Mr. Czerwinski notified AVCO of the omission of the toggle clamps and the antenna mounting plate from the anechoic chamber shipment. AVCO shipped these items directly to Georgia Tech. The assembly of the chamber is currently in progress.

Respectfully submitted,

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
Activity Supply Officer, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C, Institute of Exploratory Research
ATTN: AMSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJ: Monthly Status Report No. 4, 10 November 1967, Report
Period 1 October 1967 to 1 November 1967, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for Testing and Alignment of VHF Whip Antennas".

Gentlemen:

A theoretical study and experimental investigation directed towards the establishment of techniques and procedures for simulating a free-space environment for RF testing of VHF whip antennas over the frequency range of 30 MHz to 76 MHz was continued during this reporting period.

Low frequency reflectivity measurements have been completed on four types of absorbing materials, Eccosorb NZ-1, Eccosorb FR-350, Eccosorb HPY-72 and B. F. Goodrich 48" wedges.

Eccosorb NZ-1 is a thin broadband ferrite absorbing material in the form of tiles. The tiles are 2" x 2" and approximately 1" thick. Each tile is shaped into four 1" x 1" pyramids 1" high. Emerson and Cuming, Inc., claims the reflectivity of this material is -13 dB or better from 50 MHz to 15 GHz. Eccosorb FR-350 is a broadband rigid foam absorbing material in the form of 1' x 3' blocks 8" thick. The manufacturer claims the reflectivity of this material is -20 dB or better at 455 MHz and above. Eccosorb HPY-72 is a light weight polyurethane foam absorbing material in a pyramidal shape. Each piece is 24" x 24" and contains four pyramids 72" high and with 12" x 12" bases. The manufacturer claims the reflectivity of this material is
-20 dB or better above 75 MHz. The size of this material eliminates it from consideration in a compact chamber, but it was included in the test group primarily as a reference to evaluate the reflectivity measurement technique and to determine the effect of a good absorbing material in close proximity to an antenna. The B. F. Goodrich material is made of lightweight foam material coated with resistive cloth. Each piece is a hollow wedge which measures 18" x 24" at the base and is 4/8" thick. This material was included in the test group because it was used in a previously developed chamber for testing the AS-1729/VRC antenna.

The measurement technique and the measurement test set-up for making low frequency reflectivity measurements were described in Monthly Status Report No. 1. The reliable dynamic range of the technique and test set-up as described is at least 15 dB over the frequency range from 50 MHz to 400 MHz and, at least, 10 dB over the range from 400 to 1000 MHz. Thus, there is a high confidence factor associated with all measurement results in the 0 to -15 dB reflectivity range at frequencies between 50 and 400 MHz and with results in the 0 to -10 dB range at frequencies above 400 MHz. It is also pointed out that the reflectivity characteristics specified by the manufacturers are based on a normal incident angle while the test set-up utilized an incident angle of 15 degrees with respect to the normal of the target specimen. This difference in incident angle could have a significant effect on the thick absorbing materials, HPY-72 and 4/8" wedges, but should have little effect on the thin materials. The manufacturer claims that a change in incident angle over the range from normal to 30 degrees off normal will have a negligible effect on the reflectivity characteristics of the Eccosorb NZ-1 material.

The results from the reflectivity measurements are shown in Figure 1. The measured reflectivity characteristics of the four absorbing materials over the frequency range from 50 to 1000 MHz are shown plotted in decibels relative to a flat metal plate the same size as the test sample. It is apparent from the figure that HPY-72 is the only material which exhibits any appreciable absorption below approximately 200 MHz. The measured reflectivity of the NZ-1 material agreed quite well with manufacturer's published reflectivity curve over the frequency range from 400 to 1000 MHz, however, below 400 MHz the measured reflectivity diverged quite rapidly below the published curve. At the highest frequency of the range of interest, 76 MHz, the NZ-1 material absorbed less than half of the incident power. Below 75 MHz, the reflectivity characteristics of the B. F. Goodrich material and Eccosorb FR-350 were no better than the flat metal plate reference.
Open-field impedance measurements have been completed on AS-1729/VRC Antenna, Serial No. 2. The antenna was mounted on a 10' x 10' ground plane. The results from these measurements are shown in Figure 2. Four independent sets of open-field measurements were performed to determine the effect of weather conditions on the measurement results and the repeatability of the measurement technique. The four sets of measurements were made on different days during a four week period. Weather conditions varied considerably from set to set and varied from sunny with no wind to misty and wet with gusty winds. The results from all four sets of measurements are shown on the figure as four-dot clusters. The close agreement between the results indicates both the insensitivity of the antenna impedance to weather conditions and the high degree of repeatability inherent in the measurement technique.

The open-field impedance and VSWR of antenna Serial No. 2 measured on a 10' x 10' ground plane and on a 15' x 15' ground plane are shown in Figure 3. The right-hand column shows the difference in the VSWR of the antenna when it is operated on the two ground planes. The results in this figure indicate that the antenna impedance is sensitive to the ground plane size. For the case presented here, a 10' x 10' and a 15' x 15' ground plane, the most significant differences occur in the lower four bands of the antenna.

Since it is anticipated that any compact test chamber will present a ground plane to the antenna which is considerably different from the standard 10' x 10' ground plane, additional investigation of the effect of ground plane size on antenna impedance appears to be warranted. Arrangements are currently being made to perform antenna impedance measurements on a 2.5' x 2.5' ground plane.

Measurements were performed to determine the effect upon antenna impedance when a flat metal plate and a metal plate of the same size covered with NZ-1 absorbing material were placed in close proximity to an antenna. To accomplish these measurements, a wooden frame, capable of supporting a metal plate 10" wide and 6' high in a vertical position on the 10' x 10' ground plane, was constructed. The test planes were located on the ground plane at spacings of 6, 12, 18, 24, 36 and 48 inches from the test antenna. Two typical sets of results from these measurements are shown in Figures 4 and 5. Figure 4 shows the results obtained when the metal plate and the absorber covered plate were located at a spacing of 12" from the test antenna. The measured open-field impedances are shown as open circles, the impedance with the metal plate as a solid circle, and the impedance with the NZ-1 material as a triangle. Figure 5 shows the results obtained at a spacing of 24 inches. The results from these measurements indicate (1) that the NZ-1 material and the metal plate cause impedance changes which are approximately equal in magnitude, (2) that the direction of the impedance changes caused by the two planes appears to be more or less random and (3) that the magnitudes of the
impedance changes decrease with an increase in the spacing between the test antenna and the test planes.

Similar measurements are currently being performed with FR-350, HPY-72 and the B. F. Goodrich absorbing materials.

It is anticipated that all of the remaining basic measurements will be completed during the early part of the next reporting period, and the design plan will be completed during the remainder of this period.

Respectfully submitted:

William R. Free
Project Director

Approved: ┐

D. W. Robertson, Head
Communications Branch
Figure 1. Measured Reflectivity Characteristics of Four Absorbing Materials
Figure 2. Open-field Impedance of AS-1729/VRC Antenna Serial No. 2
On 10' x 10' Ground Plane
<table>
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<tr>
<th>FREQ - BAND</th>
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<th>15' x 15' GND. PLANE</th>
<th>Δ-VSWR</th>
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<tr>
<td>30-1</td>
<td>0.55 + J0.67</td>
<td>1.15 + J0.92</td>
<td>2.3</td>
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<tr>
<td>33-1</td>
<td>0.78 - J0.53</td>
<td>0.37 - J0.52</td>
<td>3.6</td>
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<tr>
<td>33-2</td>
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<td>1.60 - J0.00</td>
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<td>37-2</td>
<td>0.39 - J0.36</td>
<td>0.29 - J0.17</td>
<td>3.6</td>
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<td>1.62 - J0.72</td>
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FIGURE 3. OPEN-FIELD IMPEDANCE MEASUREMENTS OF AS-1729/VRC ANTENNA SERIAL NO. 2 ON 10 FT. AND 15 FT. GROUND PLANES.
Figure 4. Impedance Changes Caused By Metal Plate (18" wide x 6' high) and Metal Plate Covered With NZ-1 Material At a Spacing of 12" From Test Antenna
Figure 5. Impedance Changes Caused By Metal Plate (18'' wide x 6' high) and Metal Plate Covered With NZ-1 Material At a Spacing of 24'' From Test Antenna
December 1967

Activity Supply Officer, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C. Institute of Exploratory Research
ATTN: ANSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJ: Monthly Status Report No. 5, 10 December 1967, Report
Period 1 November 1967 to 1 December 1967, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for Test-
ing and Alignment of VHF Whip Antennas".

Gentlemen:

A theoretical study and experimental investigation directed
towards the establishment of techniques and procedures for simulat-
ing a free-space environment for RF testing of VHF whip antennas over
the frequency range of 30 MHz to 76 MHz was continued during this
reporting period.

The open-field impedance and VSWR of AS-1729/VRC Antenna,
Serial No. 2, measured on a 10' x 10' and 15' x 15' ground plane
were presented in the last report. It was pointed out that sig-
nificant differences were observed in the results obtained on the
two different size ground planes over the lower four bands of the
antenna. Additional measurements were made on a 2.5' x 2.5'
ground plane during this report period. These measurements were
repeated with an aluminum cylinder, two feet in diameter and four
feet high, lined with NZ-1 absorbing material placed on the 2.5' x 2.5'
ground plane, centered around the base of the antenna. The results
from the complete series of measurements, on the 15' x 15', 10' x 10',
2.5' x 2.5' ground planes and on the 2.5' x 2.5' ground plane with
the NZ-1 lined cylinder, are shown in Figures 1-10.

The results from the measurements on the 2.5' x 2.5' ground plane
support the previous conclusion that the antenna impedance is sen-
sitive to ground plane size over the lower four bands of the antenna.
Since it is anticipated that the compact test chamber will present a ground plane to the antenna under test considerably different from the standard 10' x 10' ground plane, obtaining the same antenna impedance in the test chamber and on a 10' x 10' ground plane does not appear feasible. Thus, the use of correction factors to correlate measurement results obtained in the test chamber with open-field antenna characteristics appears unavoidable.

The results from the measurements made on the 2.5' x 2.5' ground plane with the NZ-1 lined cylinder revealed two interesting properties of the cylinder. While these measurements were made well below the frequency where the NZ-1 material becomes a good absorber (approximately 220 MHz), the addition of the NZ-1 lined cylinder significantly reduced the difference in antenna impedance measured on the 2.5' x 2.5' ground plane compared to that measured on the 10' x 10' ground plane at the lower frequencies. Figures 1 and 2 show that the impedance change was reduced to approximately one-half in bands 1 and 2 by the addition of the lined cylinder. Also, the addition of the lined cylinder improved the antenna VSWR over that which was obtained with either the 2.5' x 2.5' or the 10' x 10' ground plane.

These results were encouraging for they seemed to indicate that even though NZ-1 material was not a good absorber in this frequency range, it exhibited characteristics which were desirable in the lining of a compact test chamber.

In order to determine the effect of a NZ-1 lined chamber over the entire length of an antenna (rather than less than half the antenna length, as was the case with the 4.8' high cylinder), measurements were made on a 35-inch base-fed monopole antenna on a 1' x 1' ground plane and in a NZ-1 lined chamber 8 inches in diameter and 38 inches long. The results from these measurements over the frequency range from 30 to 290 MHz are shown in Figure 11. It is apparent from the figure that the antenna impedance measured on the ground plane and in the chamber are different; however, of particular interest is the fact that, over the frequency range from 30 to 220 MHz, for each change in open-field impedance there is a corresponding change in chamber impedance. Above 220 MHz (where the NZ-1 material becomes a good absorber) however, the open-field impedance of the antenna continues to change significantly with frequency, but the impedance measured in the chamber remains in the vicinity of 2.6 - J2.6.

In order to get several impedance values at each test frequency, the length of the 35-inch monopole antenna was decreased in one-inch increments and additional test runs were made.
Typical results from these measurements at 75 MHz and 290 MHz, are shown in Figures 12 and 13 respectively. Figure 12 shows that for four open-field impedance values at 75 MHz, four discrete impedance values were measured in the chamber. However, Figure 13 shows that for four significantly different open-field impedance values at 290 MHz, essentially the same impedance was measured in the chamber.

Thus, it appears that in the frequency range below where the NZ-1 material is a good absorber, it may be possible to correlate the impedance measured in a compact chamber, lined with the material, with an open-field impedance; however, in the frequency range where the material is a good absorber, the correlation would be impossible.

This new insight into the problem makes it possible to consider other materials for use in the compact test chamber. Up to the present time, only absorbing materials have been investigated. Now, it appears that a lossy dielectric material is what is needed. Perhaps a satisfactory material considerably less expensive than the NZ-1 material can be found.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
Figure 1. Open-field Impedance of AS-1729/VRC Antenna as a Function of Ground Plane Size — Band 1.
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Activity Supply Officer, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C. Institute of Exploratory Research
ATTN: AMSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJ: Monthly Status Report No. 6, 10 January 1968, Report
Period 1 December 1967 to 1 January 1968, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for Test-
ing and Alignment of VHF Whip Antennas".

Gentlemen:

A theoretical study and experimental investigation directed toward
the development of a compact test chamber for RF testing of VHF whip
antennas over the frequency range of 30 to 76 MHz was continued during
this reporting period.

Mr. W. P. Czerwinski visited Georgia Tech on December 5 and 6,
1967. The results obtained on the program thus far, the current status
of the program and the plans for the remainder of the program were
discussed. It was mutually agreed that the program has not reached
the point that a realistic design plan for the final configuration of
the compact test chamber can be developed.

A letter requesting that the delivery of the design plan be
changed from 1 December 1967 to 15 February 1968 was mailed to Mr. Gene
Mongiardini on 13 December 1967.

The fabrication of an experimental model of a compact test chamber
was completed during this report period. This chamber consists on an
aluminum cylinder 12 feet long with a 1 foot inside diameter and a 1/8
inch wall thickness. An end plate is provided at each end of the cy-

The inside walls of the chamber are lined
with Ecosorb NZ-1 ferrite absorbing material.
Measurements of the impedance characteristics of the twelve AS-1729/VRC test antennas are currently being performed with the test antennas mounted on the axis of the compact test chamber.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
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Fort Monmouth, New Jersey 07703

MARKED FOR:  DIVISION C, Institute of Exploratory Research
ATTN:  AMSEL-XL-C
Mr. W. Czerwinski
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Contract No. DAAB07-67-C-0575

FOR:  ACCOUNTABLE PROPERTY OFFICER

SUBJ:  Monthly Status Report No. 7, 10 February 1968, Report
Period 1 January 1968 to 1 February 1968, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for Testing
and Alignment of VHF Whip Antennas".

Gentlemen:

A theoretical study and experimental investigation directed towards the development of a compact test chamber for RF testing of VHF whip antennas over the frequency range of 50 to 76 MHz was continued during this reporting period.

Measurements of the impedance characteristics of fourteen test antennas in an experimental compact test chamber and on a 10 x 10 foot ground plane in the open-field were completed during this reporting period. The experimental compact test chamber consisted of an aluminum cylinder 12 feet long with a 1 foot inside diameter and a 1/8 inch wall thickness. An end plate was provided at each end of the cylinder. One end plate had provisions for mounting an AS-1729/VRC antenna on the axis of the cylinder. The inside walls of the chamber were lined with Eccosorb NZ-1 ferrite absorbing material.

To determine if this compact chamber could be utilized in tuning the AS-1729/VRC antenna, it was necessary to determine if any unique relationship or correspondence existed between antenna impedances measured in the open-field and impedances measured in the compact chamber at corresponding band-frequency combinations. The fourteen AS-1729 antennas available at Georgia Tech were used in this study. For each of these antennas, the open-field impedance on a 10 x 10 foot ground plane was measured at the upper and lower frequency limits of
each of the ten bands. As expected, the measured open-field impedances corresponding to each band-frequency combination tended to group or cluster about a central impedance value. The impedance of each of the fourteen antennas was then measured in the compact chamber at the upper and lower frequency limits of each of the ten bands. The measured chamber impedances corresponding to each band-frequency combination also tended to cluster about a central impedance value. Although the chamber impedance values were quite different from the corresponding open-field impedance values for any band-frequency combination, it was noted that for each chamber cluster a unique corresponding open-field cluster existed.

It was hypothesized that if a detuned antenna were tuned in the chamber such that its impedance value at each band-frequency combination was centered in the cluster of values previously measured in the chamber for the subject combination, the corresponding open-field impedances would also lie in the center of the previously measured open-field clusters. To test this hypothesis, an AS-1729 antenna was detuned. This antenna was retuned in the compact chamber such that its chamber impedance at each band-frequency combination was centered in the appropriate chamber cluster. The lower frequency limit of band 1 and bands 3 through 9 and the upper frequency limit of band 10 were used for tuning (band 2 is not tunable in the AS-1729 antenna). These particular tuning frequencies were chosen to conform to those used for tuning of the antenna by the manufacturer.

The results of this test are summarized in Figures 1 through 19. Figures 1 through 9 show the detuned impedance value, the retuned value, and the cluster values for each band in the compact chamber at the frequency chosen for retuning. Figures 10 through 19 show the detuned values, retuned values, and cluster values for each band in the open-field at the upper and lower frequency limits of the band. The excellent results obtained from this test indicate the validity of the hypothesis that an AS-1729 antenna can be tuned in the compact chamber in the manner described.

Mr. W. P. Czerwinski and Dr. H. L. Brueckmann visited Georgia Tech 30 January through 1 February 1968. During a three-day review
of the program, the results presented in this report were discussed in detail and plans for the remainder of the program were established.

Respectfully submitted:

William R. Free
Project Director

Approved:  

D. W. Robertson, Head
Communications Branch
IMPEDEANCE OR ADMITTANCE COORDINATES

SAMPLE ANTENNA RESULTS

TEST ANTENNA-UNCALIBRATED

TEST ANTENNA-RECALIBRATED

FIGURE 2
IMPEDEANCE OR ADMITTANCE COORDINATES

- Sample Antenna Result
  - Test Antenna - Uncalibrated
  - Test Antenna - Recalibrated

Figure 3

Radially Scaled Parameters
IMPEDANCE OR ADMITTANCE COORDINATES

- SAMPLE ANTENNA RESULTS
- TEST ANTENNA-UNCALIBRATED
- TEST ANTENNA-RECALIBRATED

FIGURE 4

RADIIALLY SCALLED PARAMETERS

TOWARD LOAD — — TOWARD GENERATOR
IMPEDEANCE OR ADMITTANCE COORDINATES

Simple Antenna Results
Test Antenna - Uncalibrated
Test Antenna - Recalibrated

Figure 5

Radially Scaled Parameters

A Mega-Chart
IMPEDANCE OR ADMITTANCE COORDINATES

- SAMPLE ANTENNA RESULTS
- TEST ANTENNA-UNCALIBRATED
- TEST ANTENNA-RECALIBRATED

Figure 7

Radially scaled parameters:

1. Scale for resistance components.
2. Scale for conductance components.
3. Scale for capacitive components.
4. Scale for inductive components.

Toward load:

- Current
- Voltage

Toward generator:

- Current
- Voltage
IMPEDEANCE OR ADMITTANCE COORDINATES

- SINGLE AMPLIFIER RESULTS
- TEST AMPLIFIER UNCALIBRATED
- TEST AMPLIFIER RECALIBRATED

Figure 8
IMPEDEANCE OR ADMITTANCE COORDINATES

- SIMPLE ANTENNA RESULTS
- TEST ANTENNA-UNCALIBRATED
- TEST ANTENNA-RECALIBRATED

**Figure 9**

RADIIALLY SCALED PARAMETERS

TOWARDS LOAD

TOWARDS GENERATOR
IMPEDEANCE OR ADMISSION COORDINATES

- SAMPLE ANTEAIA RESULTS
- TEST ANTEAIA = RECUESIOM

NOTE: THIS CARB NOT TUNABLE

Figure II

RADIALY SCALED PARAMETERS

TOWARD GENERATOR
IMPEADANCE OR IMPEDANCE COORDINATES

SAMPLE ANTENNA RESULTS
- TEST ANTENNA-UNOILIZATION
- TEST ANTENNA-REINFLATION

Figure 15

RADIIALLY SCALED PARAMETERS

TOWARD GENERATOR —— TOWARD LOAD
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Fort Mommouth, New Jersey 07703

MARKED FOR: DIVISION C. Institute of Exploratory Research
ATTN: AMSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJECT: Monthly Status Report No. 8, 10 March 1968, Report
Period 1 February 1968 to 1 March 1968, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for Test-
ing and Alignment of VHF Whip Antennas"

Gentlemen:

A theoretical study and experimental investigation directed to-
ward the development of a compact test chamber for RF testing of VHF
whip antennas over the frequency range of 30 to 76 MHz was continued
during this reporting period.

During a three-day review of the program with Mr. W. P. Czerwinski
and Dr. H. L. Brueckmann at Georgia Tech 30 January through 1 February
1968, it was concluded that the experimental compact test chamber (des-
cribed in Monthly Status Report No. 7) was adequate for performing the
desired tests and alignment of the AS-1729/VRC antenna.

Subsequently, a design plan was developed for a final compact
test chamber to be delivered. The chamber described in the test plan in-
corporates the same overall dimensions, materials and basic parameters
as the experimental chamber. In addition, the chamber described in the
test plan includes provisions for repetitive assembly and disassembly
to enhance the transportability of the unit, more rigid mechanical
construction and permanent mounting of the NZ-1 tiles on the walls of
the chamber.
The design plan of the final compact test chamber was submitted for approval on 10 February 1968.

The experimental chamber has been dismantled and the NZ-1 tiles are presently being cleaned for installation in the final chamber.

The fabrication of the machined parts of the final chamber are presently being scheduled in the machine shop.

Respectfully submitted:

William R. Free  
Project Director

Approved:  

D. W. Robertson, Head  
Communications Branch
Activity Supply Officer, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C, Institute of Exploratory Research
ATTN: AMSRL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJECT: Monthly Status Report No. 9, 10 April 1968, Report
Period 1 March 1968 to 1 April 1968, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for
Testing and Alignment of VHF Whip Antennas"

Gentlemen:

A theoretical study and experimental investigation directed toward
the development of a compact test chamber for RF testing of VHF whip
antennas over the frequency range of 30 to 76 MHz was continued during
this reporting period.

The fabrication of the machined parts for the final compact chamber
and the mechanical assembly of the chamber have been completed. The NZ-1
ferrite tiles are currently being installed on the walls of the chamber.
It is anticipated that the final compact chamber will be completed by
15 April 1968.
It is presently planned that the evaluation, calibration and final testing of the compact test chamber will be performed during the period from 15 April to 15 May 1968.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
Activity Supply Officer, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C, Institute of Exploratory Research
ATTN: AMSRL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJECT: Monthly Status Report No. 10, 10 May 1968, Report
Period 1 April 1968 to 1 May 1968, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for
Testing and Alignment of VHF Whip Antennas"

Gentlemen:

A theoretical study and experimental investigation directed toward
the development of a compact test chamber for RF testing of VHF whip
antennas over the frequency range of 30 to 76 MHz was continued during
this reporting period.

The fabrication and assembly of the final compact antenna test
chamber was completed during this reporting period and the evaluation,
calibration and final testing of the chamber are currently in progress.

Measurements of the impedance characteristics of ten AS-1729/VRC
test antennas in the final test chamber have been completed. Typical
results from these measurements in bands 1, 2, 5, 8 and 10 are shown
in Figure 1 along with the equivalent results obtained in the experi-
mental test chamber.

It is apparent from Figure 1 that clusters of impedance values
are obtained for the ten antennas in both chambers and the size of the
clusters obtained in the two chambers are approximately the same. It
is also apparent from the figure that the centers of the clusters obtained for the same set of antennas in the two chambers lie at slightly different locations on the Smith chart. The difference in cluster location is particularly apparent at the lower frequencies. The more permanent type construction used in the fabrication of the final chamber resulted in slight changes in the internal configuration and dimensions of the chamber, and hence, some differences in the impedance characteristics of the two chambers were expected. The differences shown in the figure appear to be within the limits one would expect under the circumstances. A more detailed discussion of the differences between the two chambers and their effects on the impedance characteristics of antennas will be presented in the next report when more data are available for a more complete analysis. This preliminary discussion, however, is sufficient to point out the probable necessity for accurately calibrating each test chamber.

Mr. W. P. Czerwinski, ANSEL-XL-C, USAECOM, visited Georgia Tech, 30 April through 2 May 1968, for a three-day technical review of the program and to finalize plans for final testing and calibration of the compact antenna test chamber to be delivered to USAECOM.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
Figure 1. Comparison of Impedance Clusters of Ten Antennas in Experimental Test Chamber and Final Test Chamber.
GERMANY INSTITUTE OF TECHNOLOGY

Activity Supervisor, USAECOM
Building 2504, Charles Wood Area
Fort Monmouth, New Jersey 07703

MARKED FOR: DIVISION C, Institute of Exploratory Research
ATTN: AMSEL-XL-C
Mr. W. Czerwinski
Inspect at Destination
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJECT: Monthly Status Report No. 11, 10 June 1968, Report
Period 1 May 1968 to 1 June 1968, Contract
DAAB07-67-C-0575, "Compact Anechoic Chambers for
Test and Alignment of VHF Whip Antennas"

Gentlemen:

A theoretical study and experimental investigation directed toward
the development of a compact test chamber for RF testing of VHF whip
antennas over the frequency range of 30 to 76 MHz was continued during
this reporting period.

In accordance with the final test plan finalized with Mr. W. P.
Czerwinski on 2 May 1968, five (5) of the ten AS-1729/VRC test antennas
were retuned in the compact antenna test chamber. A Hewlett Packard
Model 4815A RF Vector Impedance Meter was used as the impedance indicator
during the tuning of the antennas. The HP impedance meter was used in
lieu of the ZDU because (1) some problems had been encountered with the
ZDU and there was some question as to the repeatability of measurements
with this instrument, (2) the HP instrument made it possible to con-
tinuously observe the impedance as the antennas were tuned and (3) a HP
Vector Impedance meter is available for use at the antenna manufacturer's
installation.

Measurements of the open-field impedance characteristics of the five
antennas tuned in the compact test chamber are being performed on the
10 x 10 foot ground plane. It is anticipated that these measurements will be completed by 7 June 1968. The impedance clusters obtained for these five antennas will be compared with the impedance clusters for the original ten test antennas to determine the accuracy of antenna tuning in the compact chamber.

Measurements are currently being performed on five test samples of Eccosorb NZ-1 absorbing material to determine the permeability and permittivity of this material. The five test specimens were selected from different production runs, and hence, the results from these measurements should indicate the variation in material characteristics to be expected. In addition, the results from these measurements should provide information for specifying material characteristics for future procurement.

A set of reproducible drawings for the compact antenna test chamber is currently being prepared. It is anticipated that the drawings will be completed by 10 June 1968.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
Activity Supply Officer, USACEOM  
Building 2504, Charles Wood Area  
Port Monmouth, New Jersey 07703

MARKED FOR: DIVISION C. Institute of Exploratory Research  
ATTN: AMSEL-XL-C  
Mr. W. Czerwinski  
Inspect at Destination  
Contract No. DAAB07-67-C-0575

FOR: ACCOUNTABLE PROPERTY OFFICER

SUBJECT: Monthly Status Report No. 12, 10 July 1968, Report  
Period 1 June 1968 to 1 July 1968, Contract  
DAAB07-67-C-0575, "Compact Anechoic Chambers for  
Test and Alignment of VHF Whip Antennas"

Gentlemen:

A theoretical study and experimental investigation directed toward  
the development of a compact test chamber for RF testing of VHF whip  
antennas over the frequency range of 30 to 76 MHz was continued during  
this reporting period.

To determine the extent to which antennas tuned in the final chamber  
yielded desired open-field impedances on the 10 x 10 foot ground screen,  
5 of the factory tuned antennas were detuned, retuned in the final chamber,  
and the resulting open-field impedance clusters compared with those of the  
original 10 factory tuned antennas.

Impedances as a function of sub-band and frequency were determined  
with a Hewlett-Packard Model 4813A RF Vector Impedance Meter for 10  
factory tuned antennas in the final chamber. Measurements were also  
made with the ZDU on the same 10 factory tuned antennas both in the chamber  
and on the 10 x 10 foot ground screen in the open-field.

Five of the 10 factory tuned antennas were randomly detuned. These  
antennas were then retuned in the chamber using the vector impedance
meter. Retuning was accomplished by tuning the impedance at the low frequency end of each sub-band as nearly as possible to the center of the impedance cluster formed by the impedance measurements on the original 10 factory tuned antennas. Chamber impedance measurements were also made on the retuned antennas with the ZDU.

Open-field impedance measurements of the 5 retuned antennas were made on the 10 x 10 foot ground screen. The open-field impedances of the retuned antennas were compared with the corresponding impedances of the 10 factory tuned antennas. The agreement between the open-field impedances of the retuned and factory tuned antennas is quite good in sub-bands 1, 2, 3, 4, and 7 and reasonably good in sub-bands 6 and 8. At 47.5 MHz in sub-band 5, the impedances of both the retuned and factory tuned antennas have a large impedance spread. The open-field impedance cluster agreement at 53 MHz is quite good, indicating that the chamber retuning accuracy in this sub-band is comparable with that in other sub-bands. Similarly, the agreement at 47.5 MHz in sub-band 4 is also good indicating that the impedance spread in sub-band 5 cannot be attributed to any type of frequency-ground screen interaction effects. It should be noted that the spread of impedances at 47.5 MHz in sub-band 5 of the factory tuned antennas is also large. There is every indication that the large impedance spread noted at this frequency in this sub-band is peculiar to the antennas and is not attributable to the chamber tuning.

At both the high and low frequency ends of sub-band 10 and at the high frequency end of sub-band 9, chamber retuning of the 5 test antennas yielded open-field impedance clusters which were at least as small as the original factory tuned clusters. However, the cluster centers of the retuned antennas were shifted slightly with respect to the original cluster centers. The dummy base cover was installed on one of the retuned antennas and sub-band 10 of the antenna was tuned in the open-field on the 10 x 10 foot ground screen. It was found that there was no setting of the tuning slug which yielded an open-field impedance at 70.5 MHz which fell within the original cluster. It was concluded that during the tuning process certain changes, such as the relocation of wires, had occurred within the base units of the 5 test antennas which prevented the retuning of the antennas to their original impedances. Chamber retuning yielded open-field clusters which were as close to the original clusters in sub-bands 9 and 10 as could be attained with the test antennas.

The open-field impedance clusters obtained with the antennas retuned in the final chamber were neither significantly larger or smaller than the clusters obtained with the factory tuned antennas. With the exception of the two sub-bands noted above, all retuned antenna open-field impedance clusters were centered about the corresponding open-field impedance clusters of the original antennas.
Mr. W. P. Czerwinski visited Georgia Tech June 11-13, 1968 for the final inspection and acceptance of the compact antenna test chamber to be delivered under the contract. During Mr. Czerwinski's visit, shielding and power tests were performed on the test chamber. The results from the shielding test indicate that the shielding effectiveness of the chamber is greater than 60 dB. During the power test, 70 watts of power was applied to an AS-1729 antenna mounted in the test chamber for two periods of one hour each. The impedance of the antenna was measured immediately before and immediately after power was applied. There was no discernible difference between the impedance values.

The voltages existing across the base of both the AS-1729 and the AS-2169 antenna in the test chamber were measured. The results from these measurements indicate that the base voltage in the chamber is generally lower than the base voltage on a ground plane in the open-field.

A set of reproducible drawings and a material list for the final test chamber were submitted to the Activity Supply Officer on 25 June 1968.

Respectfully submitted:

William R. Free
Project Director

Approved:

D. W. Robertson, Head
Communications Branch
TECHNICAL REPORT ECOM-0575-F

COMPACT CHAMBER FOR
IMPEDANCE AND POWER TESTING
OF VHF WHIP ANTENNAS

FINAL REPORT

By
W. R. FREE, B. M. JENKINS
AND C. W. STUCKEY

OCTOBER 1968

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ECOM
UNITED STATES ARMY ELECTRONICS COMMAND \ FORT MONMOUTH, N.J.

Contract DAAB07-67-C-0575
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia
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Disposition

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COMPACT CHAMBER FOR IMPEDANCE AND POWER TESTING OF VHF WHIP ANTENNAS

FINAL REPORT
1 JULY 1967 TO 1 JULY 1968

CONTRACT NO. DAAB07-67-C-0575
DA TASK NO. 46-10-00-120-50-00

Prepared By
W. R. FREE, B. M. JENKINS
AND C. W. STUCKEY

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

For
U. S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, N. J.

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ABSTRACT

This report summarizes the accomplishments on a program to develop a compact test chamber suitable for production testing of VHF vehicular antennas.

A compact test chamber consisting of a 12 foot long aluminum cylinder, 1 foot in diameter and lined with Eccosorb NZ-1 ferrite material was developed. This chamber was calibrated with respect to open-field antenna characteristics. Results from an extensive evaluation are presented which attest to the usefulness of the chamber in meeting production and/or field test and alignment requirements.

Investigations of the reflectivity characteristics of a number of absorbing materials, the effects of absorbing materials in the near-field of antennas, and the effects of ground plane size on antenna characteristics are described and results from these programs are presented.
FOREWORD

This report was prepared at the Georgia Tech Engineering Experiment Station on Contract No. DAAB07-67-C-0575. The work covered by this report was performed within the Electronics Division under the supervision of Mr. D. W. Robertson, Head of the Communications Branch. The report covers the results of a one year effort directed to the development of a compact test chamber for production testing of VHF antennas.
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I. FACTUAL DATA

A. Introduction

1. Purpose and Objectives of the Program

This report covers the work performed under Contract DAAB07-67-C-0575 for the period from 1 July 1967 to 1 July 1968.

The objective of this program was to develop a small indoor test chamber which could be used for production testing of VHF whip antennas over the frequency range from 30 to 76 MHz. Of particular interest was the AS-1729/VRC antenna. The tests of primary interest included the alignment of matching networks, VSWR and impedance characteristics, and power handling and efficiency characteristics.

2. Background

There are requirements for small test chambers or enclosures which can be used for production testing of VHF antennas at frequencies as low as 30 MHz.

One requirement for the compact test chamber is to isolate the antenna under test from the outside environment. The isolation requirement is two-fold. During alignment and impedance tests, isolation is desirable in order to prevent outside interference and near-by objects from affecting the antenna characteristics. During power testing, it is desirable that radiation from the antenna be minimized in order to prevent interference to others.

Another requirement for the test chamber is that the characteristics of an antenna mounted in the chamber be identical to or correlatable to the characteristics of the antenna operated in the open-field over a given (e.g., 10 x 10 foot) ground plane.

There are a number of problems associated with developing a compact test chamber for use in the VHF range. Anechoic chambers have been utilized for a number of years in the microwave frequency range to obtain an indoor "free-space" environment for a wide variety of measurements on antennas, radar cross-sections, and other propagation phenomena. This technique, however, has found very limited application in the lower frequency ranges, particularly below the UHF range. A principal reason for this lack of application at the lower frequencies is the fact that most conventional absorbing materials require that the thickness of the material be approximately one-third of a wavelength, or more, at the lowest frequency to be absorbed. Thus, for satisfactory absorption at 50 MHz, a material thickness of six feet is required. This characteristic dictates that low frequency anechoic chambers be extremely bulky and
costly. For example, to obtain a 6 x 6 x 6 foot free-space volume at 50 MHz, the outside dimensions of the chamber could be as large as 18 x 18 x 18 feet and as much as 1000 square feet of 6-foot thick absorbing material could be required. An in-house investigation at USAECOM, under the direction of Dr. H. Brueckmann, followed by a preliminary contractual effort, provided the encouragement which led to the investigation covered by this report.

A ferrite ceramic absorbing material which purportedly exhibits good absorbing characteristics down to at least 50 MHz with a material thickness of less than one inch has recently been developed. The availability of this thin low-frequency absorbing material provides the possibility of applying absorbing materials to many low-frequency reflection problems where, in the past, the use of absorbing materials had been considered prohibitive due to size or space limitations. One task of this program was to measure the reflectivity characteristics of the ferrite absorbing material and to determine the feasibility of utilizing this material in a low-frequency compact test chamber.

Another facet of the compact chamber technique which appeared to need additional investigation is the effect on the impedance and current distribution characteristics of the antenna of an absorbing and dissipating medium placed in the near-field (high level induction field). Intuitively, it appears the placement of absorbing material in the near-field of an antenna may result in power being coupled out of the induction field which would have normally returned to the antenna. This dissipation would result in a change in the current distribution on the antenna, and a change in the antenna impedance characteristics. Because of the physical size and shape of conventional absorbing materials, rigorous theoretical analysis of this phenomenon would be extremely complex and difficult. Thus, it was proposed that the determination of the magnitude of the effect of absorbing material on antenna impedance as a function of distance be analyzed experimentally.

3. Approaches

The program was conducted in three phases. Phase one consisted of a theoretical study and experimental investigation to establish the parameters and configuration for an experimental compact test chamber. Phase two consisted of an evaluation of the results from phase one to establish the design parameters and the preparation of a design plan for the final configuration of the compact test chamber. Phase three consisted of the fabrication, calibration and testing of the final chamber configuration.

Three basic measurement programs were conducted during phase one of the program. The measurement programs were (1) reflectivity measurements of absorbing materials, (2) measurements to determine the effect of absorbing materials in the near-field of antennas, and (3) measurements to determine the effect of ground plane size on antenna impedance.
Conclusions based on results from these measurements were considered necessary to establish the design parameters of the compact test chamber.

B. Investigation of Absorbing Materials

1. General

Three measurement programs were performed to determine the relative merits of the ferrite ceramic absorbing material in the 30 to 76 MHz frequency range compared to more conventional absorbing materials. The initial program compared the measured reflectivity characteristics of the ferrite material, Eccosorb NZ-1, with the measured reflectivity characteristics of three other absorbing materials. A second measurement program determined the relative effects of the four absorbing materials on the impedance characteristics of an antenna when placed in the near-field of the antenna. The third set of measurements investigated the effects of the absorber configuration on the impedance characteristics of a test antenna.

2. Reflectivity Measurements

The measurement setup used to measure the reflectivity characteristics of absorbing materials is shown in Figure 1. The absorbing material to be measured is mounted on one side of a 3' x 2' aluminum plate. The plate with absorbing material attached is mounted on an antenna positioner, or rotator, as shown in the figure. One tuned dipole antenna is used to radiate energy into the absorber-plate target and a second tuned dipole is used to receive the energy reflected from the target. The target is rotated through 360 degrees and reflection maximums are received when the plane of the absorbing material and the plane of the bare aluminum plate are normal to the bisector between the dipole antennas. The difference between the amplitudes of the two maximums is the reflectivity of the absorbing material.

During preliminary measurements, it became apparent that the direct coupling between the dipoles was so great that it overshadowed the reflected signal from the target. To overcome this problem a part of the signal from the signal generator was coupled over to the input of the receiver through a phase shifter and an attenuator. The phase shifter and attenuator are adjusted so that the phase and amplitude of the coupled signal is optimized to cancel the signal coupled directly between the dipole antennas, as well as reflected signals from arbitrary reflecting objects on and near the measurement range. This cancellation technique reduced the extraneous coupling between antennas and reflections to the extent that the desired reflectivity measurements could be made.
Figure 1. Measurement Setup for Reflectivity Measurements.
The reflectivity characteristics of four types of absorbing materials, Ecosorb NZ-1, Ecosorb FR-350, Ecosorb HPY-72, and B. F. Goodrich 48-inch wedges, were measured over the frequency range from 50 to 1000 MHz.

Ecosorb NZ-1 is a thin broadband ferrite absorbing material in the form of tiles. The tiles are 2" x 2" and approximately 1" thick. Each tile is shaped into four 1" x 1" pyramids 1" high. Emerson and Cuming, Inc., specifies the reflectivity of this material to be -13 dB or better from 50 MHz to 15 GHz. Ecosorb FR-350 is a broadband rigid foam absorbing material in the form of 1' x 3' blocks 8" thick. The manufacturer specifies the reflectivity of this material to be -20 dB or better at 455 MHz and above. Ecosorb HPY-72 is a lightweight polyurethane foam absorbing material in a pyramidal shape. Each piece is 24" x 24" and contains four pyramids 72" high and with 12" x 12" bases. The manufacturer specifies the reflectivity of this material to be -20 dB or better above 75 MHz. The size of this material eliminates it from consideration in a compact chamber, but it was included in the test group primarily as a reference to evaluate the reflectivity measurement technique and to determine the effect of a good absorbing material in close proximity to an antenna. The B. F. Goodrich material is made of light weight foam material coated with resistive cloth. Each piece is a hollow wedge which measures 18" x 24" at the base and is 48" thick. This material was included in the test group because it was used in a previously developed chamber for testing the AS-1729/VRC antenna.

The reliable dynamic range of the technique and test setup as described is at least 15 dB over the frequency range from 50 MHz to 400 MHz and at least 10 dB over the range from 400 to 1000 MHz. Thus, there is a high confidence factor associated with all measurement results in the 0 to -15 dB reflectivity range at frequencies between 50 and 400 MHz and with results in the 0 to -10 dB range at frequencies above 400 MHz. It is also pointed out that the reflectivity characteristics specified by the manufacturers are based on a normal incident angle while the test setup utilized an incident angle of 15 degrees with respect to the normal of the target specimen. This difference in incident angle could have a significant effect on the thick absorbing materials HPY-72 and 48" wedges, but should have little effect on the thin materials. The manufacturer claims that a change in incident angle over the range from normal to 30 degrees off normal will have a negligible effect on the reflectivity characteristics of the Ecosorb NZ-1 material.

The results from the reflectivity measurements are shown in Figure 2. The measured reflectivity characteristics of the four absorbing materials over the frequency range from 50 to 1000 MHz are shown plotted in decibels relative to a flat metal plate the same size as the test sample. It is apparent from the figure that HPY-72 is the only material
Figure 2. Measured Reflectivity Characteristics of Four Absorbing Materials.
which exhibits any appreciable absorption below approximately 200 MHz. The measured reflectivity of the NZ-1 material agreed quite well with the manufacturer's published reflectivity curve over the frequency range from 400 to 1000 MHz; however, below 400 MHz the measured reflectivity diverged quite rapidly from the published curve. At the highest frequency of the range of interest, 76 MHz, the NZ-1 material absorbed less than half of the incident power. Below 75 MHz, the reflectivity characteristics of the E. F. Goodrich material and Eccosorb FR-350 were no better than the flat metal plate reference.

3. Near-Field Measurements

A series of measurements was performed to determine the effects of placing absorbing materials in the near-field of an antenna. To obtain a reference for these measurements, the open-field impedance of AS-1729/VRC antenna serial no 2 was measured on a 10 x 10 foot ground plane. The impedance measurements are referred to 50 ohms in reference to the antenna input BNC connector.

It was assumed that a metal shield would be required on the outside of the test chamber in order to obtain the desired isolation from the outside environment, hence it was of interest to determine the effect on antenna characteristics of absorbing material with a metal backing. To accomplish these measurements, a wooden frame, capable of supporting a metal plate 18 inches wide and 6 feet high in a vertical position on the 10 x 10 foot ground plane was constructed. Tests were performed with the bare metal plate, the metal plate covered with Eccosorb NZ-1 absorbing material, with Eccosorb FR-350, and with Eccosorb HPY-72. The base metal plane, NZ-1 and FR-350 measurements were made with the metal plane at spacings of 6, 12, 18, 24, 36 and 48 inches from the test antenna. The HPY-72 measurements were made with the metal plane positioned 6 feet from the test antenna.

Typical sets of results from these measurements are shown in Figures 3-7. (Note: The number preceding the dash is frequency in MHz and the number following the dash designates the sub-band switch position.) Figure 3 shows the results obtained when the bare metal plate and the NZ-1 covered plate were located at a spacing of 12 inches from the test antenna. Figure 4 shows the results obtained with the metal plate at a spacing of 24 inches from the test antenna. The results from these measurements indicate (1) that the NZ-1 material and the metal plate cause impedance changes which are approximately equal in magnitude, (2) that the direction of the impedance changes caused by the two planes appears to be more or less random, and (3) that the magnitudes of the impedance changes decrease with an increase in the spacing between the test antenna and the test planes.

Results from equivalent measurements with Eccosorb FR-350 absorbing material for bands 1, 6 and 10 are shown in Figures 5 and 6. A comparison between Figures 3 and 4 and Figures 5 and 6 reveals that the effects of the NZ-1 and the FR-350 materials on the test antenna impedance characteristics were approximately the same.
Figure 3. Impedance Changes Caused by Metal Plate (18" Wide x 6' High) and Metal Plate Covered with NZ-1 Material at Spacing of 12" from Test Antenna.
Figure 4. Impedance Changes Caused by Metal Plate and Metal Plate Covered with NZ-1 Material at a Spacing of 24" from Test Antenna.
Figure 5. Impedance Changes Caused by Metal Plate and Metal Plate Covered with FR-350 Material at a Spacing of 12" from Test Antenna.
Figure 6. Impedance Changes Caused by Metal Plate and Metal Plate Covered with FR-350 Material at a Spacing of 2½" from Test Antenna.
Figure 7. Impedance Changes Caused by Metal Plate Covered with HPY-72 Material at a Spacing of 6' from Test Antenna.
In order to perform measurements with the Eccosorb HPY-72 absorbing material, the metal mounting plane was positioned 6 feet from the test antenna. Since the thickness of the material was 6 feet, this put the tips of the pyramids in the same plane as the test antenna. The material was positioned so that the test antenna was midway between the tips of the pyramids and, hence, approximately 6 inches from the material. This measurement configuration was reasonably equivalent to a 12 inch spacing with the NZ-1 and FR-350 materials. The results obtained from the HPY-72 measurements on bands 1, 6 and 10 are shown in Figure 7. No significant impedance changes were obtained with the base metal plate six feet from the antenna, and hence, these results are not shown in the figure. It is apparent from this figure that Eccosorb HPY-72, even though reflectivity measurements show it to be a good absorber in this frequency range, causes approximately the same impedance change as NZ-1 and FR-350, which were shown to be poor absorbers in this frequency range.

4. Model Antenna Measurements

Additional measurements were performed to investigate the effects of location and configuration of absorbing materials in the near-field of an antenna. It was desirable that the material used in this investigation be a good absorbing material. It had previously been established that Eccosorb NZ-1 was a good absorber above 220 MHz, and hence, these measurements were performed at 278 MHz. The reference for these measurements was the impedance characteristics of a 9.75 inch monopole antenna (resonant at 278 MHz) mounted on a 1 x 1 foot ground plane. The reference antenna is shown in Figure 8.

Figure 8. Measurement Setup for Open-Field Measurements on 9-3/4" Monopole on 1 x 1 Foot Ground Plane.
The objective of the first set of measurements was to determine the effect on the antenna impedance of a single 2 x 2 inch tile of NZ-1 material at various elevations along the reference antenna. Measurements were made with a single tile of NZ-1 one inch from the antenna (1) on the ground plane, (2) two inches above the ground plane as shown in the upper view of Figure 9, (3) four inches above the ground plane, (4) six inches above the ground plane and (5) eight inches above ground plane. A similar set of measurements were made by stacking NZ-1 tiles one inch from the antenna as shown in the lower view of Figure 9. Measurements were made with 1, 2, 3, 4 and 5 tiles stacked on the ground plane. The results from the measurements with a single piece of tile at different elevations are shown on an expanded Smith Chart in Figure 10. The reference point shown in the figure is the open-field impedance of the 9.75 inch monopole antenna on the 1 x 1 foot ground plane. The data points 1, 2, 3, 4 and 5 shown on the figure are for a single tile of NZ-1 on the ground plane and 2, 4, 6 and 8 inches above the ground plane. It is apparent from these results that placing absorbing material in the near-field of an antenna significantly changes the impedance characteristics of the antenna. The results also indicate that the magnitude of the impedance change is proportional to the current density in the region of the antenna adjacent to the absorbing material, i.e., absorbing material at the base of the antenna, where the current is a maximum, caused the maximum impedance change and material at the end, where the current is a minimum, caused the minimum impedance change.

The results from the measurements with stacked NZ-1 tiles are shown in Figure 11. These results support the conclusions based on the single tile measurements. In addition, Figure 11 indicates that the effects of the absorbing material along the length of the antenna are cumulative and that the direction of the impedance change is primarily determined by the absorbing material in the high current regions.

An additional series of measurements was performed utilizing closed rings of NZ-1 absorbing material, in lieu of single tiles, to investigate the effect of absorber configuration in the near-field of an antenna. The measurement setups for the two sets of measurements are shown in Figure 12. The upper photograph shows a single ring of NZ-1 material on the ground plane centered around the base of the monopole. The lower photograph shows two rings stacked on the ground plane. The inside diameters of the absorber rings were made 2 inches so that the surface of the absorbing material was again one inch from the antenna.

In the first set of measurements, a single ring of NZ-1 material was positioned at the same elevations along the reference antenna as the single NZ-1 tile in the previous measurements. The results from these measurements are shown in Figure 13. A comparison of Figures 10 and 13 reveals that both a single tile and a closed ring of NZ-1 absorbing material in the near-field of an antenna caused a significant change in the antenna impedance, and the magnitude of the impedance change
Figure 9. Two Views of Measurement Setup with Column of Absorbing Material Parallel to Model Antenna.
Figure 10. Impedance Characteristics of Model Antenna as a Function of Location of Single Piece of Absorbing Material.

Figure 11. Impedance Characteristics of Model Antenna as a Function of Height of Column of Absorbing Material.
Figure 12. Two Views of Measurement Setup with Rings of Absorbing Material Centered About Model Antenna.
Figure 13. Impedance Characteristics of Model Antenna as a Function of Location of Ring of Absorbing Material.

was a function of the location of the absorbing material along the length of the antenna. The ring caused a considerably greater impedance change than a single tile. This was expected since the ring placed considerably more absorbing material adjacent to a region of the antenna.

A set of measurements were made in which five rings of NZ-1 material were stacked on the ground plane centered on the reference antenna. The results from these measurements are shown in Figure 14. A comparison of Figures 11 and 14 reveals that the results from stacked single tiles and stacked rings were very similar, the major difference being the fact that the rings caused a much larger impedance change.

On the basis of these measurement results, it was concluded that the placement of absorbing material in the near-field of an antenna would significantly affect the antenna impedance.

To further investigate the antenna impedance differences which exist between measurements made in the open-field and those made in a compact chamber, additional experimental measurements were performed. For reference purposes, the impedance characteristics of AS-1729/VRC antenna serial no. 2 were measured on a 2.5 x 2.5 foot ground plane in the open-field and
Figure 14. Impedance Characteristics of Model Antenna as a Function of Height of Ring of Absorbing Material.

with the antenna positioned on the axis of an 8 x 8 x 12 foot shielded enclosure. Photographs of these measurement setups are shown in Figures 15 and 16, respectively. The impedance characteristics were then measured with an aluminum cylinder, two feet in diameter and four feet high, lined with NZ-1 absorbing material placed on the 2.5 x 2.5 ground plane and centered around the base of the antenna. This measurement configuration is shown in Figure 17. The results from measurements on a 10 x 10 foot and a 2.5 x 2.5 foot ground plane in the open-field, on a 2.5 x 2.5 foot ground plane in the shielded enclosure and in the NZ-1 lined cylinder for antenna bands 1, 6 and 10 are shown in Figure 18.

The results from the measurements made on the 2.5 x 2.5 foot ground plane with the NZ-1 lined cylinder revealed two interesting properties of the cylinder. While these measurements were made well below the frequency where the NZ-1 material becomes a good absorber (approximately 220 MHz), the addition of the NZ-1 lined cylinder significantly reduced the difference in antenna impedance measured on the 2.5 x 2.5 foot ground plane compared to that measured on the 10 x 10 foot ground plane at the lower frequencies. Figure 18 shows that the impedance change was reduced to approximately one-half in band 1 by the addition of the lined cylinder. Also, the addition of the lined cylinder improved the antenna VSWR over
Figure 15. Measurement Setup for Open-Field Measurements on 2-1/2 x 2-1/2 Foot Ground Plane.

Figure 16. Measurement Setup for Shielded Enclosure Measurements on 2-1/2 x 2-1/2 Foot Ground Plane.
that which was obtained with either the 2.5 x 2.5 or the 10 x 10 foot
ground plane at all test frequencies except for 30 MHz at which the VSWR
was slightly greater than that which was obtained with the 10 x 10 foot
ground plane.

These results were encouraging for they seemed to indicate that
even though NZ-1 material was not a good absorber in this frequency
range, it exhibited characteristics which were desirable in the lining
of a compact test chamber.

In order to determine the effect of a NZ-1 lined chamber over the
entire length of an antenna (rather than approximately half the antenna
length, as was the case with the 48" high cylinder), measurements were
made on a 35-inch base-fed monopole antenna on a 1 x 1 foot ground plane
in a NZ-1 lined chamber 8 inches in diameter and 38 inches long. The
measurement setup is shown in Figure 19. The results from these measure-
ments over the frequency range from 30 to 290 MHz are shown in Figure 20.
It is apparent from the figure that the antenna impedance measured on
the ground plane and in the chamber are different; however, of particular
interest is the fact that, over the frequency range from 30 to 220 MHz,
for each change in open-field impedance there is a corresponding change
Figure 18. Impedance Characteristics of AS-1729/VRC Antenna on 2-1/2 x 2-1/2 Foot Ground Plane in the Open-Field, in a Shielded Enclosure and in a NZ-1 Lined Cylinder.
in chamber impedance. Above 220 MHz (where the NZ-1 material becomes a good absorber) however, the open-field impedance of the antenna continues to change significantly with frequency, but the impedance measured in the chamber remains in the vicinity of 2.6 - j2.6.

In order to get several impedance values at each test frequency, the length of the 35-inch monopole antenna was decreased in one-inch increments and additional test runs were made. Typical results from these measurements at 75 MHz and 290 MHz, are shown in Figures 21 and 22 respectively. Figure 21 shows that for four open-field impedance values at 75 MHz, four discrete impedance values were measured in the chamber. However, Figure 22 shows that for four significantly different open-field impedance values at 290 MHz, essentially the same impedance was measured in the chamber.

Thus, it was concluded that in the frequency range below where the NZ-1 material is a good absorber, it may be possible to correlate the impedance measured in a compact chamber, lined with the material, with an open-field impedance; however, in the frequency range where the material is a good absorber, the correlation would be impossible.
Figure 20. Impedance Characteristics of a 35" Monopole Antenna in the Open-Field and in a NZ-1 Lined Chamber as a Function of Frequency.
Figure 21. Impedance Characteristics of Monopole Antenna in the Open-Field and in NZ-1 Lined Chamber as a Function of Antenna Length at 75 MHz.

Figure 22. Impedance Characteristics of Monopole Antenna in the Open-Field and in NZ-1 Lined Chamber as a Function of Antenna Length at 290 MHz.
This new insight into the problem made it possible to consider less expensive materials for use in the compact test chamber, since it appeared that a lossy dielectric material may be used, rather than a conventional absorbing material. To investigate this possibility, additional measurements were made on the 35 inch monopole in the 8 inch diameter and 38 inch long steel cylinder lined with a lossy material (1/2 inch thick sleeve of 6 to 1 by weight homogenous mixture of carbonyl iron powder and Shell Epox 828 epoxy). This chamber is shown in Figure 23. For reference purposes, measurements were also made in the cylinder with the lossy material removed.

Data resulting from these measurements are shown in Figures 24 and 25. It is seen from Figure 24 that the antenna impedances measured in the chamber lined with the lossy material consistently lies on the periphery of the Smith Chart, thus always presenting a large antenna VSWR. Comparing the lossy material chamber results with results obtained in the unlined chamber shown in Figure 25, it is seen that the results are similar, thus indicating the ineffectiveness of the lossy material. On the basis of these measurement results it was concluded that the carbonyl iron-epoxy material was not a satisfactory substitute for the NZ-1 material.

Figure 23. Test Chamber Lined with Carbonyl Iron.
Figure 24. Impedance Characteristics of Monopole Antenna in the Open-Field and in a Carbonyl Iron Lined Chamber as a Function of Frequency.
Figure 25. Impedance Characteristics of Monopole Antenna in the Open-Field and in an Unlined Chamber as a Function of Frequency.
C. Test Antenna Measurements

1. General

In order to establish antenna characteristic standards for use to (1) determine the effect of the compact test chamber on a "standard" antenna; (2) calibrate the test chamber and (3) evaluate the adequacy of the compact test chamber for performing the desired tests, the parameters of a set of ten typical AS-1729/VRC antennas were measured on a 10 x 10 foot ground plane in the open-field.

Figure 26 shows the test configuration used for making impedance measurements on the test antenna. The Rohde and Schwarz Type ZDU Diagraph is an instrument for measuring the impedance or admittance of antennas and other devices over the frequency range from 30 to 420 MHz. The results are displayed directly on a Smith Chart without any calculation or graphical interpretation. Initially, two 50 ohm coaxial lines were cut to the same electrical length. One line was used to connect the diagraph and the test antenna. The other was terminated with a short and connected to the reference port of the diagraph. This procedure insured that when the diagraph was properly calibrated, the test antenna impedance measured would be the impedance at the antenna input terminals and would not include the effects of the connecting cable.

![Diagram of Test Configuration for Measuring Antenna Impedance.](image-url)
The test antenna was mounted on a 10 x 10 foot ground plane resting on a four foot high platform mounted atop the roof of the antenna laboratory. With the antenna at this location the nearest object at the same elevation as the antenna was over one hundred feet away.

The internal crystal calibrators of the two signal generators used were frequency calibrated prior to any measurements. The signal generators were tuned during the measurement program using the internal crystal calibrators to insure frequency repeatability. The diaphragm was recalibrated each time the test frequency was changed. The procedure produced highly repeatable impedance measurements on the test antenna.

Open-field impedance measurements were performed on AS-1729/VRC Antenna Serial No. 2. The antenna was mounted on a 10 x 10 foot ground plane. The results from these measurements are shown in Figure 27. Four independent sets of open-field measurements were performed to determine the effect of weather conditions on the measurements results and the repeatability of the measurement technique. The four sets of measurements were made on different days during a four week period. Weather conditions varied considerably from set to set and varied from sunny with no wind to misty and wet with gusty winds. The results from all four sets of measurements are shown on the figure as four-dot clusters. The numbers at each cluster designate the test frequency and antenna band. For example, 33-1 implies 33 MHz on antenna band 1 and 33-2 implies 33 MHz on antenna band 2. The close agreement between the results indicates both the insensitivity of the antenna impedance to weather conditions and the high degree of repeatability inherent in the measurement technique.

2. Ground Plane Impedance Clusters

The measured open-field impedance characteristics of ten typical AS-1729/VRC test antennas are shown in Figure 28. The impedance at the low frequency end of nine bands are shown (band seven is omitted because it overlapped with band six). It is apparent from the figure that the impedances corresponding to each band-frequency combination tended to group or cluster about a central impedance value. The centers of the open-field impedance clusters were defined as the standard antenna impedance values and served as the target impedance values for all subsequent antenna tuning procedures.

3. Effects of Ground Plane Size

In the process of performing the multitude of investigations that were necessary on this program, it became apparent that the impedance of the AS-1729/VRC antenna is, to some extent, sensitive to ground plane size. Since it was anticipated that any compact test chamber
Figure 27. Open-Field Impedance of AS-1729/VRC Antenna Serial No. 2 on 10 x 10 Foot Ground Plane.
Figure 28. Open-Field Impedance Clusters for Ten AS-1729/VRC Test Antenna.
would present a ground plane to the antenna which was considerably different from the standard 10 x 10 foot ground plane, additional investigation of the effect of ground plane size on antenna impedance appeared to be warranted.

To accomplish this investigation the impedance and VSWR characteristics of AS-1729/VRC Antenna Serial No. 2, were measured on three different size ground planes, 10 x 10, 15 x 15 and 2.5 x 2.5 feet. The results from these measurements are shown in Table I. It is apparent from the table that the antenna impedance is sensitive to ground plane size, particularly over the lower four bands of the antenna. In view of these results, the concept of obtaining the same antenna impedance in a compact test chamber and on a 10 x 10 foot ground plane does not appear feasible.

D. Development of Experimental Test Chamber

1. General

As a result of the various experimental investigations, it was concluded that it did not appear possible to develop a compact antenna test chamber which would yield the same impedance characteristics as obtained on a 10 x 10 foot ground plane over the frequency range from 30 to 76 MHz. The conclusion was based on the fact that the results from the experimental measurements indicated that absorbing materials in the near-fields of antennas significantly changed the impedance characteristics of the antennas and that changes in ground plane dimensions significantly changed the impedance characteristics.

With this conclusion, it was necessary to abandon the initial objective to develop a compact chamber which would yield the same characteristics as a 10 x 10 foot ground plane and concentrate on the development of a compact chamber in which the chamber measurement results could be corrected to or correlated with results obtained on a 10 x 10 foot ground plane. In order for the correction factor or correlation approach to be successful, it is necessary that the chamber exhibit a unique impedance value for a given ground plane impedance value. It is desirable that the impedance change in the chamber for a given impedance change on the ground plane be equal to or greater than the ground plane change to insure an equivalent or better impedance resolution in the chamber. In order for the chamber to be useful for power testing of the antenna, it is desirable that the VSWR characteristics of the antenna in the chamber be approximately the same as the VSWR characteristics on the ground plane.
<table>
<thead>
<tr>
<th>FREQ. - BAND</th>
<th>10' x 10' GND. PLANE</th>
<th>15' x 15' GND. PLANE</th>
<th>2.5' x 2.5' GND. PLANE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R + JX</td>
<td>VSWR</td>
<td>R + JX</td>
</tr>
<tr>
<td>30-1</td>
<td>0.55 + J0.67</td>
<td>2.8</td>
<td>1.15 + J0.92</td>
</tr>
<tr>
<td>33-1</td>
<td>0.78 - J0.53</td>
<td>1.9</td>
<td>0.37 - J0.52</td>
</tr>
<tr>
<td>33-2</td>
<td>0.95 - J0.80</td>
<td>2.2</td>
<td>1.60 - J0.00</td>
</tr>
<tr>
<td>37-2</td>
<td>0.39 - J0.36</td>
<td>2.9</td>
<td>0.29 - J0.17</td>
</tr>
<tr>
<td>37-3</td>
<td>1.30 + J1.60</td>
<td>3.8</td>
<td>1.62 - J0.72</td>
</tr>
<tr>
<td>42-3</td>
<td>0.22 - J0.05</td>
<td>4.5</td>
<td>0.38 + J0.07</td>
</tr>
<tr>
<td>42-4</td>
<td>0.75 - J1.15</td>
<td>3.5</td>
<td>1.90 - J0.90</td>
</tr>
<tr>
<td>47.5-4</td>
<td>0.40 - J0.44</td>
<td>3.0</td>
<td>0.56 + J0.34</td>
</tr>
<tr>
<td>47.5-5</td>
<td>0.46 - J0.27</td>
<td>2.3</td>
<td>0.62 - J0.40</td>
</tr>
<tr>
<td>53-5</td>
<td>0.80 + J1.10</td>
<td>3.2</td>
<td>0.81 + J0.91</td>
</tr>
<tr>
<td>53-6</td>
<td>0.76 + J0.55</td>
<td>1.9</td>
<td>0.73 + J0.39</td>
</tr>
<tr>
<td>56-6</td>
<td>2.80 + J0.20</td>
<td>2.8</td>
<td>2.10 + J0.45</td>
</tr>
<tr>
<td>56-7</td>
<td>0.69 + J0.55</td>
<td>2.2</td>
<td>0.53 + J0.43</td>
</tr>
<tr>
<td>60-7</td>
<td>2.30 - J1.00</td>
<td>2.8</td>
<td>3.00 - J0.00</td>
</tr>
<tr>
<td>60-8</td>
<td>0.55 + J0.50</td>
<td>2.8</td>
<td>0.37 + J0.58</td>
</tr>
<tr>
<td>65-8</td>
<td>3.00 - J0.20</td>
<td>3.2</td>
<td>3.50 - J0.10</td>
</tr>
<tr>
<td>65-9</td>
<td>1.95 + J1.56</td>
<td>3.4</td>
<td>1.22 + J1.40</td>
</tr>
<tr>
<td>70.5-9</td>
<td>0.95 - J1.05</td>
<td>2.8</td>
<td>1.10 - J1.25</td>
</tr>
<tr>
<td>70.5-10</td>
<td>2.30 - J0.30</td>
<td>2.4</td>
<td>2.40 - J0.60</td>
</tr>
<tr>
<td>76-10</td>
<td>0.42 - J0.08</td>
<td>2.4</td>
<td>0.43 - J0.02</td>
</tr>
</tbody>
</table>

**TABLE I.** Open-Field Impedance Measurements of AS-1729/VRC Antenna Serial No. 2 On 10 x 10, 15 x 15 and 2.5 x 2.5 Ft. Ground Planes.
2. Design and Fabrication of Experimental Chamber

Once the fact that the antenna impedance characteristics in the chamber would not be the same as the characteristics on a 10 x 10 foot ground plane was accepted, decisions on the dimensions and configuration of the compact chamber were considerably less critical. Consequently, impedance differences, due to absorbing material being in the near-field of the antenna and due to a ground plane significantly different from 10 x 10 feet being exhibited to the antenna, can be tolerated. Under this concept, the location of absorbing material relative to the antenna under test and the size of the ground plane presented to the antenna by the chamber becomes, to a great extent, arbitrary. The major objectives in selecting the dimensions and configuration of the chamber were to make the chamber as small as possible, and at the same time, to place the absorbing material sufficiently far away from the antenna that any differences in the open-field characteristics of antennas would be discernible in the chamber.

An experimental model of a compact test chamber was fabricated in an attempt to satisfy these objectives. The chamber consisted of an aluminum cylinder 12 feet long with a 1 foot inside diameter and a 1/8 inch wall thickness. An end plate was provided at each end of the cylinder. One end plate had provisions for mounting an AS-1729/VRC antenna on the axis of the cylinder. The inside walls of the chamber were lined with Ecosorb NZ-1 ferrite absorbing material. Two views of the experimental compact test chamber are shown in Figure 29. The upper view shows the chamber assembled with an AS-1729 antenna mounted and ready for testing. The lower view shows the chamber with the base plate removed. This view shows the NZ-1 material inside the chamber and details of the mounting of the AS-1729 antenna on the chamber end plate.

3. Evaluation of Experimental Chamber

Measurements were initially made to determine the VSWR of the AS-1729 antennas in the experimental chamber as a function of sub-band and frequency. Measurements made in the previously discussed small test chambers indicated that to successfully correlate compact chamber impedance measurements to corresponding open-field impedance measurements, chamber VSWR ratios of 10 to 1 or less are highly desirable from the standpoint of resolution and repeatability of data. Table II indicates the minimum VSWR attainable in each sub-band for the AS-1729 antenna in the experimental chamber. Table III shows typical chamber VSWR measurements as a function of frequency in each sub-band. All VSWR measurements as well as all impedance measurements discussed in this section were made with a Rohde and Schwarz ZDU.
Figure 29. Two Views of the Experimental Compact Antenna Test Chamber. (Note: Antenna Mounting Flange is Shown Outside Chamber. All Measurements in Final Chamber were Made with Flange Inside Chamber.)
<table>
<thead>
<tr>
<th>Sub-Band</th>
<th>Frequency Range (MHz)</th>
<th>Minimum VSWR</th>
<th>Test Frequency (MHz)</th>
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<tr>
<td>1</td>
<td>30-33</td>
<td>3.3</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>33-37</td>
<td>4.3</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>37-42</td>
<td>4.5</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>42-47.5</td>
<td>5.5</td>
<td>43</td>
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<td>5</td>
<td>47.5-53</td>
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<td>52</td>
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<td>7</td>
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<td>5.0</td>
<td>58</td>
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<td>8</td>
<td>60-65</td>
<td>4.5</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>65-70.5</td>
<td>3.6</td>
<td>70</td>
</tr>
<tr>
<td>10</td>
<td>70.5-76</td>
<td>2.9</td>
<td>72</td>
</tr>
</tbody>
</table>

**TABLE II. Minimum VSWR for the AS-1729 Antenna In the Experimental Chamber.**

Having determined that the VSWR measurements in the experimental chamber were acceptable, an experiment was initiated to ascertain the relationship between the impedance of the antenna as measured in the chamber and the corresponding impedance as measured on the 10 x 10 foot ground screen. This experiment consisted of measuring the open-field and chamber impedance of a single antenna as it was tuned at the factory. These corresponding impedances were measured at the lowest frequency in each tunable sub-band except sub-band 10, where the highest frequency was used. Since sub-band 2 was not tunable, no measurements were made on this sub-band. The open-field impedance measured in each sub-band for the "factory tuned" antenna was defined as the open-field desired tuning for the antenna. The corresponding chamber measurement was defined as the chamber desired tuning. The antenna was then detuned by removing the glyptol from the tuning slugs in the base unit and turning all slugs in to their limits. Again, open-field and chamber impedance measurements were determined. These measurements were repeated with all slugs turned out to their limits. The results of these measurements are shown on the Smith Charts of Figures 30 through 32.

As shown in Figure 30(A), the tuning range in sub-band 1 is approximately the same in the chamber as in the open-field; however, in all other bands the tuning range is compressed in the chamber as compared to the corresponding open-field results. In sub-bands 8, 9 and 10 (Figures 31(C), 31 (D) and 32) the chamber tuning range appears to be extremely restricted. To some extent these figures are misleading for
<table>
<thead>
<tr>
<th>SUB-BAND</th>
<th>FREQUENCY RANGE (MHz)</th>
<th>VSWR AT INDICATED FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30MHz</td>
<td>35MHz</td>
</tr>
<tr>
<td>1</td>
<td>30-33</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>33-37</td>
<td>3.3</td>
</tr>
<tr>
<td>3</td>
<td>37-42</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>42-47.5</td>
<td>19</td>
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<tr>
<td>5</td>
<td>47.5-53</td>
<td>20</td>
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<tr>
<td>6</td>
<td>53-56</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>56-60</td>
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<tr>
<td>8</td>
<td>60-65</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>65-70.5</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>70.5-76</td>
<td>13</td>
</tr>
</tbody>
</table>

TABLE III. VSWR as a Function of Frequency and Sub-Band.
Figure 30. End Limit Tuning Ranges – Bands 1, 3, 4 and 5.
- Slug Out To Limit
- Slug In To Limit
- Desired Tuning-Open-Field
- Desired Tuning-Chamber

Figure 31. End Limit Tuning Ranges - Bands 6, 7, 8 and 9.
the higher frequency sub-bands. Since the tuning coils for these sub-bands have few turns of wire, the impedance that results when the tuning slug is turned in to its limit is very nearly the same impedance as that which is measured when the slug is turned out to its limit. The only significantly different impedances occur over a narrow range where the slug is near its center position adjacent to the turns of wire. As shown in Figures 31(D) and 32, the extreme positions of the tuning slug do not include the desired tuning in sub-bands 9 and 10, even in the open-field.

The data shown in Figures 30 through 32 indicate that even though the impedances in the open-field differed from those in the experimental chamber, there seemed to be a unique relationship in each sub-band between the open-field and chamber impedances. It is evident from these figures that a change in tuned impedances in the chamber in a given sub-band produces a corresponding change in the resultant open-field impedance for that sub-band. It was therefore conjectured that if an antenna could be tuned to a predetermined impedance in the chamber, which reliably corresponded to a desired open-field impedance, the chamber could be used to tune the AS-1729 antennas. Measurements were made to determine to what extent the experimental chamber could be used to tune
antennas to predetermined open-field impedances. In order to predetermine the target impedance in each sub-band in the chamber, the chamber impedance of each of 12 factory tuned antennas was measured at the lowest frequency in sub-bands 1 through 9 and at the highest frequency in sub-band 10. These chamber measurements tended to form small impedance clusters when plotted on a Smith Chart. The individual measured chamber impedances are shown on Figures 33 through 35. Since sub-band 2 is not tunable in the AS-1729 antenna, no data points are shown for this sub-band.

The impedances were also determined for both end frequencies of each tunable sub-band for each of the 12 factory tuned antennas on the 10 x 10 foot ground screen in the open-field. These measurements are shown in Figures 36 through 38. The clustering of the impedances in the open-field is evident from these figures. The center of the open-field impedance clusters was defined as the target or "desired" impedance for each sub-band in the open-field. It was hypothesized that to tune an antenna in the chamber to yield the target open-field impedance, it would be necessary to tune the chamber impedance in each sub-band to the center of the sub-band chamber impedance clusters shown in Figures 33 through 35.

To test this hypothesis, one of the 12 factory tuned antennas was detuned by randomly positioning each of the tuning slugs after removal of the glyptol. The impedance of the detuned antenna was measured at each frequency of interest in the chamber. These impedances are also shown on Figures 33 through 35. The impedances of the detuned antenna were also measured on the open-field ground screen; the results are shown on Figures 36 through 38.

The detuned test antenna was fitted with a dummy base cover as shown in the upper view of Figure 39 and returned to the chamber. Using the measurement configuration shown in the lower view of Figure 39, each sub-band was retuned by observing the impedance on the ZDU as the tuning slug was varied. An attempt was made to retune the impedance of each sub-band to the center of its respective chamber cluster. The final retuned chamber impedance, after replacing the standard base cover, is shown for each sub-band in Figures 33 through 35. As indicated in Figures 34(D) and 35, for example, it was not possible to retune the impedances of all sub-bands to the exact center of their respective chamber clusters. Two reasons for this were apparent. First, the pertinent tuning slug did not always have sufficient range to reach the center of the cluster, and second, the locus of possible impedances did not always pass through the center of the cluster. In every case the chamber impedance was tuned as close as possible to the center of the cluster.

The open-field impedances of the antenna retuned in the chamber were measured; the results are shown in Figures 36 through 38. The
Sample Antenna Results

Test Antenna-Uncalibrated

Test Antenna-Recalibrated

Figure 33. Antenna Calibration in Compact Chamber - Bands 1, 3, 4 and 5.
Sample Antenna Results
Test Antenna-Uncalibrated
Test Antenna-Recalibrated

Figure 34. Antenna Calibration in Compact Chamber - Bands 6, 7, 8 and 9.
results in sub-band 2 are shown in Figure 40, although there is no provision for tuning this sub-band. Generally, the open-field impedances of the retuned antenna fell in the center of the target clusters, indicating the feasibility of chamber tuning of the AS-1729 antenna in the NZ-1 ferrite lined experimental chamber.

E. Development of Final Compact Test Chamber

1. General

The results from the evaluation of the experimental compact test chamber were reviewed with the program technical monitors, and it was concluded that this chamber concept would be useful for performing the desired tests and alignment of the AS-1729/VRC antenna.

Subsequently, a design plan was developed for a final compact test chamber to be delivered. The chamber described in the test plan incorporated the same overall dimensions, materials and basic parameters as the experimental chamber. In addition, the chamber to be
Figure 36. Open-Field Results of Antenna Recalibration - Bands 1, 3, 4 and 5.
Figure 37. Open-Field Results of Antenna Recalibration - Bands 6, 7, 8 and 9.
delivered included provisions for repetitive assembly and disassembly to enhance the transportability of the unit, more rigid mechanical construction and permanent mounting of the Eccosorb NZ-1 tiles on the walls of the chamber.

2. Design and Fabrication of Chamber

The configuration of the final compact test chamber is shown in Figure 41. The upper view in this drawing shows the compact test chamber assembled. The bottom view shows a cross-section view of the four sections of the chamber unassembled.

Each of the four sections of the chamber consists of a 36 inch length of aluminum cylinder with a 12 inch inside diameter and 1/8 inch wall thickness. An assembly drawing of Section I of the chamber, showing details of the construction, is shown in Figure 42. The inside wall of the cylinder is lined with Eccosorb NZ-1 ferrite absorbing material. Assembly rings are provided at the mating ends of the sections to facilitate the alignment and assembly of the
Figure 39. Two Views of Antenna Recalibration Setup in Compact Chamber.
sections. The assembly rings provide mechanical strength and maintain the shielding integrity at the joints. End rings are provided at the two ends of the chamber to provide additional mechanical strength and to facilitate mounting the end plates. The base end plate has provisions for mounting an AS-1729/VRC antenna on the axis of the chamber. Supports of expanded polyethylene foam are provided in Sections II and III to position and maintain the antenna under test on the axis of the test chamber.

Photographs of the completed compact test chamber are shown in Figures 43 and 44. The upper photograph in Figure 43 shows the chamber completely assembled with an AS-1729/VRC antenna mounted in the chamber and ready for testing. The lower photograph in this figure shows the assembled chamber with the base plate removed showing the NZ-1 material on the inside of the chamber and the antenna positioned on the axis of the chamber. The upper photograph in Figure 44 shows the chamber disassembled with the sections in their relative positions for assembly. The lower photograph shows the four sections in parallel showing more detail of the NZ-1 material inside the sections and the whip support in Section II.
Figure 4.1. Drawing of Final Compact Antenna Test Chamber—Assembled and Unassembled.
Figure 42. Assembly Drawing of Section I of Compact Antenna Test Chamber.
Figure 43. Two Views of Assembled Compact Antenna Test Chamber.
Figure 44. Two Views of Compact Antenna Test Chamber Unassembled.
3. Evaluation of Final Chamber

da. Calibration

Impedance measurements were made on 10 factory tuned AS-1729 antennas in the final test chamber. Typical results from these measurements in sub-bands 1, 2, 5, 8 and 10 are shown in Figure 45 along with the equivalent results obtained in the experimental test chamber. Although the corresponding impedance clusters obtained in both chambers are approximately the same size, it is apparent from the figure that the clusters obtained for the same 10 antennas in the two chambers lie at slightly different positions on the Smith Chart. This difference is particularly apparent at the lower frequencies. The more permanent construction used in the fabrication of the final chamber resulted in slight changes in the internal configuration and dimensions of this chamber, and hence some differences in the impedance characteristics of the two chambers were expected.

One major construction difference which contributed noticeably to differences in internal dimensions of the two chambers involved the attaching of the ferrite tiles to thin metal sleeves in the experimental chamber. Since these sleeves had an undersized diameter so that they could be inserted into the experimental chamber, there was a tendency for the tiles attached at the top of the sleeve to droop while the sides of the sleeves expanded to conform with the sides of the chamber cylinder. A cross-section view of this chamber would have shown a nearly circular configuration for the tiles below the center line of the cylinder and an ellipsoidal or egg shaped configuration above the center line. The tiles at the top of the chamber were about one inch closer to the test antenna whips than were those at the bottom. In contrast, in the final chamber all ferrite tiles were attached directly to the cylinder walls, producing a circular cross-section in which all tiles were equidistant from the antenna whips.

The impedance differences shown in Figure 45 appear to be within the limits one would expect under the circumstances. It should be emphasized that the same ferrite tiles were used in the experimental and final chambers. Thus, the data in Figure 45 do not include possible effects of ferrite tile differences which could be encountered in future chamber construction. This consideration points out the probable future necessity for accurately calibrating each different test chamber, even though the chambers are nominally "identical".

To determine the extent to which antennas tuned in the final chamber yielded desired open-field impedances on the 10 x 10 foot ground screen, it was decided that 5 of the factory tuned antennas would be detuned, retuned in the final chamber, and the resulting open-field impedance clusters compared with those of the original 10
Figure 45. Comparison of Impedance Clusters of Ten Antennas in Experimental Test Chamber and Final Test Chamber.
factory tuned antennas. It was further decided that a Hewlett-Packard 4815-A Vector Impedance Meter would be used to retune the 5 antennas in the final chamber. This decision was prompted in part by the desire to compare the relative difficulty of tuning with the ZDU and with the vector impedance meter, and in part by an electronic failure in the ZDU, which, when corrected, left the ZDU slightly out of original calibration. While absolute calibration accuracy of impedance measurements was not required for evaluation of the final chamber, the use of the vector impedance meter as well as the ZDU seemed desirable.

Impedances as a function of sub-band and frequency were determined with the vector impedance meter for 10 factory tuned antennas in the final chamber. Results of these impedance measurements are shown on the Z-8 charts in Figures 46 through 48.* Similarly, corresponding measurements were made with the ZDU on the same 10 factory tuned antennas both in the chamber and on the 10 x 10 foot ground screen in the open-field. The chamber results are shown on the Smith Charts of Figures 49 through 51. The open-field results are shown in Figures 52 through 54. It should be noted that the measurements shown on these and subsequent Smith Charts differ in absolute calibration from those of Figure 45 and previously presented Smith Charts because of the calibration error discussed above. Since the vector impedance meter input is not frequency selective (no front end tuning), no open-field impedance measurements could be made with this instrument because of the high environmental signal levels existing in the open-field.

It is interesting to note that while the chamber impedance measurements made with the vector impedance meter (Figures 46 through 48) differ slightly in absolute value from those made with the ZDU (Figures 49 through 51), the impedance cluster sizes are approximately the same. In those sub-bands where certain antennas had impedance values which were removed from the general cluster, both instruments recorded the discrepancy to about the same extent. Comparison of Figures 47(B) and 50(B) serves to illustrate this point.

b. Antenna Retuning

Five of the 10 factory tuned antennas were randomly detuned. These antennas were then retuned in the chamber using the vector impedance meter. Retuning was accomplished by tuning the impedance

*Because the measured impedance values of many antennas were very nearly equal, it was not possible to plot all the values on the charts shown in this section. Where several values coincide on a chart, only one point is plotted. The extreme points of all clusters are plotted as measured.
Figure 46. Impedance of Original and Retuned Antennas in Final Chamber as Measured with a Vector Impedance Meter - Bands 1, 2, 3 and 4.
Figure 47. Impedance of Original and Retuned Antennas in Final Chamber as Measured with a Vector Impedance Meter - Bands 5, 6, 7 and 8.
at the low frequency end of each sub-band as nearly as possible to the center of the impedance cluster formed by the impedance measurements on the original 10 factory tuned antennas. The final impedances recorded with the retuned antennas at both the high and low frequency of each sub-band are plotted on the Z-0 charts of Figures 46 through 48. Chamber impedance measurements were also made on the retuned antennas with the ZDU; the results are shown on the Smith Charts of Figures 49 through 51.

Open-field impedance measurements on the 5 retuned antennas were made on the 10 x 10 foot ground screen. The open-field impedances of the retuned antennas are compared with the corresponding impedances of the 10 factory tuned antennas in Figures 52 through 54. The agreement between the open-field impedances of the retuned and factory tuned antennas is quite good in sub-bands 1, 2, 3, 4 and 7, and reasonably good in sub-bands 6 and 8. At 47.5 MHz in sub-band 5 (Figure 53(A)), the impedances of both the retuned and factory tuned antennas have a large impedance spread. This spread is not as apparent in the corresponding chamber data for this sub-band (Figures 47(A) and 50(A)). The open-field impedance cluster agreement at 53 MHz is quite good, indicating that the chamber retuning accuracy in this sub-band is
Figure 49. Impedance of Original and Retuned Antennas in Final Chamber as Measured with a ZDU - Bands 1, 2, 3, and 4.
Figure 50. Impedance of Original and Retuned Antennas in Final Chamber. as Measured with a ZDU - Bands 5, 6, 7 and 8.
comparable with that in other sub-bands. Similarly, the agreement at 47.5 MHz in sub-band 4 (Figure 52(D)) is also good, indicating that the impedance spread in sub-band 5 cannot be attributed to any type of frequency-ground screen interaction effects. It should be noted that the spread of impedances at 47.5 MHz in sub-band 5 of the factory tuned antennas is also large. There is every indication that the large impedance spread noted at this frequency in this sub-band is peculiar to the antennas and is not attributable to the chamber tuning. Several further tests were performed at 47.5 MHz in sub-band 5. One antenna base was fitted with 5 different whips and the open-field impedance of each base-whip combination was recorded. All five impedances were found to be equal to the originally measured value for this antenna base to within the repeatability of the ZDU. In another test, the antenna which exhibited one of the extreme open-field impedance readings ($0.46 - j0.32$) was retuned in the chamber using a criterion that instead of being tuned as nearly as possible to the center of the chamber cluster, it would be tuned to the line connecting the center of the chamber cluster and the origin ($1.0 + j0.0$). This retuning resulted in an open-field impedance slightly more extreme ($0.45 - j0.24$) with respect to the open-field cluster than the original
Figure 52. Impedance of Original and Retuned Antennas in the Open-Field - Bands 1, 2, 3 and 4.
Figure 53. Impedance of Original and Retuned Antennas in the Open-Field - Bands 5, 6, 7 and 8.
chamber tuning. It is suspected that a resonance effect in the base units in sub-band 5 at or near the 47.5 MHz frequency is contributing significantly to the large impedance spreads noted in the open-field. Since the results indicated that the problem was not functionally related to the chamber, further investigations seemed beyond the scope of this effort.

At both the high and low frequency ends of sub-band 10 and at the high frequency end of sub-band 9, chamber retuning of the 5 test antennas yielded open-field impedance clusters which were at least as small as the original factory tuned clusters. However, as shown in Figures 54(A) and 54(B), the cluster centers of the retuned antennas were shifted with respect to the original cluster centers. The dummy base cover was installed on one of the retuned antennas and sub-band 10 of the antenna was tuned in the open-field on the 10 x 10 foot ground screen. It was found that there was no setting of the tuning slug which yielded an open-field impedance at 70.5 MHz which fell within the original cluster. It was concluded that during the tuning process, certain changes, such as the relocating of wires, had occurred within the base units of the 5 antennas which prevented the retuning of the antennas to their
original impedances. Chamber retuning yielded open-field clusters which were as close to the original clusters in sub-bands 9 and 10 as could be attained with the test antennas.

As indicated in Figures 52 through 54, the open-field impedance clusters obtained with the antennas retuned in the final chamber were neither significantly larger nor significantly smaller than the clusters obtained with the factory tuned antennas. With the exception of the two sub-bands noted above, all retuned antenna open-field impedance clusters were centered about the corresponding open-field impedance clusters of the original antennas. As noted in Section D, in the higher frequency sub-bands, small chamber impedance changes produced relatively larger open-field impedance changes. While this is intuitively undesirable from the standpoint of tuning in the chamber, the open-field results indicate no appreciable loss of tuning accuracy (e.g., significantly larger clusters) in the higher frequency sub-bands. It appears that in all sub-bands the variation in components between antenna bases produces impedances variations that are significantly larger than those encountered in (chamber) tuning. The effects of the former mask the effects of the latter. Hence, if chamber tuning is less precise than tuning with dummy loads (e.g., factory tuning)—and there is no evidence that it is—the practical significance of such a discovery might be of minor importance since the available evidence indicates that the inaccuracies of both methods are negligible with respect to impedance variations associated with base unit component differences.

For the purpose of evaluating the final chamber, the concept of tuning antennas to the center of chamber impedance clusters of randomly selected factory tuned antennas seems adequate. Provided the chamber tuning techniques used were valid, one would expect open-field impedance clusters that were no larger than the impedance clusters of the factory tuned antennas. However, recognizing that because of component differences the center impedance of the factory tuned antennas could not be achieved with all test antennas, one should not expect open-field impedance clusters smaller than those of the factory tuned antennas either. This tuning concept in effect will insure the retention of most tuning differences that already exist in the factory tuned antennas. It is apparent that careful thought needs to be given to the selection of an optimum target impedance to which to tune in any practical usage of the test chamber. This problem is discussed further in the conclusions and recommendations section of this report.

c. AS-2165/VRC Antenna Measurements

To demonstrate that the compact chamber could be used to test and align antenna types other than the AS-1729/VRC, open-field and chamber impedance measurements were made on a AS-2165/VRC antenna. Antenna base serial no. 422 and whip serial no. 14 were used for these
measurements. The open-field impedance of the AS-2165 antenna, measured on a 10 x 10 foot ground plane at the low and high frequency of each of the ten bands, is shown in Figure 55. It is seen from the figure that the VSWR of the antenna ranges from 1.8 to 6 for the 20 data points, and 9 of the 20 data points lie within a 3:1 VSWR circle.

The impedance of the same antenna was measured with the antenna mounted in the compact test chamber. Since the AS-2165 antenna is only 6' 9.5" long, three chamber sections, Sections I, II and IV, were assembled to form a 9 foot long test chamber for these measurements. The measurement results are shown in Figure 56. It is seen from the figure that the VSWR of the antenna in the chamber ranges from 2.8 to 10. This change in VSWR appears to be equivalent to the change obtained with the AS-1729 antenna, from a 1.7 to 4 range in the open-field to a 3.3 to 7.0 range in the chamber.

From the limited number of measurements it was possible to make on the AS-2165 antenna in the time available, it appears that the conclusions regarding the use of the compact test chamber with the AS-1729 antenna apply equally well to the AS-2165 antenna.

d. Antenna Base Voltage Measurements

The voltage which exists across the base of an antenna when maximum rated power is applied is useful in evaluating the performance of the antenna. These values are available and have been used extensively for antennas operating in the open-field on a ground plane. It was of interest to determine the effect of the compact chamber on these voltages and to obtain values which could be used with antennas operated in the test chamber.

To accomplish these measurements, the same procedure was used that had previously been used to obtain the open-field voltages. This procedure consisted of placing a remote probe on the ground plane at the base of the antenna, calibrating the probe in terms of probe voltage versus actual voltage across the antenna base, applying a known low-level power to the antenna, measuring the base voltage, and calculating the base voltage for a 70 watt input level.

Measurement setups for calibrating the remote probe are shown in Figure 57. The upper photograph shows the remote probe mounted on the chamber base plate and a RF vacuum tube voltmeter probe connected across the base of the antenna. The lower photograph shows the base plate mounted on the test chamber, the VTM probe cable passing through a slot in the base plate to the probe across the antenna base, the remote probe connected to a Boonton (Model 91DA) RF voltmeter, and a signal generator connected to the input terminal of the antenna. At each test frequency—the high and low frequency of each antenna band—the signal
Figure 55. Open-Field Impedance of AS-2165/VRC Antenna Serial No. 422 (Whip S/N 14).
Figure 56. Chamber Impedance of AS-2165/VRC Antenna Serial No. 122 ( Whip S/N 14).
Figure 57. Two Views of Calibration Setup for Base Voltage Measurements.
The generator output was adjusted to obtain a desired voltage \( E_3 \) across the antenna base, measured on the VTVM. The probe voltage \( E_2 \), indicated on the Boonton RF Voltmeter, was recorded. The probe calibration factor at this test frequency is then \( \frac{E_2}{E_2} \). In addition to the 2 1/2 inch E probe with a coaxial terminated sampler shown in Figure 57, the measurements were repeated with a high-impedance RF probe. The principal difference between these probes was the presence of a 50 ohm termination on the former. A small shield was provided over both probes to insure that only that part of the field generated by the antenna base influenced the probe. The calibration factors for both probes as used with the AS-1729 antenna are shown in Figure 58. The calibration factors for use with the AS-2165 antenna are shown in Figure 59.

The setup for the base voltage measurements is shown in Figure 60. The VTVM probe which was connected across the antenna base during the probe calibration is now connected to measure the voltage at the input terminal of the antenna. The rest of the setup remains the same as the probe calibration setup. The signal generator output was adjusted to obtain a desired voltage level at the input terminal of the antenna \( (E_1) \) and the probe voltage \( (E_4) \) as indicated on the Boonton RF Voltmeter was recorded. The input power is then \( (E_1)^2 \) G, where G is the conductance of the test antenna in the chamber at the test frequency, and the base voltage is \( \left( \frac{E_3}{E_2} \right) E_4 \), where \( \left( \frac{E_3}{E_2} \right) \) is the probe calibration factor. The antenna base voltage can be calculated for any input power level by

\[
E_p = \frac{E_3}{E_2} E_4 \sqrt{\frac{P}{E_1^2 G}},
\]

where:

\( P \) = input power,

\( E_p \) = Antenna Base Voltage for input power \( P \).

Measurements were made in the chamber at the high and low frequency of each band on both the AS-1729 and the AS-2165 antennas utilizing both probes. The measured data and calculated base voltages for 70 watts input are tabulated in Tables IV - VII. An input power of 70 watts at 30 MHz was applied to the AS-1729 antenna mounted in the test chamber to
Figure 58. Probe Calibration for AS-1729/VRC Antenna.

Figure 59. Probe Calibration for AS-2165/VRC Antenna.
verify the base voltage calculations. The base voltage was measured with both the coaxial and high-impedance probes. The measured base voltages compared well with the calculated values. For the coaxial probe the measured base voltage with 70 watts applied was 210 volts compared with the calculated value of 200 volts. For the high impedance probe, the measured value was 205 volts compared with a calculated value of 189 volts.

The ratios of the chamber base voltages to the open-field ground plane base voltages are shown in Tables VIII and IX. It is apparent from Table VIII that the base voltages for the AS-1729 antenna in the chamber are lower than the corresponding base voltages for the antenna in the open-field with the exception of 76 MHz. For the AS-2165 antenna, the chamber base voltages varied from 0.25 to 1.5 times the open-field values with an approximately equal distribution above and below the open-field values.
**Table IV. Base Voltage Data on AS-1729/VRC Antenna Using Coaxial Probe.**

<table>
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<tr>
<th>Freq-Band</th>
<th>G (Cond.)</th>
<th>E₁ (Input)</th>
<th>E₂ (Loaded)</th>
<th>E₃ (Base)</th>
<th>E₄ (Unloaded)</th>
<th>E₃/E₂ x 10⁴</th>
<th>E₇₀ volts</th>
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<td>30-1</td>
<td>0.01820</td>
<td>2.000</td>
<td>0.00375</td>
<td>6.00</td>
<td>0.00404</td>
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<td>33-1</td>
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$E_{70}$ = Calculated Base Voltage with 70 watts input.
Antenna: AS-1729/VRC  
S/N: 18406  
Probe Type: Boonton High-Impedance RF Probe

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<th>E₂ (Loaded) (volts)</th>
<th>F₃ (Base) (volts)</th>
<th>F₄ (Unloaded) (volts)</th>
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<th>( E_{70} ) (volts)</th>
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<td>60-8</td>
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<td>4.0</td>
<td>0.00689</td>
<td>10.0</td>
<td>0.00137</td>
<td>1.450</td>
<td>65.0</td>
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<tr>
<td>65-8</td>
<td>0.00855</td>
<td>4.0</td>
<td>0.00701</td>
<td>10.0</td>
<td>0.00162</td>
<td>1.430</td>
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<td>65-9</td>
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<td>4.0</td>
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<td>10.0</td>
<td>0.00105</td>
<td>1.540</td>
<td>39.0</td>
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<td>70.5-9</td>
<td>0.04310</td>
<td>4.0</td>
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<td>0.00619</td>
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<td>0.00375</td>
<td>1.610</td>
<td>54.0</td>
</tr>
</tbody>
</table>

\( E_{70} \) = Calculated Base Voltage with 70 watts input.

**TABLE V.** Base Voltage Data on AS-1729/VRC Antenna Using High-Impedance Probe.
Antenna: AS-2165/VRC  
S/N: 422/14  
Probes Type: 2 1/2" E Probe with Terminated Coaxial Sampler

<table>
<thead>
<tr>
<th>Freq-Band</th>
<th>G (Cond.) mhohs</th>
<th>E1 (Input) volts</th>
<th>E2 (Loaded) volts</th>
<th>E3 (Base) volts</th>
<th>E4 (Unloaded) volts</th>
<th>E3/E2 x 10^3</th>
<th>E70 volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-1</td>
<td>0.01760</td>
<td>2.0</td>
<td>0.00313</td>
<td>4.60</td>
<td>0.00340</td>
<td>1.470</td>
<td>157.6</td>
</tr>
<tr>
<td>33-1</td>
<td>0.00440</td>
<td>2.0</td>
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<td>3.05</td>
<td>0.00150</td>
<td>1.280</td>
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</tr>
<tr>
<td>33-2</td>
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<td>0.00760</td>
<td>10.50</td>
<td>0.00470</td>
<td>1.380</td>
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</tr>
<tr>
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<td>2.0</td>
<td>0.00520</td>
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<td>0.00200</td>
<td>1.170</td>
<td>233.9</td>
</tr>
<tr>
<td>37-3</td>
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<td>2.0</td>
<td>0.00620</td>
<td>8.00</td>
<td>0.00580</td>
<td>1.290</td>
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</tr>
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<td>0.00470</td>
<td>5.20</td>
<td>0.00290</td>
<td>1.110</td>
<td>223.7</td>
</tr>
<tr>
<td>42-4</td>
<td>0.00860</td>
<td>2.0</td>
<td>0.00850</td>
<td>9.70</td>
<td>0.00600</td>
<td>1.140</td>
<td>308.9</td>
</tr>
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<td>0.00493</td>
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<td>0.00375</td>
<td>0.973</td>
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</tr>
<tr>
<td>47.5-5</td>
<td>0.00400</td>
<td>2.0</td>
<td>0.00990</td>
<td>10.00</td>
<td>0.00560</td>
<td>1.010</td>
<td>374.1</td>
</tr>
<tr>
<td>53-5</td>
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<td>2.0</td>
<td>0.00605</td>
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<td>0.00796</td>
<td>0.892</td>
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</tr>
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<td>53-6</td>
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<td>0.00840</td>
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<td>56-6</td>
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<td>0.01300</td>
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<td>0.01540</td>
<td>0.825</td>
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<td>0.01370</td>
<td>0.877</td>
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</tr>
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<td>65-8</td>
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<td>0.00530</td>
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<td>0.00655</td>
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<td>1.5</td>
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<td>0.00410</td>
<td>2.80</td>
<td>0.00480</td>
<td>0.683</td>
<td>222.5</td>
</tr>
</tbody>
</table>

\[ E_{70} = \text{Calculated Base Voltage with 70 watts input.} \]

**TABLE VI.** Base Voltage Data on AS-2165/VRC Antenna Using Coaxial Probe.
Antenna: AS-2165/VRC  
S/N: 422/14  
Probe Type: Boonton High-Impedance RF Probe

<table>
<thead>
<tr>
<th>Freq-Band</th>
<th>G</th>
<th>E_1</th>
<th>E_2</th>
<th>E_3</th>
<th>E_4</th>
<th>E_3/E_2 x 10^3</th>
<th>E_70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Cond.)</td>
<td>(Input)</td>
<td>(Loaded)</td>
<td>(Base)</td>
<td>(Unloaded)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mhos</td>
<td>volts</td>
<td>volts</td>
<td>volts</td>
<td>volts</td>
<td>x 10^3</td>
<td>volts</td>
</tr>
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<td>4.60</td>
<td>.00391</td>
<td>1.28</td>
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</tr>
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<td>.0044</td>
<td>2.0</td>
<td>.00253</td>
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<td>.00150</td>
<td>1.21</td>
<td>114.0</td>
</tr>
<tr>
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<td>.00740</td>
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<td>.00510</td>
<td>1.20</td>
<td>210.0</td>
</tr>
<tr>
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<tr>
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<td>.00490</td>
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</tr>
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</tr>
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<td>.00325</td>
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<td>.00215</td>
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<tr>
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<td>.00187</td>
<td>2.80</td>
<td>.00212</td>
<td>1.50</td>
<td>215.4</td>
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</table>

E_70 = Calculated Base Voltage with 70 watts input.

TABLE VII. Base Voltage Data on AS-2165/VRC Antenna Using High-Impedance Probe.
<table>
<thead>
<tr>
<th>Freq-Band MHz</th>
<th>Base Voltages on 10 x 10 Ft. Ground Plane in Open-Field (70 watts)</th>
<th>Ratio of Chamber Base Voltages to Open-Field Base Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Coaxial Probe</td>
</tr>
<tr>
<td>30-1</td>
<td>294.0</td>
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<td>37-3</td>
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<td>.796</td>
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<td>.657</td>
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<td>47.5-4</td>
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<td>.663</td>
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<td>.532</td>
</tr>
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<td>.561</td>
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<tr>
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<tr>
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<td>.469</td>
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<tr>
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</table>

**TABLE VIII.** Ratio of Chamber Base Voltage To Open-Field Base Voltage For AS-1729/VRC Antenna.
<table>
<thead>
<tr>
<th>Freq-Band Mix</th>
<th>Base Voltages on 10 x 10 Ft. Ground Plane in Open-Field (70 watts)</th>
<th>Ratio of Chamber Base Voltages to Open-Field Base Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Coaxial Probe</td>
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<tr>
<td>30-1</td>
<td>295</td>
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<td>.641</td>
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<tr>
<td>33-2</td>
<td>359</td>
<td>.602</td>
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<tr>
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<td>42-4</td>
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<td>.741</td>
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</tr>
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<td>361</td>
<td>1.270</td>
</tr>
<tr>
<td>60-7</td>
<td>365</td>
<td>.432</td>
</tr>
<tr>
<td>60-8</td>
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<td>1.180</td>
</tr>
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<td>.249</td>
</tr>
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<td>70.5-10</td>
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<td>.486</td>
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<tr>
<td>76-10</td>
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<td>.800</td>
</tr>
</tbody>
</table>

**TABLE IX.** Ratio of Chamber Base Voltage To Open-Field Base Voltage For AS-2165/VRC Antenna.
e. Power Test

The ability to test antennas with the maximum input power applied was one objective of the compact test chamber. This test requires that an input power of 70 watts be applied to the antenna under test. To determine if this level of input power would have any effect on the chamber characteristics or any temporary or permanent effects on the NZ-1 material, a power test was performed as part of the chamber evaluation.

The measurement setup for the power test is shown in Figure 6.1. An amplifier capable of providing 100 watts of output power over the frequency range from 30 to 42 MHz was utilized to provide the necessary power for the test. An AS-1729 antenna was mounted in the test chamber and the impedance at all test frequencies was measured immediately before the power test. The amplifier was connected to the antenna terminal and 70 watts of forward power at 30 MHz was applied to the antenna. The fact that 70 watts of forward power was applied to the antenna was established by means of a wattmeter in the line between the amplifier and the antenna as shown in the figure. The power was applied for a period of one hour. At the end of this period, the power was removed and the antenna impedance at all test frequencies was measured again. The power was applied for another hour and the impedance was measured again.

Figure 6.1. Power Test Measurement Setup.
There was no discernable difference between any of the impedance measurements. It was therefore concluded that the compact chamber was satisfactory for performing the desired power tests.

f. Shielding Tests

A primary objective of the compact test chamber was the isolation of the antenna under test from the outside environment. To evaluate the shielding effectiveness of the chamber, measurements were performed utilizing the test setups shown in Figure 62.

The determination of the shielding effectiveness of the test chamber was accomplished by the comparison of the power necessary to produce a given coupling between two parallel AS-1729 antennas separated a distance of 10 inches without the chamber, as shown in the upper photograph of the figure, to the power required to produce the same coupling between the same two antennas with one of the antennas mounted in the test chamber as shown in the lower photograph of the figure. The difference in the two input signal levels was defined as the shielding effectiveness of the chamber.

The input signals required to produce the same coupling were -68 dBm in the open-field as compared to -2.4 dBm for the chamber setup. Thus a shielding effectiveness of 65.6 dB was obtained for the chamber.

g. Permeability and Permittivity Measurements

It was of interest to determine the relative complex permeability ($\mu^*$) and relative complex permittivity ($\varepsilon^*$) of the Eccosorb NZ-1 absorbing material. These quantities were desired for use in the specification of material for possible future chamber fabrication.

The technique used in determining these parameters is known as the thin sample technique. In this technique a thin toroid of the material is placed in an air-filled coaxial transmission line; first in a region of predominately electric field and then in a region of predominately magnetic field. These fields were generated respectively by terminating the sample with an open-circuit and then a short-circuit. The requirement that the sample be thin, $\lambda/16$ or less, is to insure that the entire sample is in a constant $E$-field and essentially zero $H$-field under open-circuit conditions and in a constant $H$-field and essentially zero $E$-field under short-circuit conditions. This electrical thickness, $\lambda/16$ or less, was verified by observing the shift of the slotted line null pattern when the sample was inserted. If the shift was less than $\lambda/16$ the sample was considered electrically thin.
Figure 62. Two Views of Shielding Measurement Setup.
The impedance of the sample filled portion of the coaxial line under open-circuit and short-circuit conditions was calculated using measured data and the following equation.

\[
Z_{\text{in}} = \frac{\frac{1}{\rho} - \frac{1}{\rho_0} - j \tan \frac{2\pi d}{\lambda_o}}{1 - j \left( \frac{1}{\rho} - \frac{1}{\rho_0} \right) \tan \frac{2\pi d}{\lambda_o}} \tag{2}
\]

where:

\[
Z_{\text{in}} = \text{normalized input impedance at the face of the sample,}
\]

\[
\rho = \text{the VSWR with sample inserted,}
\]

\[
\rho_0 = \text{the VSWR of air-filled coaxial line,}
\]

\[
\lambda_o = \text{free space wavelength, and}
\]

\[
d = \text{the distance from the voltage minimum to the front face of the sample.}
\]

From these impedance values \( \mu^* \) and \( \varepsilon^* \) were calculated using the following relationships. \(^7\)

\[
\mu^* = \mu' - j\mu'', \tag{3}
\]

\[
\varepsilon^* = \varepsilon' - j\varepsilon'', \tag{4}
\]

\[
Z_{sc} = Z_c \tanh \gamma l, \tag{5}
\]

\[
Z_{oc} = Z_c \cotanh \gamma l, \tag{6}
\]

\[
Z_c = \sqrt{\frac{\mu^*}{\varepsilon^*}}, \text{ and}
\]

\[
\gamma = j \frac{2\pi}{\lambda_o} \sqrt{\mu^*\varepsilon^*} \tag{8}
\]
where:

\[ Z_{sc} = \text{normalized short-circuit impedance existing at the face of the sample}, \]

\[ Z_{oc} = \text{normalized open-circuit impedance existing at the face of the sample}, \]

\[ Z_c = \text{the normalized characteristic impedance of that part of the line containing the sample}, \]

\[ \gamma = \text{propagation constant of that part of the line containing the sample, and} \]

\[ \ell = \text{length of the sample}. \]

Noting that for small arguments, \( \gamma \ell < 0.3 \), the tanh function can be replaced by its argument with an error less than 3\%, equations (5) and (6) can be simplified to

\[ Z_{sc} = Z_c \gamma \ell, \text{ and} \]  

\[ Z_{oc} = Z_c \frac{1}{\gamma \ell}. \]  

Using equations (7) and (8),

\[ Z_{sc} = \sqrt{\mu^* \frac{1}{\varepsilon^*}} j \frac{2\pi \ell}{\lambda} \sqrt{\mu^* \varepsilon^*} = j \frac{2\pi \ell}{\lambda} \mu^*, \]  

and

\[ Z_{oc} = \sqrt{\mu^* \frac{1}{\varepsilon^*}} \frac{\lambda}{j \sqrt{2\pi \ell \mu^* \varepsilon^*}} = \frac{\lambda}{j 2\pi \ell \varepsilon^*}, \]

which becomes

\[ \mu^* = \mu' - j\mu'' = -j \frac{\lambda}{2\pi \ell} Z_{sc}, \]

and

\[ \varepsilon^* = \varepsilon' - j\varepsilon'' = -j \frac{\lambda}{2\pi \ell} Z_{oc}. \]
The results from these measurements performed on four test samples from a selected group of NZ-1 tiles are shown in Tables X - XIII. The average values for the four samples at five test frequencies over the frequency range of interest are shown in Table XIV.

In addition to the use in specifying materials for possible future chambers, these values should be of considerable value in any attempt to develop a more complete theoretical description of the operation of the ferrite lined test chamber.
Sample A

$l = .00637 m$

<table>
<thead>
<tr>
<th>Freq. MHz</th>
<th>$\rho_{10}$</th>
<th>$\rho_{20}$</th>
<th>$\rho_1$</th>
<th>$\rho_2$</th>
<th>$S_1$ (Meters)</th>
<th>$S_2$ (Meters)</th>
<th>$\mu'$</th>
<th>$\mu''$</th>
<th>$\varepsilon'$</th>
<th>$\varepsilon''$</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSWR Line With</td>
<td>30</td>
<td>39.81</td>
<td>44.67</td>
<td>4.70</td>
<td>44.67</td>
<td>.435</td>
<td>.070</td>
<td>69.0</td>
<td>47.0</td>
<td>12.4</td>
</tr>
<tr>
<td>VSWR Open With</td>
<td>40</td>
<td>79.43</td>
<td>70.80</td>
<td>3.98</td>
<td>70.8</td>
<td>.380</td>
<td>.066</td>
<td>57.2</td>
<td>49.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Null Shift With</td>
<td>50</td>
<td>70.79</td>
<td>141.30</td>
<td>3.55</td>
<td>56.23</td>
<td>.355</td>
<td>.060</td>
<td>58.5</td>
<td>47.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Null Shift Open</td>
<td>60</td>
<td>89.13</td>
<td>31.62</td>
<td>2.82</td>
<td>17.80</td>
<td>.340</td>
<td>.070</td>
<td>50.6</td>
<td>51.7</td>
<td>12.1</td>
</tr>
<tr>
<td>Real Part of $\mu^*$</td>
<td>76</td>
<td>31.62</td>
<td>25.10</td>
<td>2.51</td>
<td>20.00</td>
<td>.280</td>
<td>.060</td>
<td>40.4</td>
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<td>10.3</td>
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**TABLE X.** Measured Data and Calculated Permeability and Permittivity of NZ-1 Absorbing Material. (Sample A)
Sample B

$\lambda = 0.00637\text{m}$

<table>
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<tr>
<th>Freq. MHz</th>
<th>$\rho_{10}$</th>
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<th>$\rho_1$</th>
<th>$\rho_2$</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$\mu'$</th>
<th>$\mu''$</th>
<th>$\varepsilon'$</th>
<th>$\varepsilon''$</th>
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<td>Line</td>
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<td>VSWR</td>
<td>VSWR</td>
<td>Null</td>
<td>Null</td>
<td>Real</td>
<td>Imag.</td>
<td>Real</td>
<td>Imag.</td>
<td>Real</td>
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<tr>
<td>With Short</td>
<td>With Open</td>
<td>With Sample</td>
<td>With Sample</td>
<td>Open Shift</td>
<td>Open Shift</td>
<td>Part of $\mu^*$</td>
<td>Part of $\mu^*$</td>
<td>Part of $\varepsilon^*$</td>
<td>Part of $\varepsilon^*$</td>
<td></td>
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<tr>
<td>30</td>
<td>39.81</td>
<td>44.67</td>
<td>3.55</td>
<td>25.12</td>
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<td>.075</td>
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<td>67.0</td>
<td>13.00</td>
<td>4.34</td>
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<td>70.81</td>
<td>3.55</td>
<td>45.30</td>
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<td>.063</td>
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<td>50</td>
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<td>141.30</td>
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<td>50.5</td>
<td>11.85</td>
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TABLE XI. Measured Data and Calculated Permeability and Permittivity of NZ-1 Absorbing Material. (Sample B)
Sample C
ℓ = .00637m

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<th>ρ₂₀</th>
<th>ρ₁</th>
<th>ρ₂</th>
<th>S₁</th>
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<th>μ''</th>
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<td>VSWR</td>
<td>VSWR</td>
<td>VSWR</td>
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<td>Null</td>
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<td>Imag.</td>
<td>Real</td>
<td>Imag.</td>
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<tr>
<td>Line</td>
<td>Line</td>
<td>Short</td>
<td>Open</td>
<td>Shift</td>
<td>Shift</td>
<td>Open</td>
<td>Part</td>
<td>of μ*</td>
<td>Part</td>
<td>of e*</td>
</tr>
<tr>
<td>With</td>
<td>With</td>
<td>With</td>
<td>With</td>
<td>Short</td>
<td>Open</td>
<td>Sample</td>
<td>(Meters)</td>
<td>(Meters)</td>
<td>μ*</td>
<td>e*</td>
</tr>
<tr>
<td>Short</td>
<td>Open</td>
<td>Sample</td>
<td>Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>44.67</td>
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<td>1.13</td>
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**TABLE XII.** Measured Data and Calculated Permeability and Permittivity of NZ-1 Absorbing Material. (Sample C)
Sample D

\( l = .00637 \) m

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<th>Null</th>
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<td>70.80</td>
<td>4.47</td>
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<td>36.6</td>
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<td>1.60</td>
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<td>42.5</td>
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<td>2.82</td>
<td>15.85</td>
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<td>.060</td>
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<td>10.8</td>
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**TABLE XIII.** Measured Data and Calculated Permeability and Permittivity of NZ-1 Absorbing Material. (Sample D)
<table>
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<td>$\mu'$</td>
<td>64.20</td>
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<td>51.80</td>
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<td>36.10</td>
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<tr>
<td>$\mu''$</td>
<td>55.70</td>
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<td>48.30</td>
<td>48.30</td>
<td>40.80</td>
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<td>$\varepsilon'$</td>
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<td>11.42</td>
<td>12.20</td>
<td>13.00</td>
<td>10.30</td>
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<td>$\varepsilon''$</td>
<td>3.73</td>
<td>1.11</td>
<td>4.17</td>
<td>6.02</td>
<td>2.09</td>
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**TABLE XIV.** Average Permeability and Permittivity Values of NZ-1 Absorbing Material.
II. CONCLUSIONS AND RECOMMENDATIONS

A compact test chamber lined with Eccosorb NZ-1 ferrite material was developed, and on the basis of results from an extensive evaluation of this chamber, it was concluded that the chamber is satisfactory for performing the desired antenna tests.

Results from investigations of absorbing materials in the near-field of antennas and the effect of ground plane size on antenna impedance characteristics indicated that it was not feasible to develop a compact test chamber which would yield the same antenna impedance characteristics that would be obtained with the antenna operating in the open-field. The developed chamber is based on a modified approach which permits the antenna impedance in the chamber to be calibrated in terms of open-field characteristics. The calibration of the chamber included the determination of equivalent chamber impedance values for desired open-field impedance values.

It was found that the agreement between the open-field impedances of factory tuned antennas and test antennas tuned in the compact test chamber lined with ferrite tile was quite good when the test antennas were tuned to the center of the chamber impedance clusters of the factory tuned antennas. It was also found that a given impedance change in the compact test chamber produced a correspondingly larger change in the open-field impedance in most sub-bands. This effect was found to be frequency dependent, with the most chamber impedance compression occurring in the higher frequency sub-bands. The test results, however, indicated that this chamber impedance compression effect resulted in no appreciable loss of tuning accuracy in the higher frequency sub-bands.

For chamber evaluation purposes the concept of tuning antennas to the center of chamber impedance clusters of randomly selected factory tuned antennas proved valid. It is recognized, however, that more attention needs to be directed toward the selection of chamber target tuning impedances in any practical application of the compact test chamber to antenna impedance tuning. A possible solution would involve the selection of one or more antennas to serve as "standards". The selection of these "standard" antennas would be based on their yielding the desired open-field impedances either on a standard ground screen or a particular vehicle. The corresponding chamber impedances of these "standard" antennas would then be measured in the compact test chamber to determine the target chamber impedances or impedance clusters to which all other antennas would be tuned.

Impedance measurements made in the experimental chamber and in the final chamber revealed that the slight differences in internal dimensions of the two chambers had an effect on the measured impedances of the antennas. Although the corresponding impedance clusters obtained in the
two chambers were the same size, they were located at slightly different positions on the Smith Charts. Since the same ferrite tiles were used in both chambers, this possible source of impedance variation was not included in the measurements. Because of these considerations, it is recommended that future compact test chambers be individually calibrated until an accurate appraisal can be made of the effects of construction differences on chamber impedance.

Both a ZDU and a Vector Impedance Meter were used in tuning the antennas in the compact chamber. Of these two instruments, tuning with the Vector Impedance Meter was faster because of the continuous Impedance display available with this instrument. When the ZDU was used, it was necessary to rebalance the instrument each time the antenna tuning was slightly altered in order to determine the new impedance. While this was somewhat time consuming, the visual Smith Chart display available on the ZDU provided a distinct advantage in tuning. Under the criterion of tuning to the center of an impedance cluster, the ZDU Smith Chart, on which the target cluster could be pre-sketched, proved most useful. From the standpoint of tuning accuracy the ZDU is thought to be slightly superior, although no direct measurements were made to evaluate this opinion. What did become apparent in the course of the measurements was that the ultimate tuning accuracy attainable with the antennas was not significantly limited by the tuning accuracy of either instrument, but rather by base component variations from antenna to antenna and by the choice of the target impedances with respect to the available tuning range of these components.

It is recommended that additional investigation be performed to develop a detailed plan for adapting the compact test chamber to practical production testing of vehicular whip antennas. Some of the goals of this proposed investigation would be (1) the development of antenna impedance standards for use during base alignment in the test chamber, (2) the development of optimum tuning procedures for use with the chamber, (3) the development of detailed procedures and test plans for performing all of the required tests with the test chamber and (4) the development of techniques for minimizing the time necessary to perform the required tests.

It is also recommended that additional investigation be performed to develop a more complete theoretical description of the operation of the ferrite-lined test chamber. The results from such an investigation may provide the means for developing more optimum test chambers.
III. LITERATURE CITED


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COMPACT CHAMBER FOR IMPEDANCE AND POWER TESTING OF VHF WHIP ANTENNAS

Final Report, 1 July 1967 to 1 July 1968

Free, William R., Jenkins, Bernard M., and Stuckey, Charles W.

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Antenna Test Chamber
VHF Antenna Tests

This report summarizes the accomplishments on a program to develop a compact test chamber suitable for production testing of VHF vehicular antennas.

A compact test chamber consisting of a 12 foot long aluminum cylinder, 1 foot in diameter and lined with Ecosorb NZ-1 ferrite material was developed. This chamber was calibrated with respect to open-field antenna characteristics. Results from an extensive evaluation are presented which attest to the usefulness of the chamber in meeting production and/or field test and alignment requirements.

Investigations of the reflectivity characteristics of a number of absorbing materials, the effects of absorbing materials in the near-field of antennas, and the effects of ground plane size on antenna characteristics are described and results from these programs are presented.
14.

**KEY WORDS**

- Antenna Impedance
- Antenna Test Chamber
- Antenna Tests
- VHF Antennas
- Absorbing Materials
- Absorber Reflectivity Characteristics
- Ferrite Permeability
- Ferrite Permittivity

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