TECHNICAL REPORT ECOM 2549

A FORESHORTENED CENTER-FED WHIP ANTENNA

BY

WATSON P. CZERWINSKI

JANUARY 1965

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

TECHNICAL REPORT ECOM-2549

A FORESHORTENED CENTER-FED WHIP ANTENNA

by

Watson P. Czerwinski
Exploratory Research Division C
Institute for Exploratory Research

January 1965

DA Task No. 1P0 14501 B31A 00

U. S. ARMY ELECTRONICS LABORATORIES
U. S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

ABSTRACT

An experimental investigation was conducted to determine whether the degradation in electrical performance commonly observed with reduced-height helical-wound vertical dipoles can be avoided. A new design approach has been explored which helped define a major cause of this degradation. Data obtained during this investigation supports a working hypothesis that losses associated with circulating currents in the capacitance between turns of a helically wound, electrically short vertical dipole greatly reduce antenna bandwidth and efficiency. A six-foot-high experimental model was constructed and tested as a replacement for the 10-foot whip of Antenna AS-1729( )/VRC. The design of this foreshortened model minimized circulating current losses throughout the operating band of 30 to 76 Mc and resulted in an average efficiency of 90% compared to the 10-foot whip.

CONTENTS

FIGURES

TABLES

A FORESHORTENED CENTER-FED WHIP ANTENNA

INTRODUCTION

Antenna AT-912( )VR[1] and its improved version Antenna AS-1729( )/VRC[2,3] are vehicular antennas designed to operate in the VHF band from 30 to 76 Mc. Antenna AS-1729( )/VRC, which had been called AT-912-A or AT-912(XE-2) during its development phase (Fig. 1), was recently classified "Standard A" for use with Radio Set AN/VRC-12. Service-test reports[4] have indicated that this antenna has a potential for additional tactical applications with other radio sets. In order to increase this potential, an investigation was initiated to determine whether the presently used 10-foot whip, consisting of Antenna Elements AT-1095 and AS-1730, can be reduced in height without a corresponding loss in efficiency, and hopefully, without major modification of the base isolation unit MX-6707( )/VRC, which is also a part of Antenna AS-1729( )/VRC.

EXPERIMENTAL PROCEDURE

Preliminary measurements determined that the feed-point impedance of the presently used 10-foot whip must be reproduced closely in the foreshortened version in order to permit the use of base isolation unit MX-6707 without major modifications. The feed-point is defined as the point approximately halfway up the whip, where the outer conductor of the encapsulated coaxial cable ends, corresponding to the driving point of a dipole antenna. The feed-point impedance, in turn, depends on the accuracy with which the standing-wave current distribution of the 10-foot whip is reproduced in the foreshortened model. It was also determined that the adjustment of feed-point impedance and current distribution at the two end frequencies of the operating band, namely 30 and 76 Mc (for a given circuit Q), suffices to obtain satisfactory performance over the entire band. The preselected susceptance values of the base isolation unit listed in Table 1 control these two parameters throughout the operating band. Fig. 2a illustrates simplified circuit elements of the 10-foot whip used as a reference in this investigation. Fig 2b shows the additional series inductance needed to reproduce the same feed-point impedance in the foreshortened model, plus the associated shunt capacitance and loss conductance that must be minimized to achieve this reproduction.

An arbitrary goal of 40% reduction in height was selected for the laboratory model. A 68-inch length of 1-inch-diameter paper-phenolic tubing mounted on the base isolation unit provided a form for the model. An outline sketch of the final laboratory model is shown in Fig. 3.

Initial measurements of a helically wound radiator showed poor radiation efficiency when wide copper tape was used as the conductor. The efficiency increased somewhat with a reduction in tape width. This evidence suggested that the reduced capacitance between turns resulted in an increase in the effective series inductance, permitting a reduction in the total number of turns required. The optimum was approached when the conductor was reduced to a minimum diameter consistent with the operating power rating. Reducing the surface area of the conductor also led to reduced circulating current losses resulting from stored energy in the capacitance between turns.

By tapering the winding gradually from maximum pitch at the point where the standing-wave current on the radiator is maximum, to minimum pitch where this current approaches zero while monitoring field intensity, we improved the efficiency to a marked degree. This technique provides an additional control for further reducing the stored energy in the antenna at the point where the current is maximum. For the largest part of the operating band, the current is maximum near the feed point. The magnitude of stored energy also affects the bandwidth of the antenna. Fig. 4 shows the bandwidth characteristics achieved in the final foreshortened model tested, as compared to that of the 10-foot whip.

The procedure for adjusting the current distribution along the model whip was similar to the one used in the design of Antenna AS-1729( )/VRC. The portion of the whip above the feed point was made slightly shorter than a half wave at 76 Mc. In order to make the radiation resistance as high as possible it is desirable to effect a steep rise in current at the top of the whip. In the final foreshortened model, the author achieved this kind of distribution by placing a ferrite-core inductor together with a capacity-top copper band at the top of the radiator, and making this termination electrically equivalent to an open-ended line of 45 degrees at 76 Mc. From this line length and an estimated characteristic impedance[6] of 250 ohms, an input reactance corresponding to 8.4 pF is derived. This value was used as a target while the termination on an admittance bridge was adjusted and optimized. The measuring arrangement is shown in Fig. 5. The inductor winding was adjusted for a bridge reading close to the target capacitance while the conductance was minimized. The final measured values were $B/2\pi F = 8.5$ pF, with .13 millimhos conductance. It was noted that the number of turns and their spacing depend on the $\mu \cdot Q$ of the particular ferrite core material used. This termination also proved effective at 30 Mc but to a lesser degree. Plotting the measured current distribution at 76 Mc helped us to establish the feed-point location as 33¼ inches down from the top of the whip.

The series inductance in the section of the whip between the feed point and the base isolation unit is adjusted at 30 Mc by the number of turns required in the helical winding to bring the current at the base to .4 of its maximum value. The current distribution at 30 and 76 Mc may approach the desired contour when plotted as in Fig. 6. However, fine adjustment of both the top reactance and the non-uniformly wound helical winding in the lower section may be required in order to reproduce closely the target feed-point impedance given in Fig. 7. In the final model this impedance was transformed (similar to the technique used in the 10-foot whip) by a section of 130-ohm coaxial cable in order to group the transformed impedance within a 3:1 VSWR circle referenced to 50 ohms. Fig. 8 illustrates the helical-wound transformer cable located between the feed point and the splice with the RG-188 feed cable. The RG-188 then completes the tapered winding and terminates within the base isolation unit at the input BNC connector.

Figs. 9 and 10 show the probe used in measuring current distribution during these experiments. Fig. 11 shows the calibration curve for this probe.

RESULTS

The four models listed in Fig. 12 are essentially representative of the many configurations explored during this investigation. The model designated " △ " had linear elements without any additional series inductance above and below the feed point. This model requires a major modification of the base isolation unit, resulting in admittance values different from those listed in Table 1. This modification is not desirable because it tends to increase losses in the base isolation unit particularly at the lower frequencies because of the higher voltages that will develop at the base.

The model designated " ⊙ " with a constant-pitch winding throughout the entire 6-foot whip also proved lossy. The relatively large capacitance between turns seemed to be a fundamental limitation in this approach. However, reducing the conductor surface area from that of a wide copper tape to a thin wire correspondingly increased the efficiency. Increasing the pitch uniformly throughout the 6-foot whip in order to further reduce the capacitance between turns also reduced the inductance appreciably. Fig. 12 shows an optimized design of this approach tested for relative efficiency.

In the third approach, using the model designated " ⊡ " in Fig. 12, the design was based on the theory that stored energy in the capacitance between turns will produce large losses <u>only</u> when there are large currents present. The design of Antenna AS-1729( )/VRC was based on reconstituting a half-wave current distribution envelope on a constant-height vertical dipole throughout the operating range of 30 to 76 Mc in 10 sub-bands. Therefore, throughout the major portion of this range the current maximum will develop at the center of the whip near the feed point. With this in mind and using the number of turns determined by the previous model, we adjusted the pitch of the helical winding for maximum at the feed point while monitoring field intensity, and gradually reduced to minimum at both the top and the bottom of the whip. This arrangement proved very encouraging as shown in Fig. 12. Fig. 13 shows this model mounted on a 3/4-ton weapons-carrier vehicle.

The final arrangement tested is designated with a "dot" in Fig. 12. It is essentially the same as the tapered pitch model described above, but modified to remove the winding located above the feed point, and replaced with a ½-inch-wide copper strip that terminates at the top in a ferrite-core lump inductance with a capacity-top copper sleeve. As previously stated, this lump termination was designed to represent $\lambda/8$ at 76 Mc. Fig. 3 shows this experimental model and some of its construction details. The capacity-top sleeve is one inch long with a 1/8-inch gap to prevent it from becoming a shorted turn. The ferrite-core lump inductance was made of 5 turns of #18 magnet wire space wound on the one-inch-diameter phenolic tubing that serves as the antenna support. The length of this coil is approximately 3 inches. Within this coil is a 3/4-inch-diameter 5-inch-long ferrite rod, General Ceramics No. MF-6784. (If available, MF-2761 should be used because it is a better material at these frequencies.) From the lower end of this coil to the inner conductor of the coaxial cable at the feed point is the ½-inch-wide 29-inch-long copper strip. Before the coaxial transformer cable was incorporated in this model, the coaxial cable from the feed point to the connector at the lower end of this phenolic tubing consisted of 13 turns of RG-188, having a stretch-out length of approximately 75 inches. This winding occupied the remaining 35 inches of the support tubing. To compensate for any variation in construction, the number of turns should be adjusted so the feed-point impedance at 30 Mc in sub-band 1, and at 76 Mc in sub-band 10 closely approaches the target impedance given in Fig. 7. This adjustment will also control the current distribution shown in Fig. 6. For a given number of turns, the winding taper has little effect on either the feed-point impedance or the current distribution; its major influence is on antenna bandwidth and efficiency. When the feed-point impedance, current distribution, and winding taper are satisfactory, a portion of the RG-188 cable beginning at the feed point is substituted with a calculated length of 130-ohm cable designed to cluster the transformed impedance within a 3:1 VSWR circle referenced to 50 ohms. Although the VSWR as shown in Fig. 4 exceeds that of the 10-foot whip, optimizing the coaxial transformer will locate the impedance arcs more uniformly about the 3:1 circle. Table 2 shows the field-intensity measurements made with this model normalized to the field-intensity measurements of the referenced 10-foot whip while each in turn was mounted on a 3/4-ton weapons-carrier vehicle.

APPLICATIONS

Both the 6-foot whip height and the 1-inch-diameter support tubing used in these models have been chosen arbitrarily and are not meant to signify that they represent limits in the design of a foreshortened whip antenna. These two dimensions should rather be selected to meet the requirements of the application of the antenna. The author believes that further exploitation of the principles used in this investigation will lead to a still shorter, perhaps 5-foot-high radiating element at the cost of only a modest reduction in efficiency for applications where antenna height is a limiting factor. The whip can be made flexible by selection of a pliant support member in place of the rigid tubing used in the models.

Use of a high-impedance coaxial cable of smaller diameter than that in the model would aid in further reducing the stored energy between turns of the coaxial transformer cable. This would tend to improve the antenna bandwidth so that it approaches more closely that of the 10-foot whip.

CONCLUSIONS

The final foreshortened model explored during this investigation met the design objectives for efficiency and interchangeability with the 10-foot whip of Antenna AS-1729( )/VRC. Although other investigators have explored various characteristics of top-loaded[6,7] and short helical radiators,[8] the design principles evolved during this investigation are new and have produced interesting and unexpectedly favorable results. Experimental measurements corroborated a working hypothesis that the magnitude of stored energy between turns of a helically wound short dipole controls the bandwidth and efficiency of the antenna.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the helpful suggestions received from Dr. Helmut Bureckmann and the assistance during measurements provided by Mr. Kenneth Murphy.

REFERENCES

1. H. Brueckmann, "Theory and Performance of Vehicular Center-Fed Whip Antenna," IRE Transactions on Vehicular Communications, VC-9, No. 3 . 10-20 (December 1960).

2. "Development of an Improved Center-Fed Whip Antenna," AVCO Corp., Final Report, No. 4, Contract DA 36-039 SC-90897 (3 Nov 1963).

3. W. P. Czerwinski, "Field-Intensity Efficiency of Vehicular-Antenna AT-912(XE-2)/VRC," USAEL Test Report 1564, Fort Monmouth, N.J., March 1964.

4. Report of USATECOM Product Improvement Test of "Improved Center-Fed Whip Antenna AT-912A/VR," Proj. Nr. 6-3-2310-01 (CE-3163), Hq., U. S. Army Airborne Electronics and Special Warfare Board, Fort Bragg, North Carolina, (31 October 1963).

5. E. C. Jordan, "Electromagnetic Waves and Radiating Systems," Prentice-Hall Electrical Engineering Series, Chapter 13, p. 463, 1961 Edition.

6. C. E. Smith and E. M. Johnson, "Performance of Short Antennas," Proceedings of the IRE, 35, October 1947.

7. W. P. Czerwinski, "Novel Antenna for 40 and 80 Meters," QST, December 1961.

8. A. G. Kandoian and W. Sichak, "Wide-Frequency-Range Tuned Helical Antennas and Circuits," Convention Record of the IRE, 1953 National Convention, Part 2, Antennas and Communications, pp. 42-47.

Figure 1. Antenna AS-1729( )/VRC installed on a 3/4-ton weapons-carrier vehicle.

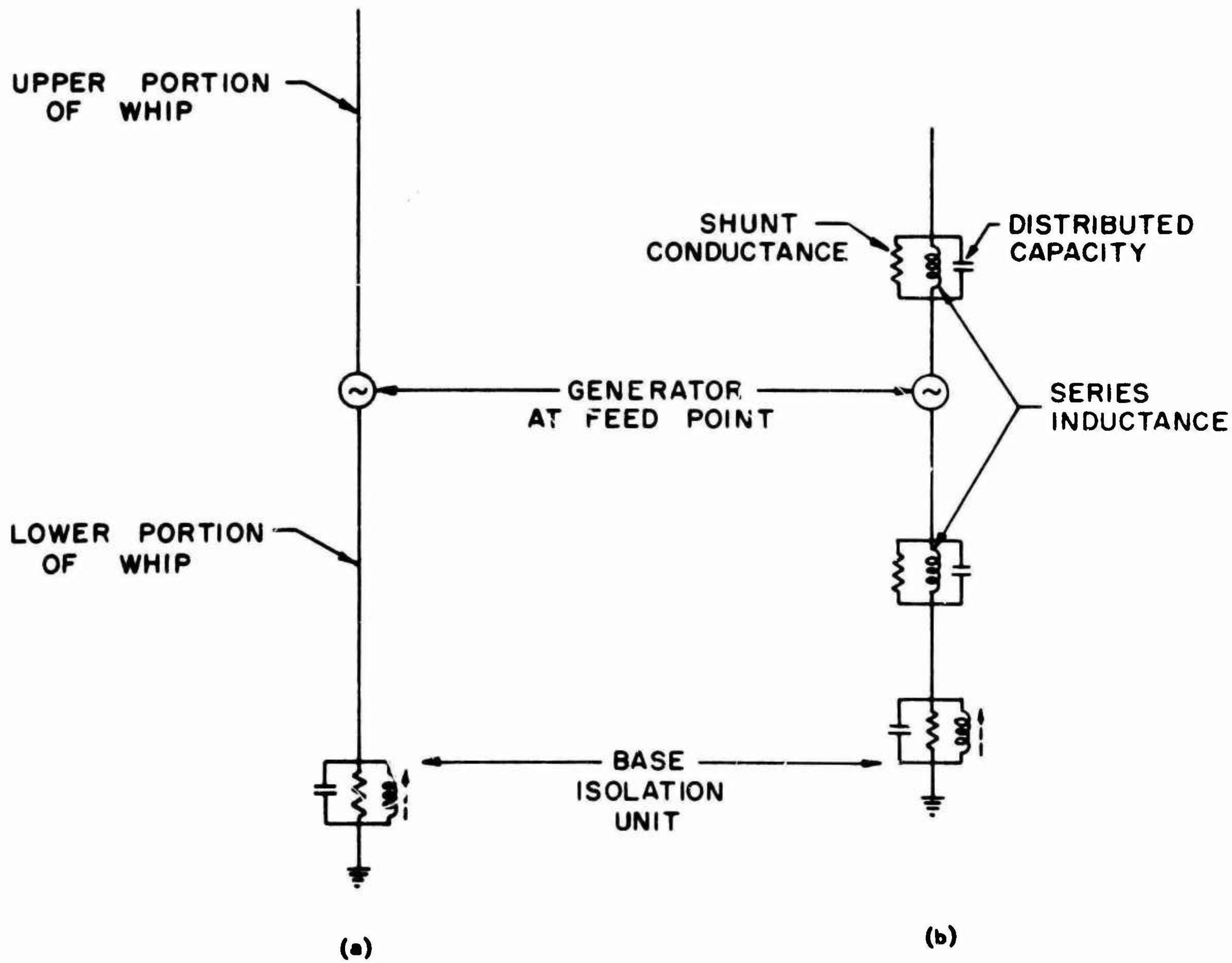


Figure 2. Simplified circuit elements in the center-fed whip antenna.

FORESHORTENED, CENTER-FED, BASE-ISOLATED VERTICAL ANTENNA

FOR 30 TO 76 MC.

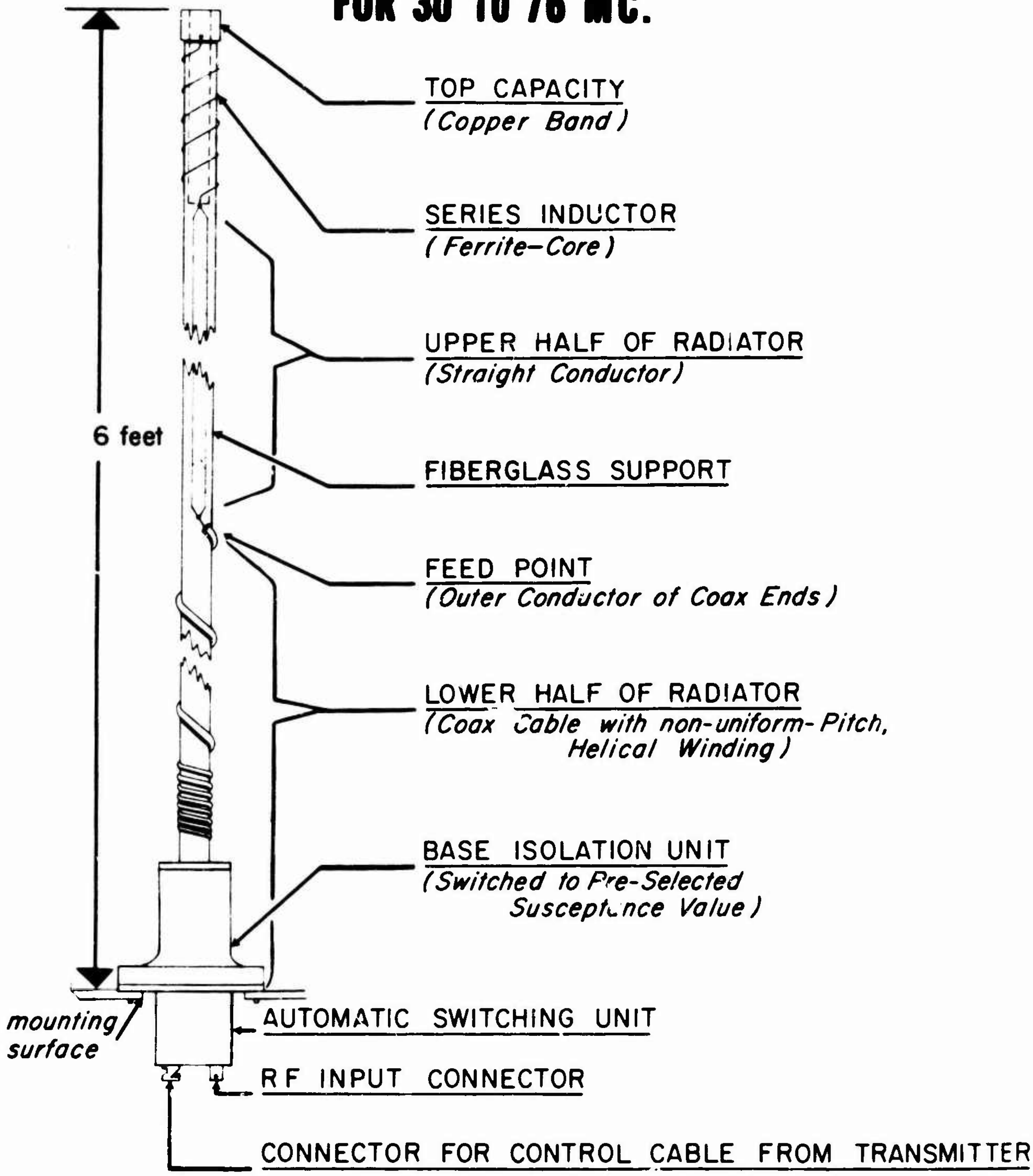


Figure 3.

IMPEDANCE AT INPUT BNC CONNECTOR, REF. TO 50 OHMS

● WITH 10' WHIP MOUNTED ON 3/4 TON WEAPONS CARRIER

▲ WITH 6' WHIP MOUNTED ON 3/4 TON WEAPONS CARRIER

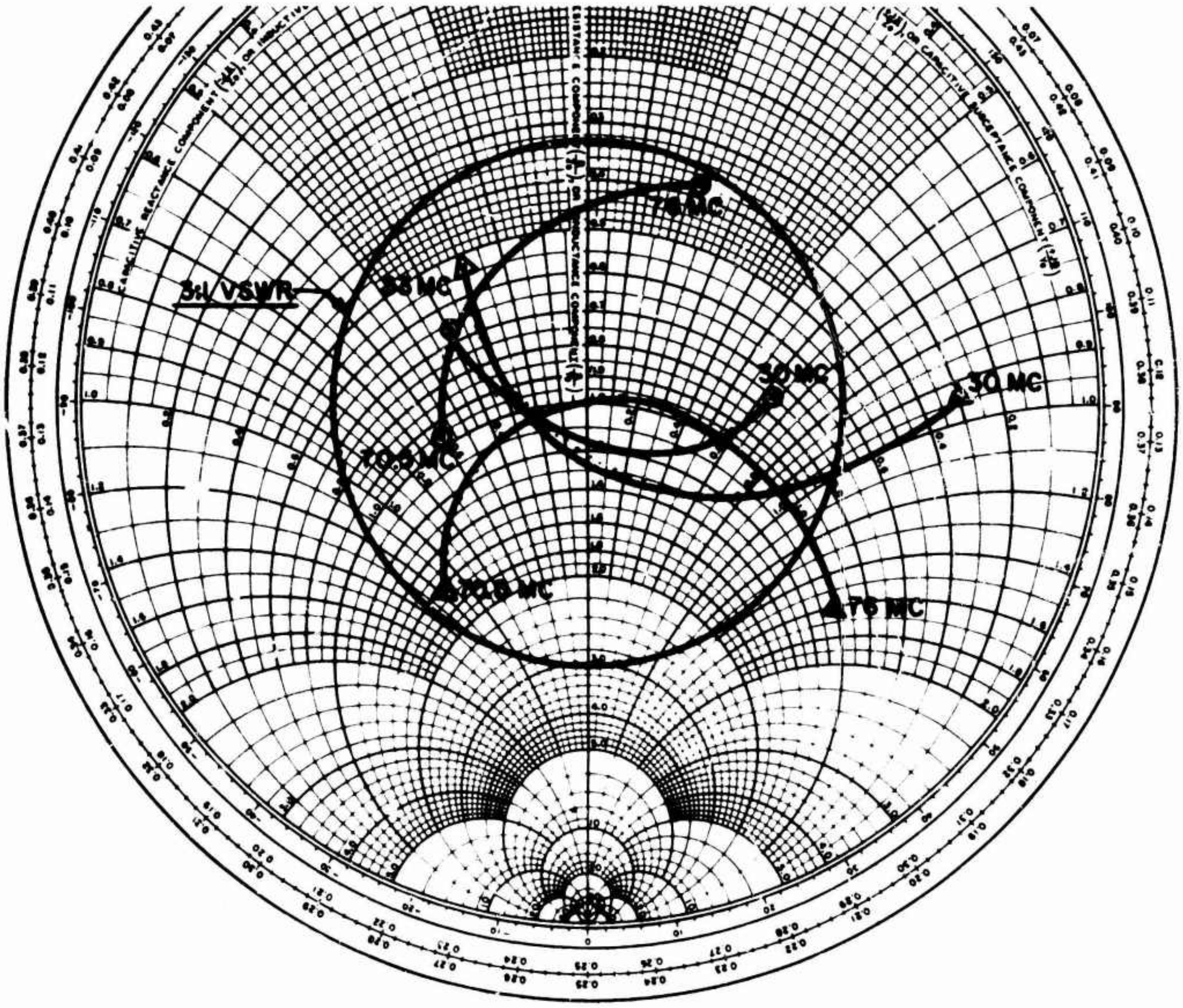


Figure 4.

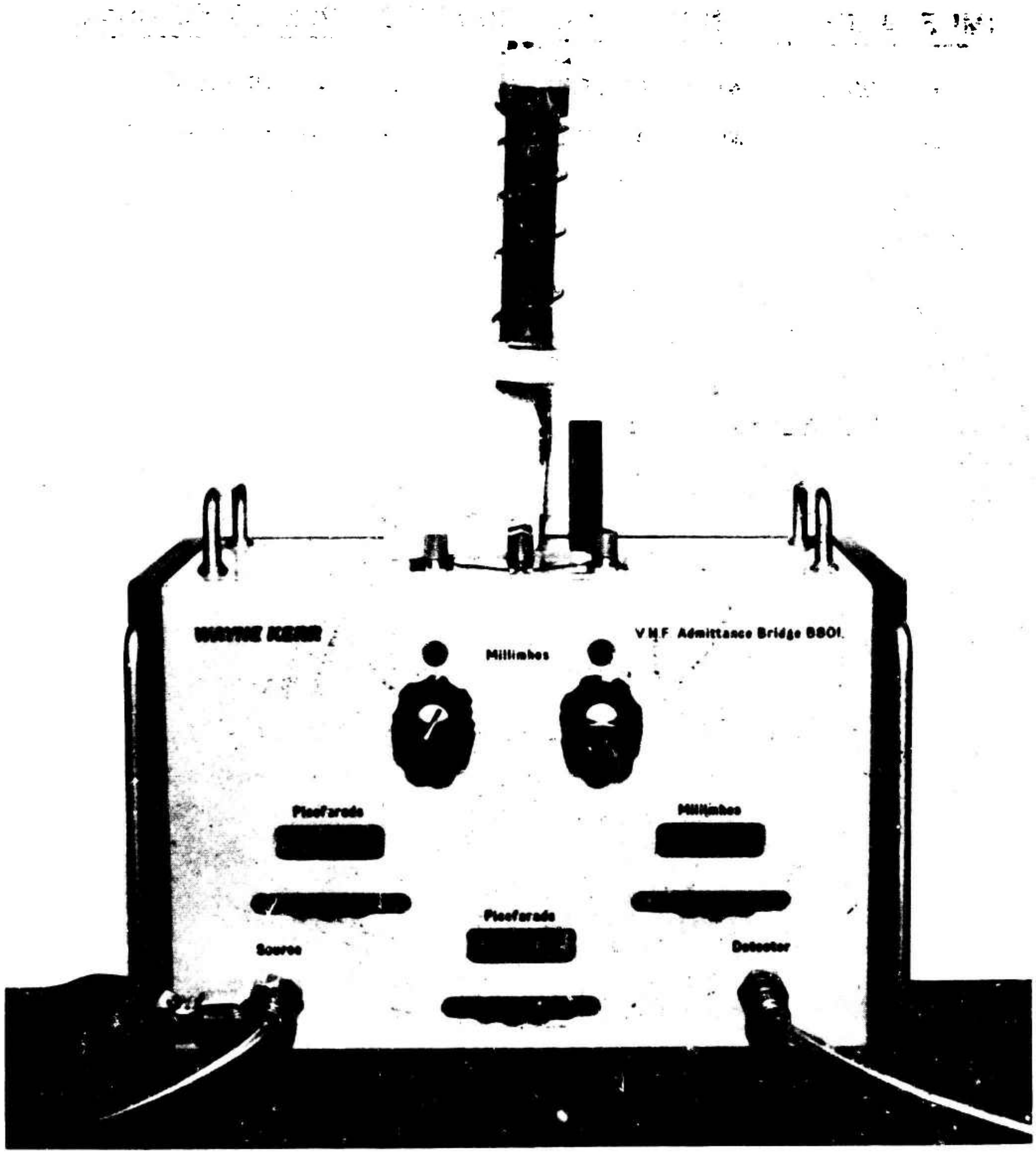
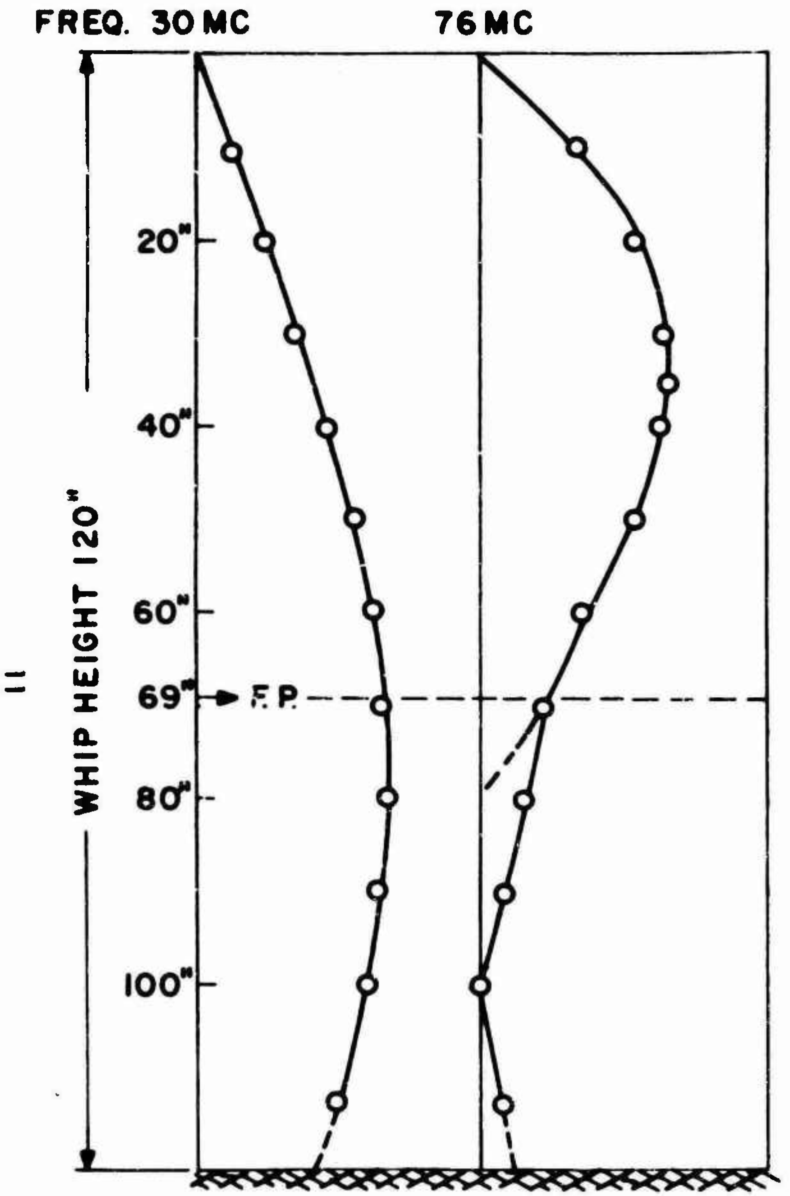
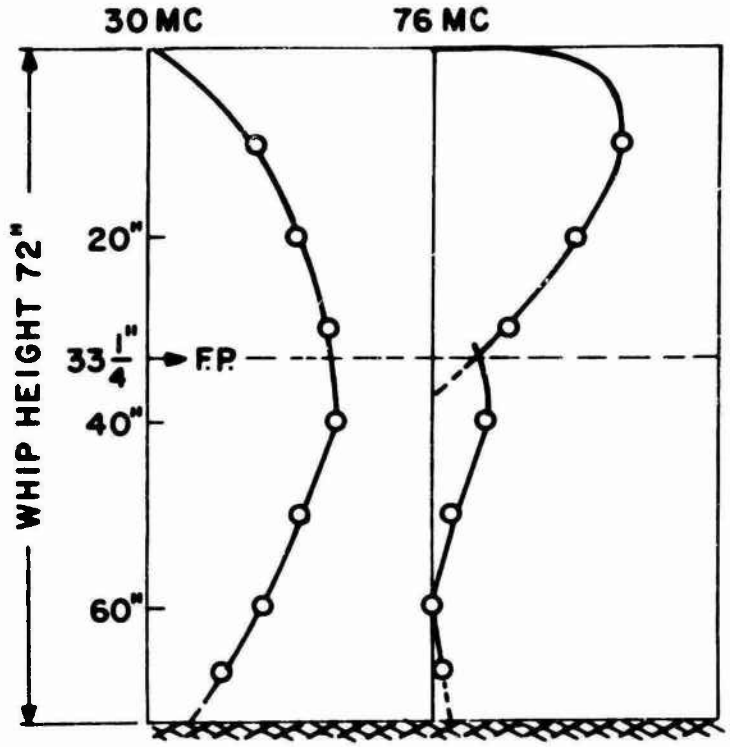


Figure 5. Setup used in measuring the lumped circuit termination designed to represent $\lambda/8$ at 76 Mc.



MEASURED CURRENT DISTRIBUTION
ON WHIP OF ANTENNA AS-1729( )/VRC



MEASURED CURRENT DISTRIBUTION
ON FORESHORTENED WHIP
(FINAL MODEL)

Figure 6.

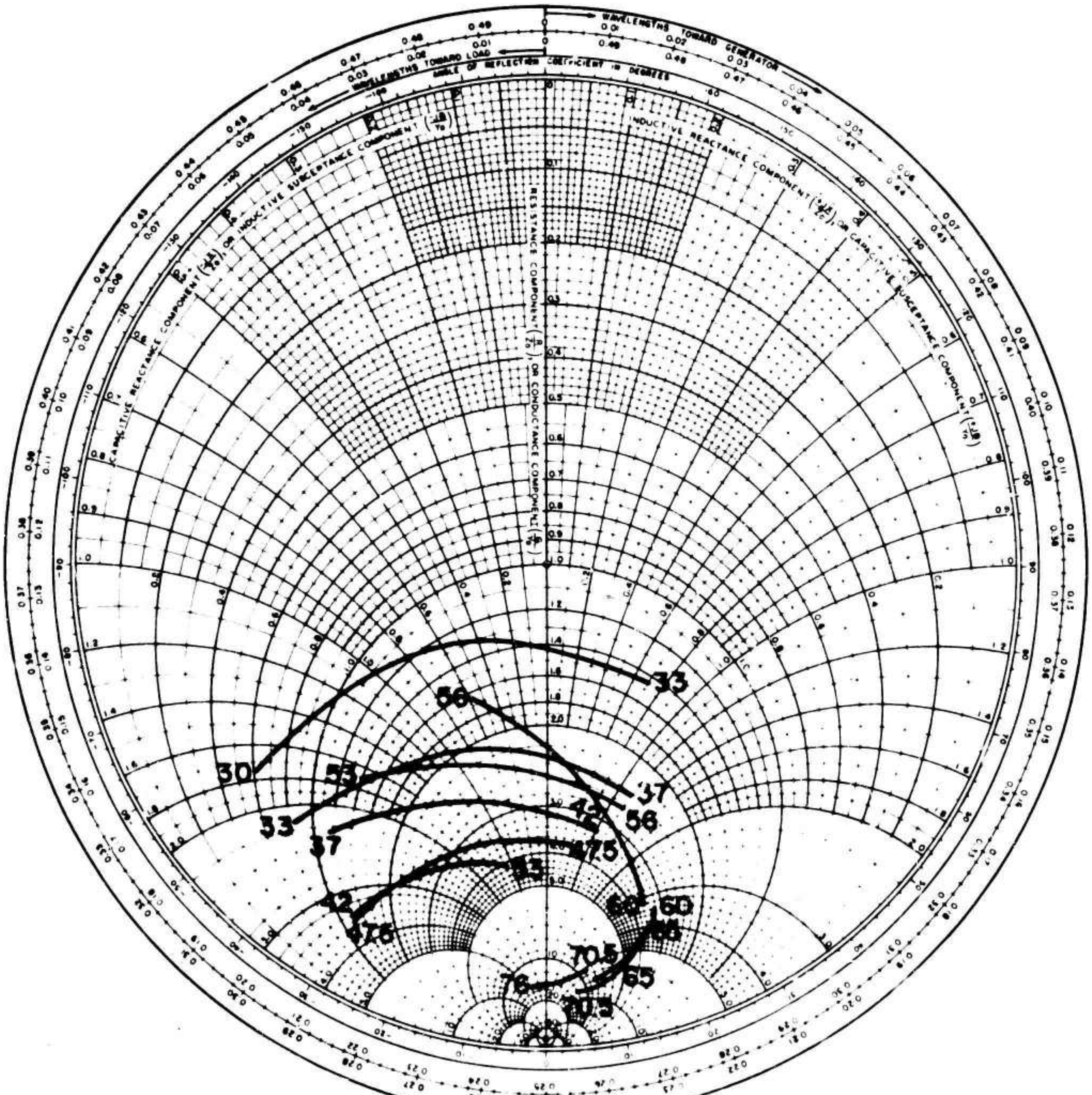


Figure 7. Feed-point impedance of Antenna AS-1729( )/VRC (used as target values for the foreshortened center-fed whip).

Figure 8. Close-up view of the helical-wound transformer cable in the final model of the foreshortened center-fed whip.

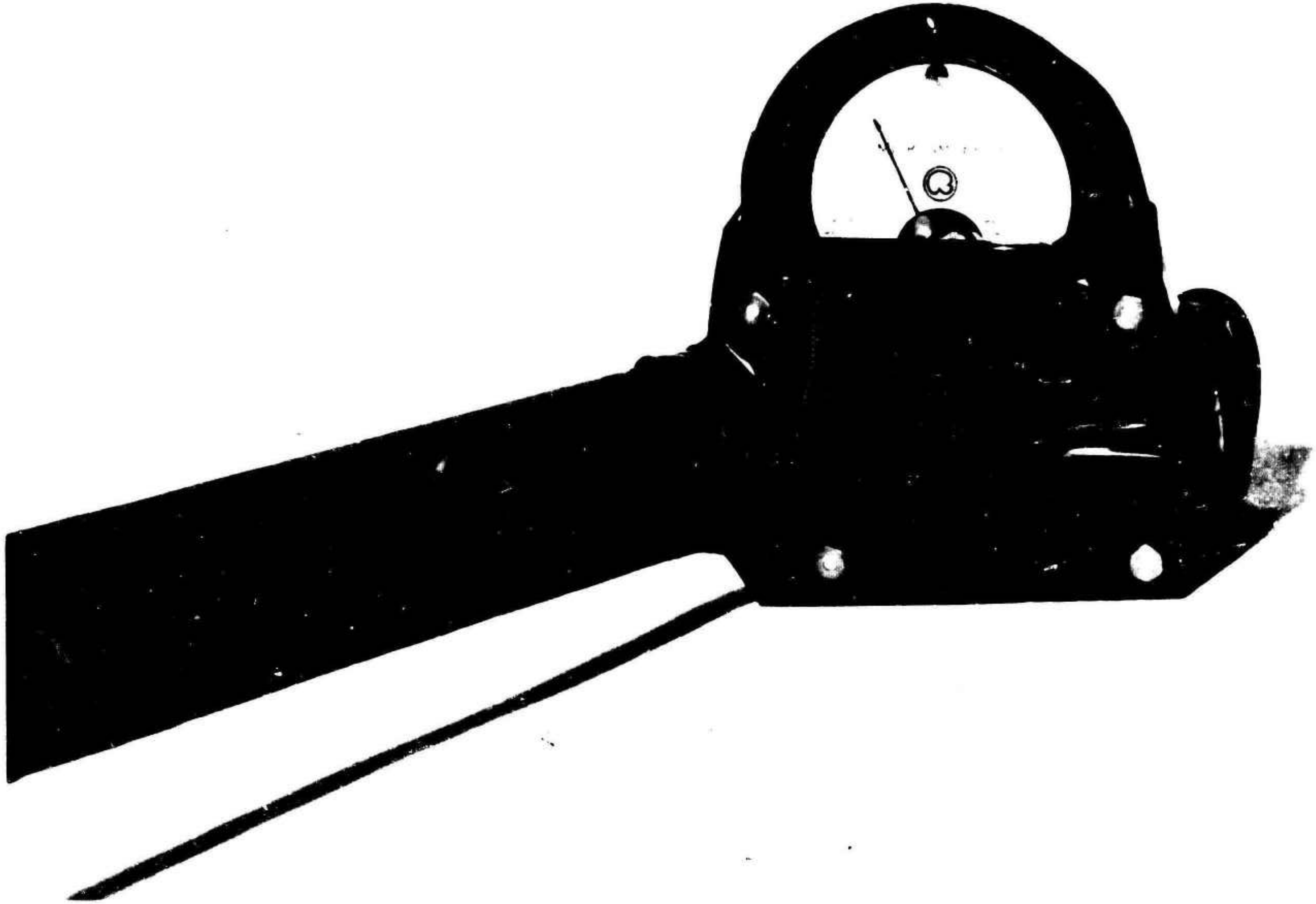


Figure 9. Current distribution probe used to measure current amplitude along the antenna whips.

Figure 10. Back view of current measuring probe.

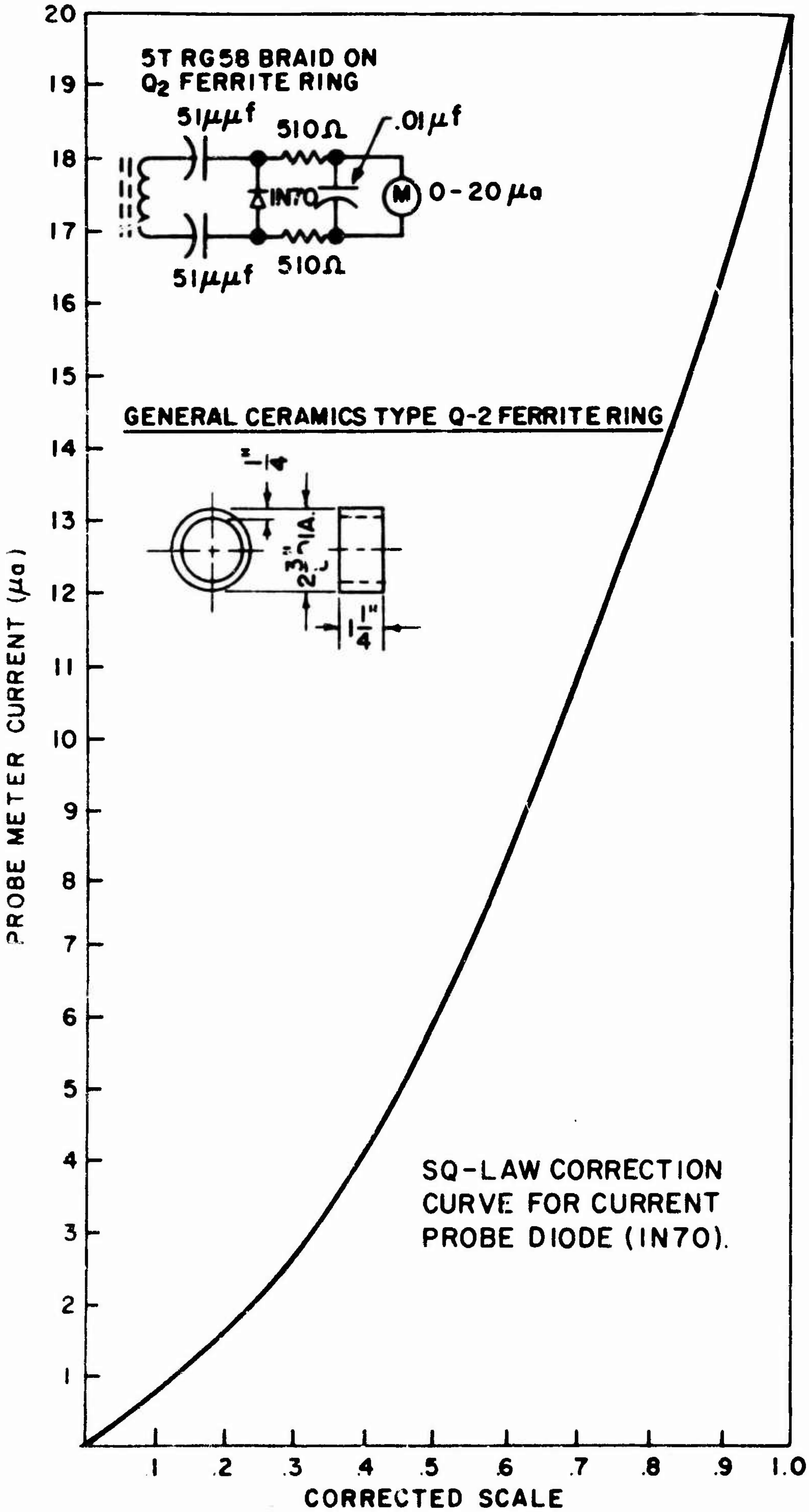

5T RG58 BRAID ON
Q_2 FERRITE RING
51μμf
510Ω
.01μf
IN70
0-20μa
51μμf
510Ω
GENERAL CERAMICS TYPE Q-2 FERRITE RING
SQ-LAW CORRECTION CURVE FOR CURRENT PROBE DIODE (IN70).
PROBE METER CURRENT (μa)
CORRECTED SCALE
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

Figure 11.

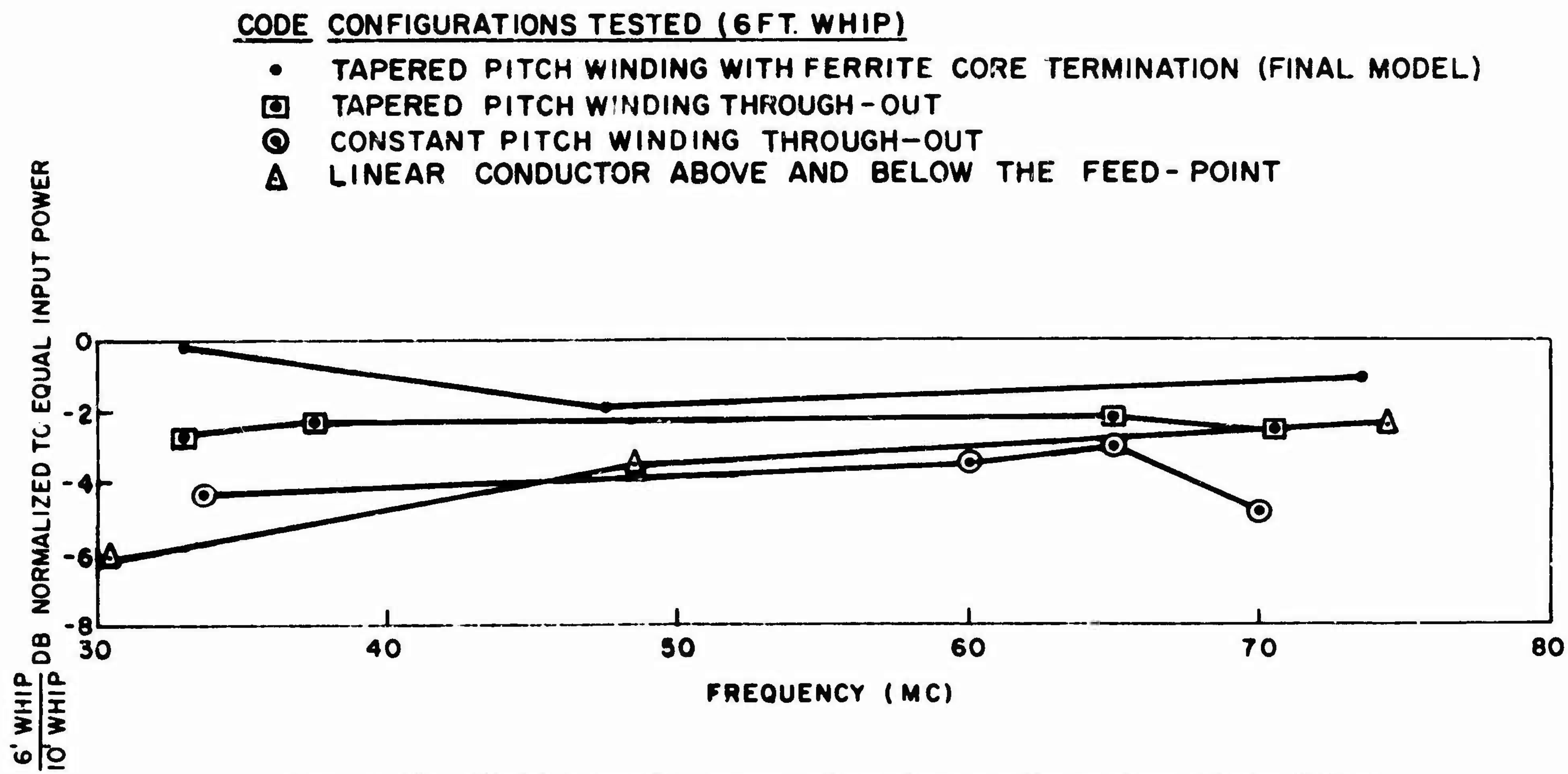


Figure 12. Field intensity curves of various configurations of the 6-foot foreshortened whip versus the 10-foot whip of Antenna AS-1729( )/VRC.

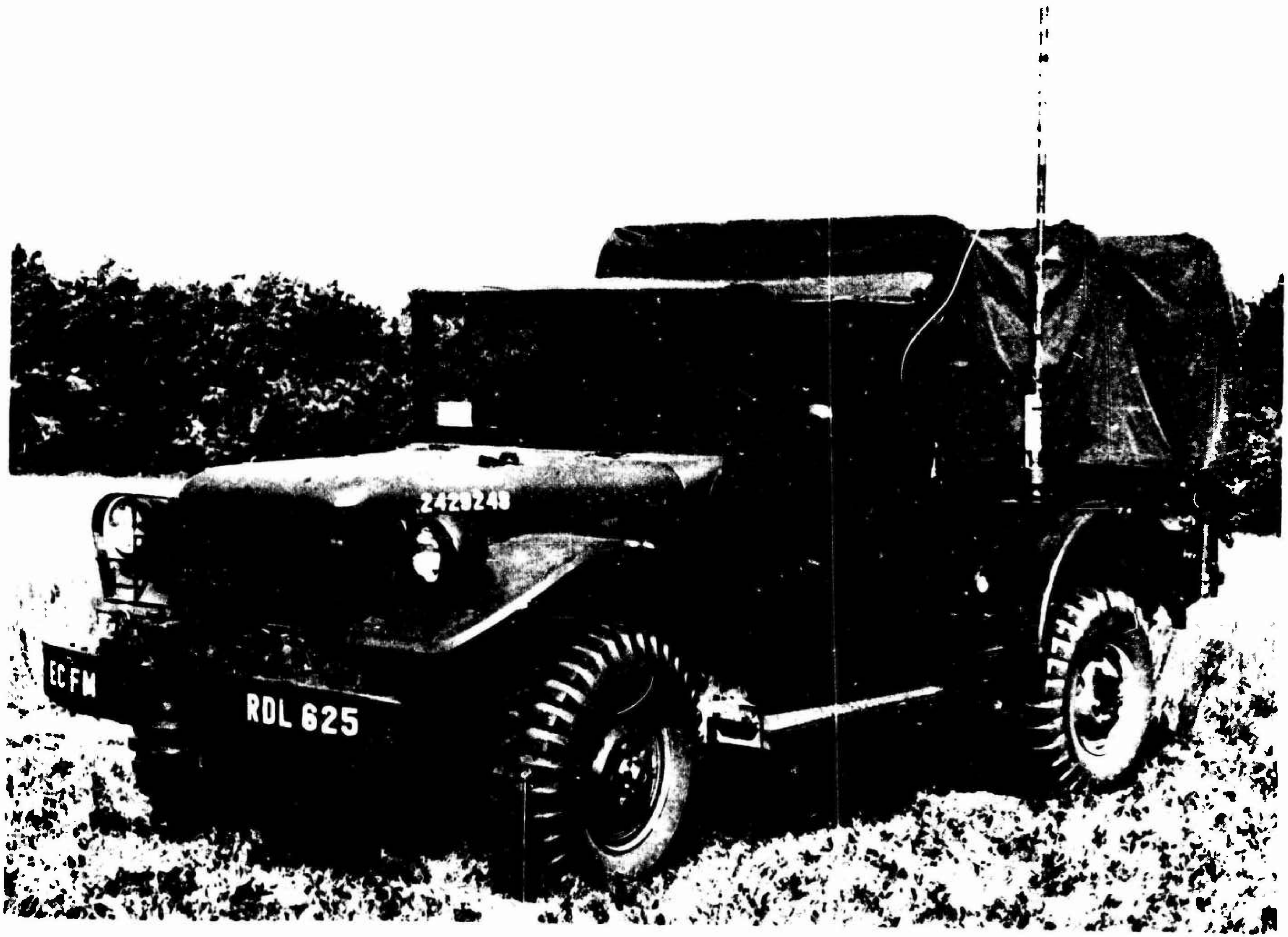


Figure 13. Experimental foreshortened center-fed whip installed on a 3/4-ton weapons-carrier vehicle.

ADMITTANCE AT BASE ISOLATION UNIT OF ANTENNA AS-1729( )/VRC

Measured at high-impedance end with whip and spring removed. (Wayne Kerr Admittance Bridge Model B-801).

SUB-BAND	FREQ(MC)	$\frac{B}{2\pi F}$ (picofarads)	G (Millimhos)
1	30	+21.1	.04
1	33	+23.3	.05
2	33	+10.6	.05
2	37	+12.2	.05
3	37	+ 3.2	.07
3	42	+ 7.0	.08
4	42	- 2.0	.08
4	47.5	+ 2.2	.11
5	47.5	- 4.6	.10
5	53	- 0.2	.08
6	53	- 3.5	.10
6	56	- 1.8	.10
7	56	- 5.2	.11
7	60	- 2.8	.15
8	60	- 5.3	.16
8	65	- 2.5	.20
9	65	- 8.0	.24
9	70.5	- 5.4	.30
10	70.5	- 9.4	.24
10	76	- 6.6	.25

TABLE I

FIELD INTENSITY MEASUREMENTS AT APPROX. 3/4 MILE RANGE THROUGH LIGHT WOODS & DIRT ROADS.

SUB-BAND	FREQ. (MC)	MEASURED "E"	MEASURED $\frac{G}{Y_o}$	"G" ($\frac{G}{Y_o} \cdot .02$)	INPUT POWER $E^2 \cdot G$	CORRECTION FOR EQUAL INPUT $10 \log_{10} \frac{P_1}{P_2}$ DB	MEASURED FIELD INTENSITY (DB ABOVE 1 μV)	FIELD INTENSITY NORMALIZED TO EQUAL INPUT POWER (DB)	$\frac{6' \text{WHIP}}{10' \text{WHIP}}$ (DB)	WINDING CABLE TRANSMISSION LOSS (DB)
FORESHORTENED 6' WHIP (P_1)										
1	33.0	8.3	1.05	2.1×10^{-2}	1.445	+2.8	35.0	37.8	-.2	.2
4	47.5	14.5	.54	1.08×10^{-2}	2.27	+.4	40.5	40.9	-1.9	.4
10	73.5	7.3	1.35	2.7×10^{-2}	1.435	-.3	28.4	28.1	-1.1	.4
REFERENCE 10' WHIP (P_2)										
1	33.0	7.4	2.50	5×10^{-2}	2.74		38.0	38.0		
4	47.5	15.0	.55	1.1×10^{-2}	2.48		42.8	42.8		
10	73.5	12.0	.46	$.92 \times 10^{-2}$	1.325		29.5	29.5		

TABLE 2

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

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

1 ORIGINATING ACTIVITY (Corporate author) U. S. Army Electronics Command Fort Monmouth, N. J.	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP

3 REPORT TITLE

A FORESHORTENED CENTER-FED WHIP ANTENNA

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5 AUTHOR(S) (Last name, first name, initial)

Czerwinski, Watson P.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
January 1965	20	8

8a CONTRACT OR GRANT NO. b PROJECT NO 1PO-14501B31A c Task No. -00 d Subtask No. -45	9a ORIGINATOR'S REPORT NUMBER(S) ECOM-2549 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 AVAILABILITY/LIMITATION NOTICES

QUALIFIED REQUESTORS MAY OBTAIN COPIES OF THIS REPORT FROM DDC.
THIS REPORT HAS BEEN RELEASED TO OTS.

11 SUPPLEMENTARY NOTES Investigation of losses in a reduced-height helical-wound vertical dipole.	12 SPONSORING MILITARY ACTIVITY U.S. Army Electronics Labs., AMSEL-RD-X U.S. Army Electronics Command Fort Monmouth, N. J. 07703

13 ABSTRACT

An experimental investigation was conducted to determine whether the degradation in electrical performance commonly observed with reduced-height helical wound vertical dipoles can be avoided. A new design approach has been explored which helped define a major cause of this degradation. Data obtained during this investigation supports a working hypothesis that losses associated with circulating currents in the capacitance between turns of a helically wound, electrically short vertical dipole greatly reduce antenna bandwidth and efficiency. A six-foot-high experimental model was constructed and tested as a replacement for the 10-foot whip of Antenna AS-1729( )/VRC. The design of this foreshortened model minimized circulating current losses throughout the operating band of 30 to 76 Mc and resulted in an average efficiency of 90% compared to the 10-foot whip. (Author).

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Foreshortened Dipole						
Inductively Loaded Whip						
VHF Antenna						
Short Dipole						
Center-Fed Whip Antenna						
Optimized Efficiency						
Optimized Bandwidth						
Taper Wound Helical Antenna						
Base-Isolated Whip						
Stored Energy in an Antenna						
Distributed Winding Inductance						
Capacitance Between Turns						
Losses in Short Antenna						
Vertical Dipole Antenna						
Antenna AS-1729( )/VRC, Vehicular, VHF						

INSTRUCTIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

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

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

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

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

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