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12 Oct 53

WADC TECHNICAL REPORT 52-194

ANTENNA COUPLER CU-215/APT
(Balancing Transformer)

LUCIEN A. REGNIER
AIRCRAFT RADIATION LABORATORY

AUGUST 1952

Statement A
Approved for Public Release

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Lucien A. Regnier
Aircraft Radiation Laboratory

August 1952

RDO No. 112-110

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report describes the design of Antenna Coupler CU-215/APT (Balancing Transformer). The equipment was designed and tested by Mr. Lucien A. Regnier, of Antenna Design Section, Aircraft Radiation Laboratory, as a sub-project of Research and Development Order No. 112-110, "Flush-Mounted Antennas for Guided Missiles and New Aircraft." Mr. Lucien Regnier was project engineer on the work conducted.

Acknowledgement is gratefully made to the following WADC personnel: to Mr. Robert Rawhouser for mathematical assistance; to Mr. Warren S. D. Leland and Mr. Everett O. Miller for fabrication and suggested mechanical design of the experimental model; to Mr. John S. Brown for drawing and final mechanical design of the balancing transformers. Acknowledgement is also made to Mr. John Albano, formerly of Aircraft Radiation Laboratory, for help and advice in the design of the equipment.

ABSTRACT

The design, development, and testing of a transformer to convert an unbalanced to a balanced transmission line are described. Application of known principles has resulted in a transformer of broad frequency range. There is, also, a brief mathematical explanation of the theory involved in the procedure. An impedance match with a voltage standing wave ratio of 2:1 or less was obtained. Although two 50-ohm dummy loads were used in the design, application of the transformer with loads which have a mismatch of not greater than 2:1 voltage standing wave ratio proved satisfactory.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

for CLARENCE H. LEWIS
Colonel, USAF
Chief, Aircraft Radiation Laboratory
Directorate of Laboratories

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INTRODUCTION

In order to obtain more complete pattern coverage, it is sometimes necessary to install two antennas, using unbalanced transmission lines or coaxial cable, one on each side of the airplane, both excited from the same source and complementing each other. A balancing transformer converts the unbalanced transmission line to a balanced transmission line. One of these two conductors of the balanced line becomes the inner conductor of one unbalanced transmission line and the other conductor becomes the inner conductor of another unbalanced transmission line. The currents in the two unbalanced lines maintain the same relation as the currents in the two balanced conductors, or, in other words, 180° out of phase. Incorporated in the balancing transformer is an impedance-matching network which maintains an impedance match with a 50-ohm transmission line of a voltage standing wave ratio of not over 2:1 over the respective frequency band.

SECTION I

DISCUSSION OF THE MECHANICAL CONSTRUCTION

Factual Data

The balancing transformer which was developed in the course of this study is shown on Air Force Drawing No. 49C14638. The unit is in the form of a cross whose over-all dimensions are approximately 1 in. in diameter, 8 in. in length on the long member, and 5 in. in length on the short member. It is constructed of brass and Textolite (1422) dielectric and weighs approximately 6.37 lbs. It complies with joint Army-Navy Specification AN-E-19.

Description

The balancing transformer consists of a brass tube 6-1/2 in. long with the outer diameter 1.00 in. and the inner diameter .944 in. One end of the tube is fitted with a type LN connector. The other end of the tube is closed. The pin of the connector forms the end of a brass rod of .093 in. diameter, which is the inner conductor and extends half of the length of the tube and is centered in the tube.

Around the .093 in. rod is a dielectric tube of .359 in. outer diameter. The dielectric tube is also inside of a brass tube of outer diameter .409 in. and inner diameter .359 in. and extends half of the length of the larger tube. The impedance between the rod of .093 in. diameter and the smaller brass tube is 50 ohms. Also, the impedance between the smaller brass tube and the larger brass tube is 50 ohms.

The end of the brass rod of .093 in. diameter is connected to a tube of .409 in. outer diameter which extends the other half of the larger tube.

The two balanced conductors are connected opposite each other, normal to the tube and at a midpoint of the length of the tube. The length of each balanced conductor is 1.39 in. plus the type LN connector. The diameters of the balanced conductors are such that each is 34 ohms impedance.

SECTION II

DISCUSSION OF THEORY

The purpose of a balancing transformer is to convert an unbalanced transmission line to a balanced transmission line, or vice versa. In order to outline the theory of a balancing transformer, it is first necessary to consider the operation of a simple unbalanced transmission line. In such a transmission line, there exist currents on both the outer surface of the inside conductor and the inner surface of the outside conductor. The current on the inner conductor of a coaxial line is theoretically equal and opposite to the current on the outer conductor. Likewise, for the proper operation of a balancing transformer, the same relationship in current amplitude and phase must be maintained between the two balanced lines. (See Fig. 1a.)

If a skirt is placed over the coaxial line, shorted to the outer conductor at one end and open at the other end, which is a quarter wave in length as shown in Fig. 1b, or $\lambda/4$ where λ is the wavelength, the impedance between the open end of the skirt and the outer conductor of the coaxial line is infinite at one frequency; that is, between points B and C. At other frequencies, the impedance is equal to $Z = Z_o \text{ Tan } (2\pi l/\lambda)$ or $Z_o \text{ Tan } \theta$ where Z_o is the characteristic impedance between the skirt and the outer conductor and θ is the electrical length of this section. When θ is equal to $\lambda/2$, there is a direct short between the open end of the skirt and the outer conductor, or points B and C.

Furthermore, the points on the inner and outer conductors of the coaxial line one quarter wavelength from the shorted ends are isolated in space. It is only necessary then to form two transmission lines: the inner conductor of one connected to the inner conductor of the coaxial line and the inner conductor of the other connected to the outer conductor of the coaxial line, as shown in Fig. 1c. The currents in the two additional transmission lines will be equal and the phase relation maintained.

By extending the length of the skirt an additional quarter wave and shorting the extended end to the inner conductor of the coaxial line, which for the additional section has become equal in diameter to the outer diameter of the coaxial line,--as shown in Fig. 1d--the impedance between the inner conductor of the coaxial line and the skirt is equal to the impedance between the outer conductor of the coaxial line and the skirt or infinite at one frequency. The extension of the outer skirt puts its impedance in series with the impedance of the other quarter wave section; that is, doubles the impedance of the shorted shunt section. This condition permits broader bandwidth as shown in Paragraph entitled "Calculation" on page 6 of this report.,

In order that there be maximum power transfer, the impedance of the balanced lines must be matched to the impedance of the unbalanced lines. The input impedance must be nearly equal to the load impedance with no more than 2:1 voltage standing wave ratio over the frequency band specified.

The logical procedure in designing a matching network is to measure the impedance characteristics first of the unit when it is terminated in the load impedance and calculate the dimensions of the network from the data. But, in this case it is impossible, because there is already a shorted shunt section formed by the outer skirt of the balancing transformer and the outer conductor of the coaxial transmission line. The diameters of this shorted shunt section must still be determined.

From the transmission line equation

$$Zin = Zo' \frac{Z_l + j Zo' \text{ Tan } \theta}{Zo' + jZ_l \text{ Tan } \theta}$$

Where Z_l is the load impedance; Zin is the input impedance; Zo' is the characteristic impedance of the line transformer; θ is the electrical length of the line transformer. It is shown below that when θ equals 90°, the tangent of the angle is infinite and the characteristic impedance of the line transformer

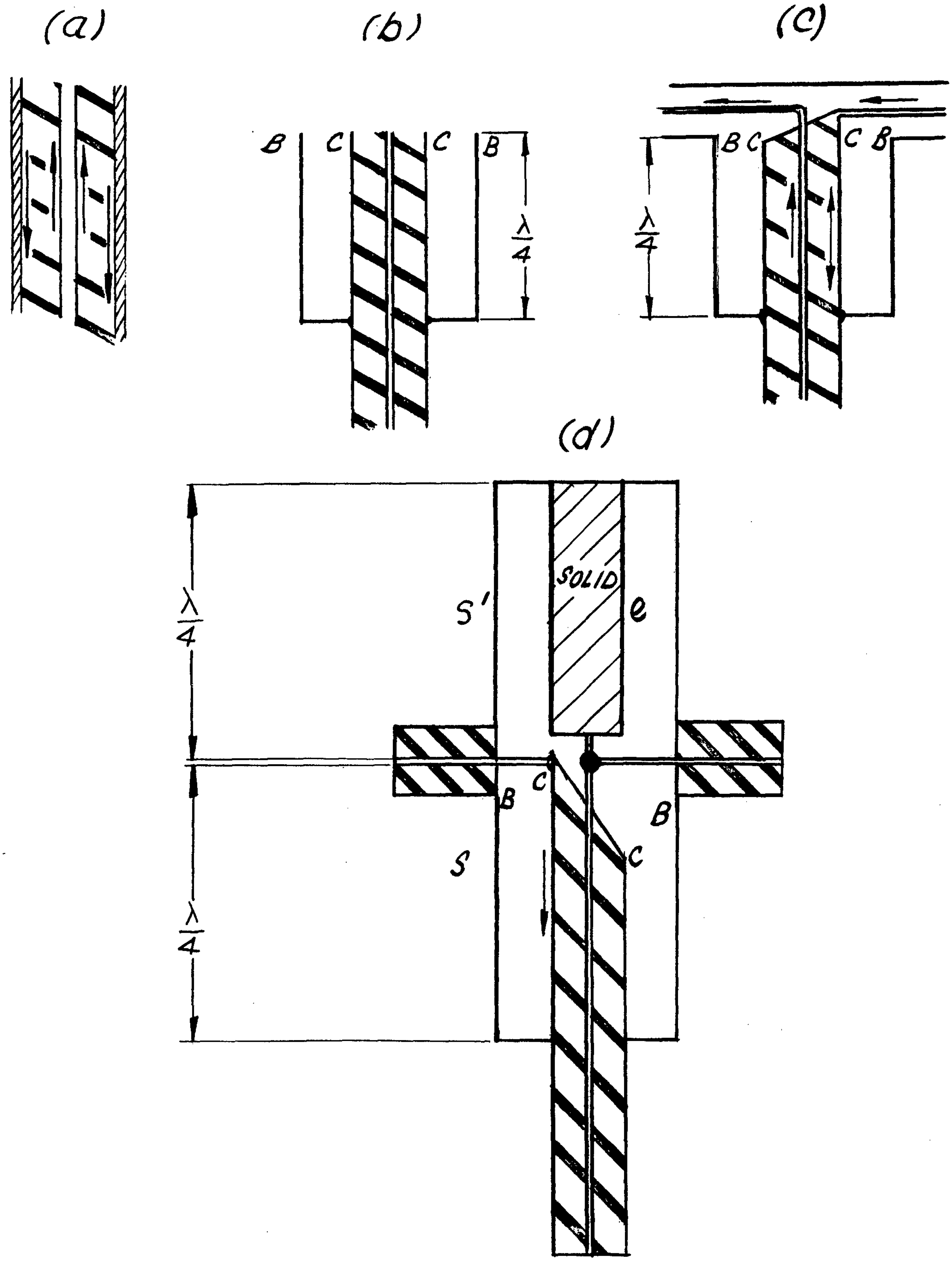

Figure 1. Development of Antenna Coupler CU-215/APT From a Transmission Line

equals the square root of the product of the load impedance and the input impedance. The input impedance is matched to the load impedance by a line transformer one quarter wave in length.

$$Zo' = \sqrt{Zin \; Z_1}$$

Explanation of Formula

$$Zin = Zo' \frac{Z_e + Zo' \; \mathrm{Tan}\,\theta}{Zo' + jZ_e \; \mathrm{Tan}\,\theta}$$

Where Zin is the impedance at the input of the line transformer, Z_e the impedance of the antenna, Zo' the characteristic impedance of the line transformer, and θ is the electrical length of the line transformer.

Divide numerator and denominator by Tan θ.

Then:

$$Zin = Zo' \frac{\frac{Z_e}{\mathrm{Tan}\,\theta} + jZo'}{\frac{Zo'}{\mathrm{Tan}\,\theta} + jZ_e}$$

As θ approaches 90°, Tan θ approaches infinity. A finite number divided by infinity is zero.

$$Zin = Zo' \left(\frac{jZo'}{jZ_e} \right)$$

The j's cancel

$$Zin = \frac{Zo'^2}{Z_e}$$

$$Zo' = \sqrt{Zin \quad Z_e}$$

It is therefore possible to determine theoretically the dimensions of the matching network. For, it is known that at one frequency where the length of the line transformer is one quarter of the wavelength, the reactance is zero. At other frequencies, the electrical length of the line transformer, maintaining the same physical length, will no longer be a quarter wavelength. The ratio of the mismatch is Z_1/Zin. By rotating this ratio on a Smith chart through a quarter wave, it is readily seen that the load impedance and the input impedance are matched. The impedance characteristics at other frequencies are obtained by rotating the ratio through the respective fraction of a wavelength. The impedance curve for frequencies each side of the resonant frequency can be plotted. Since it is more convenient to design a parallel section, the admittance curve for a 70 ohm line transformer is shown in Table I. From these data, the impedance of the shorted shunt section can be determined, as the

TABLE I

THEORETICAL DATA FOR MATCHING NETWORK FOR ANTENNA COUPLER CU-215/APT

Z_o = 70 Ohms (Series) Z_o = 100 Ohms (Shunt)

Freq	Air	1/	R/Z_o	X/Z_o	R	X	R^2	X^2	$R^2 + X^2$	$\times 10^{-2}$ G	$\times 10^{-2}$ B	θ	Cot.θ	B	B
475	63 cm	.110	1.00	-.38	70	-26.6	4900	707.5	5607.5	1.24	+.474	39.6°	1.2088	-1.208	-.734
500	60	.116	.97	-.37	67.9	-25.9	4610	670.8	6280.8	1.28	+.49	41.7°	1.1224	-1.122	-.632
600	50	.139	.88	-.33	61.6	-23	3794	529	4323	1.42	+.53	50.04°	.8391	- .839	-.339
700	45	.1548	.83	-.29	58	-20.3	3364	412	3776	1.53	+.537	55.72°	.68173	- .68	-.143
800	37.5	.1858	.75	-.20	52.5	-14	2756	196	2952	1.77	+.47	66.88°	.42722	-.427	+.043
900	33.3	.209	.72	-.13	50.4	-9	2540	81	2621	1.92	+.34	75.24°	.26359	-.263	+.077
1000	30	.232	.70	-.06	49	-4	2401	16	2417	2.02	+.165	83.5°	.1139	-.1139	+.051
1075	27.9	.25	.704	0	49.2	0	2420	0	2420	2.03	0	90°	0	0	0
1100	27.2	.256	.69	+.02	48.3	+1.4	2332	1.96	2333.9	2.06	-.059	92.16°	.03929	+.039	-.02
1200	25	.278	.71	+.09	49.7	+6.3	2470	39.6	2509.6	1.98	-.25	100°	.17933	+.179	-.071
1300	23.07	.302	.74	+.17	51.8	+11.9	2683	14.1	2697	1.92	-.44	108.7°	.33848	+.338	-.102
1400	23.4	.325	.77	+.24	53.9	+16.8	2905	282.2	3817.2	1.69	-.527	117°	.50953	+.509	-.018
1500	20	.348	.84	+.30	58.8	+21	3457	441	3898	1.50	-.538	125°	.70021	+.700	+.162
1600	18.75	.371	.93	+.35	65	+24.5	4225	600.2	4824.2	1.34	-.507	133.5°	.94896	+.948	+.441
1675	17.9	.389	1.00	+.37	70	+25.9	4900	670.8	5570.8	1.25	-.464	140°	1.1918	+1.191	+.727

1 = 6.97 cm. at 1075 Mc.

$\theta = 2\pi l/\lambda$

length is already known, being one quarter wavelength at the resonant frequency. The effect of the shorted shunt section is plotted in Fig. 2. With the impedance of the shorted shunt section known, the diameter of the outer skirt of the balancing transformer can be calculated from the formula

$$Z = 138 \,(\log.\ d/D)$$

Where d is the outer diameter of the coaxial transmission line and D is the inner diameter of the skirt.

The theoretical calculated data for the line transformer and the shorted shunt section are shown in Table I.

SECTION III

DISCUSSION OF CALCULATION AND THEORETICAL DESIGN PROCEDURE

Design Procedure

The admittance curve for the theoretical line transformer was plotted, as shown in Fig. 2 for the frequencies from 475 to 1675 megacycles. This shows the effect of the line transformer. To determine the impedance of the shorted shunt section, the following equation is used.

$$BZ_o = \text{Cot.}\ \theta$$

Where B is the greatest numerical value of the susceptance; that is, the highest point on the admittance curve of the line transformer. θ is the electrical length of the shorted shunt section for that particular frequency which is known. Z_o, which is to be determined, is the impedance of the shorted shunt section. The equation is solved for Z_o.

Calculation

From Table I at the frequency 700 megacycles, which is the highest point of the admittance curve.

$B = -.537$ $\qquad$ $1/\lambda = .1548$

$\theta = 360° \times .1548 = 55.72°$

$\text{Cot.}\ \theta = .68173$

$$Z_o = \frac{.68173 \times 10^{-5}}{537 \times 10^{-5}} = 126.9 \text{ ohms}$$

For convenience, 100 ohms was chosen for the impedance Z_o.

the impedance of the shorted shunt section.
For the equation $Z_o = 138 \log.\ d/D$

d is the smaller diameter which is known (that is, the outer diameter of the coaxial line). As there are two shunt sections in series, Z_o is 100/2 or 50

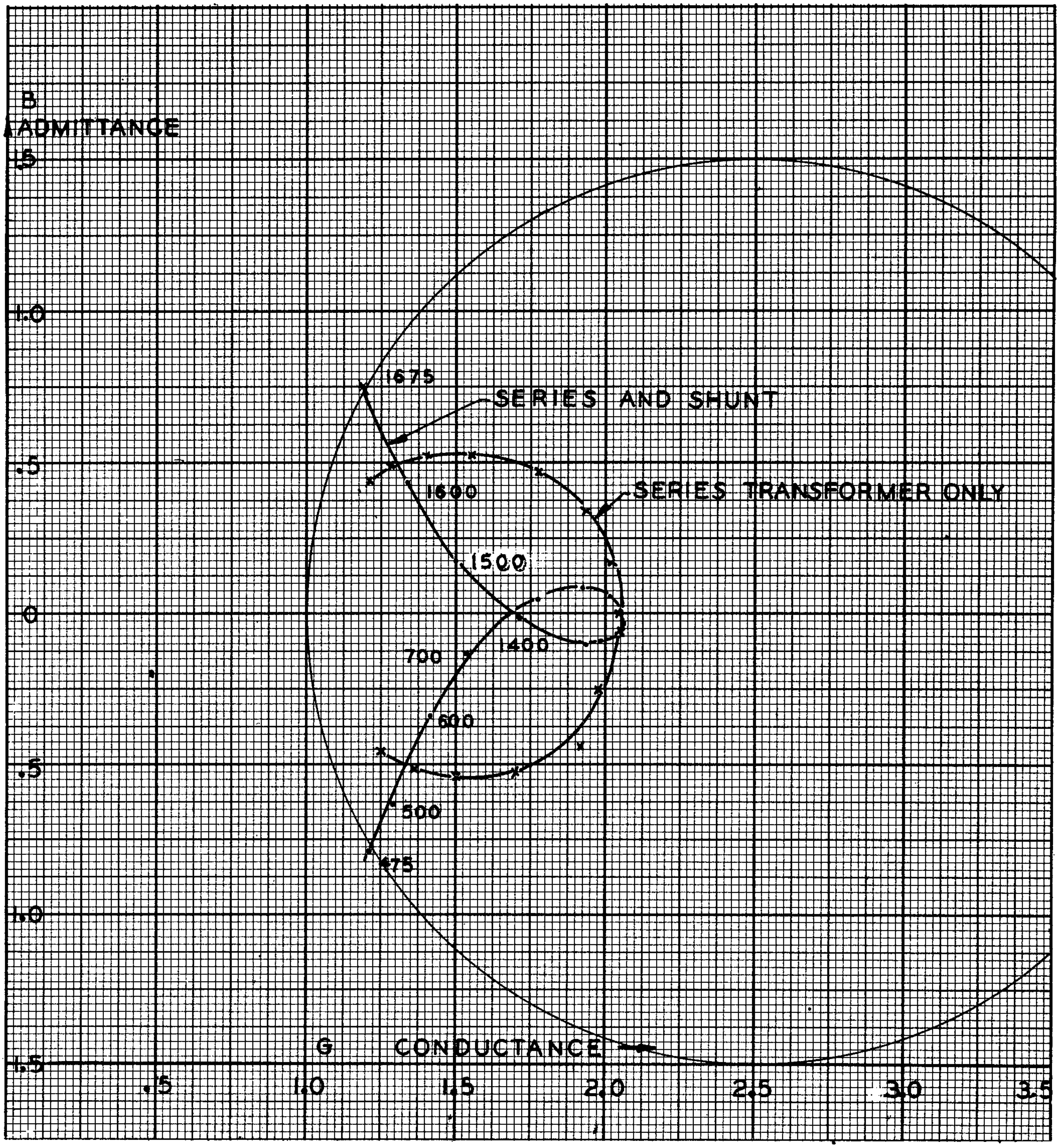

Figure 2. Admittance Curve of Final Experimental Model Antenna Coupler CU-215/APT

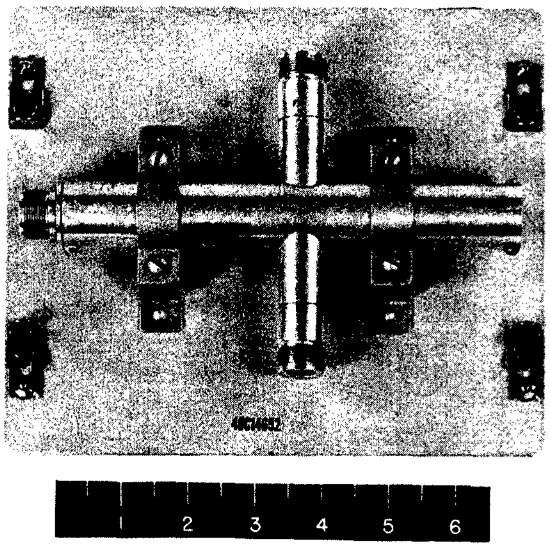

Figure 3. Antenna Coupler CU-215/APT (With Mounting Plate)

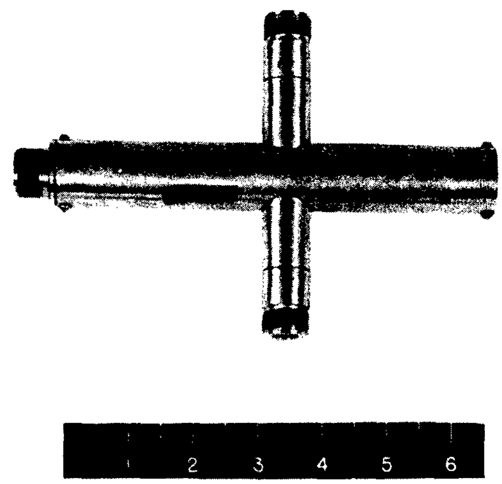

Figure 4. Antenna Coupler CU-215/APT (Without Mounting Plate)

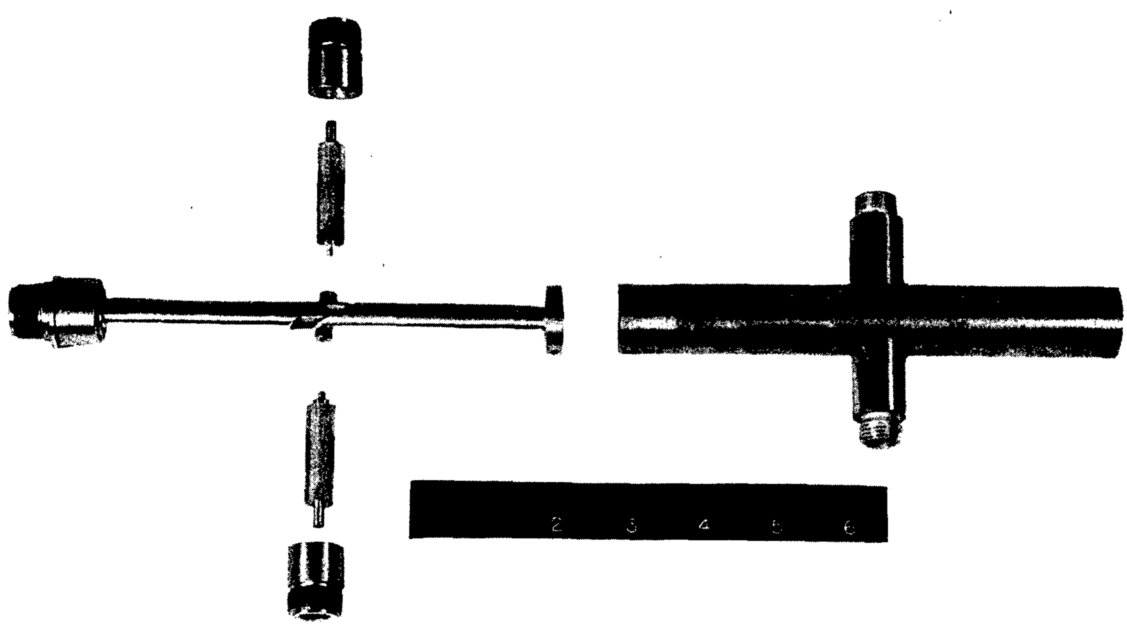

Figure 5. Antenna Coupler CU-215/APT (Unassembled Showing Detail Structure)

ohms. The equation is solved for D which is the larger diameter of the shunt sections or the inner diameter of the outer skirt of the balancing transformer.

SECTION IV

FABRICATION OF EXPERIMENTAL MODEL

Model

An experimental model was fabricated with variable shorts for the two shunt sections; also, line transformers a little longer and shorter than the calculated length. Measurements of the voltage standing wave ratio were made after terminating the balanced lines in dummy loads of 50 ohms each until an optimum was reached. The final data are recorded on Table II. The final dimensions are shown on the drawing of Fig. 7. The voltage standing wave ratio from the experimental data is plotted on Fig. 6.

Correlation of Experimental Data

The balancing transformer was designed with an ideal load for a voltage standing wave ratio of not less than 2:1. When it is used with a different load such as an antenna that has a mismatch of a voltage standing wave ratio of 2:1, it is possible that the resulting mismatch might be more than 2:1. Measurements were taken using two antennas connected to the balancing transformer and mounted each on a ground screen which was at right angles to the other screen. The results were satisfactory.

SECTION V

CONCLUSIONS

The conversion from a 50 ohm unbalanced transmission to a balanced 100 ohm line was accomplished with a balancing transformer CU-215/APT with a voltage standing wave ratio under 2:1 over the frequency range from 475 to 1675 megacycles and under 3:1 over a frequency range from 325 to 1800 megacycles. The balancing transformer CU-215/APT is a small, compact unit easily mounted on a standard mounting base MT-784/U as shown in Fig. 3. The same design technique can be used for frequencies other than those specified in this report.

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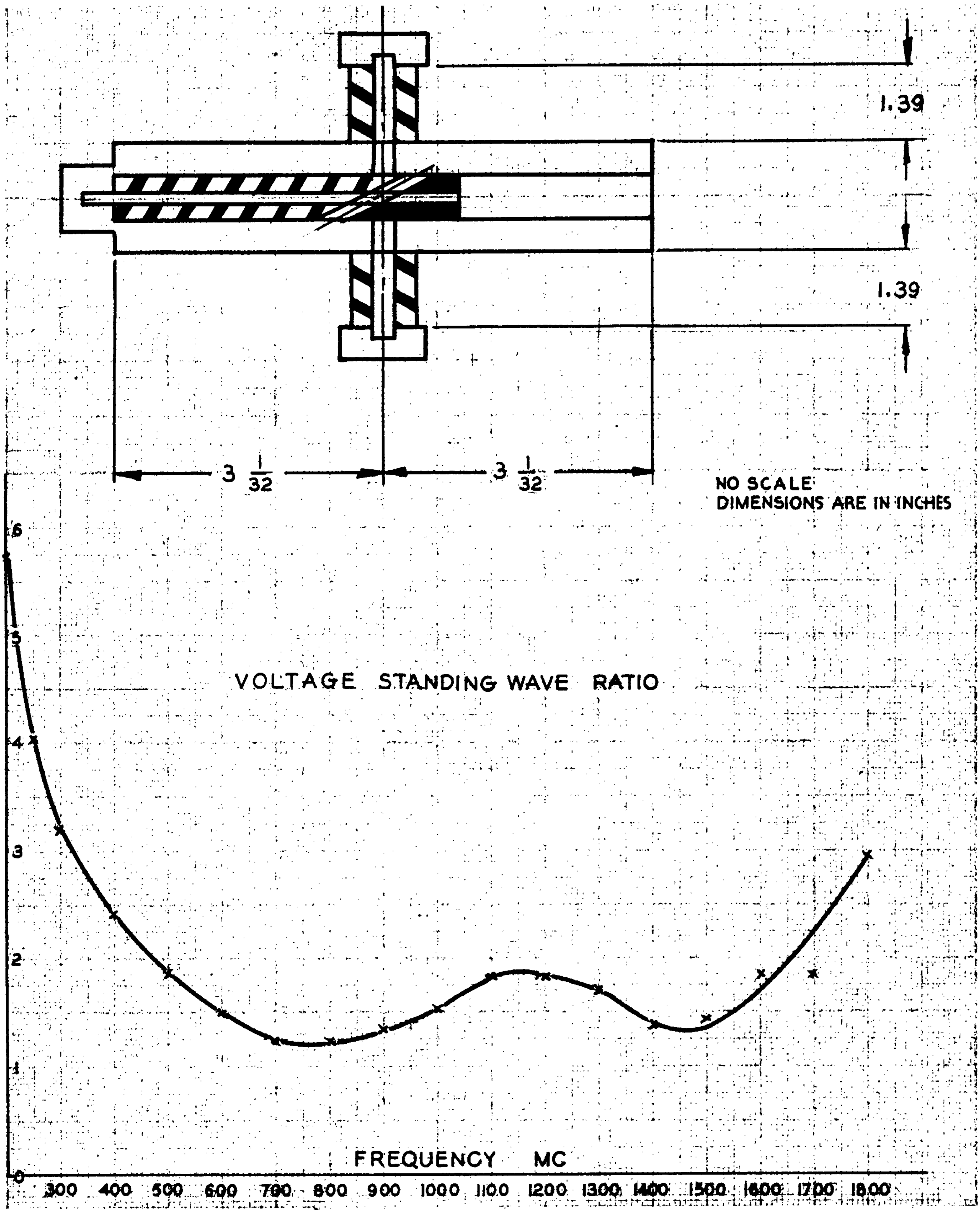

Figure 6. Curve Showing Voltage Standing Wave Ratio of the Final Model

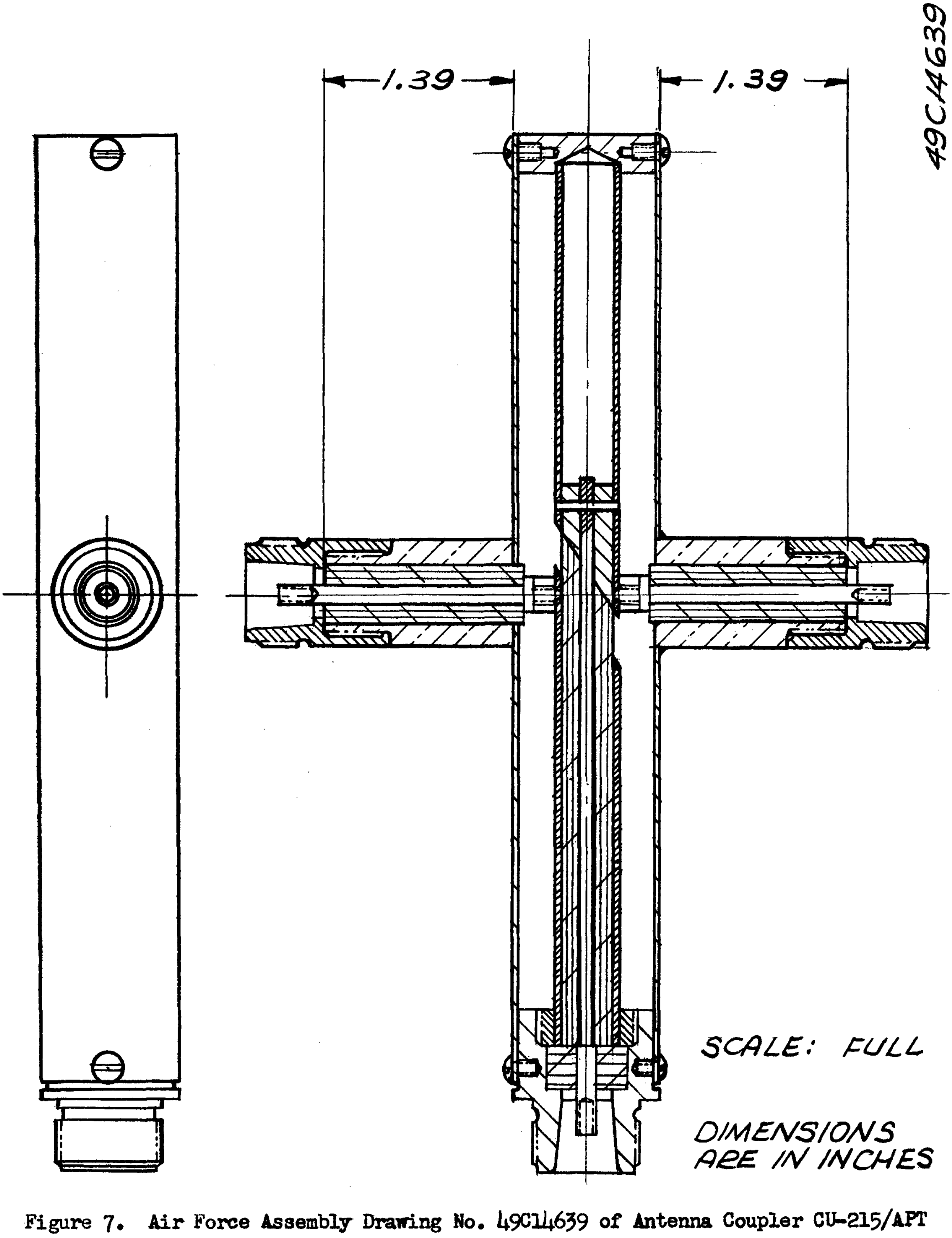

Figure 7. Air Force Assembly Drawing No. 49C14639 of Antenna Coupler CU-215/APT

TABLE II

IMPEDANCE DATA, FINAL EXPERIMENTAL MODEL ANTENNA COUPLER CU-215/APT

Freq.	E max	E min	ρ^2	ρ
200	98	3	32.6	5.7
250	92.7	5.7	16.13	4.03
300	92.2	8.7	10.63	3.2
400	95	16	5.93	2.43
500	96.7	28	3.45	1.85
600	93	40	2.34	1.52
700	94	595	1.57	1.25
800	98	63	1.55	1.24
900	93.5	58.2	1.76	1.32
1000	98.5	42.2	2.33	1.52
1100	93.5	28	3.33	1.82
1200	92	28	3.28	1.81
1300	95	32	2.96	1.72
1400	93	49.5	1.87	1.36
1500	94	47	2.00	1.41
1600	93.2	27.7	3.36	1.86
1700	96.5	27.5	3.32	1.82
1800	92.7	10.5	8.83	2.96

TABLE III

DRAWING INDEX

Drawing Number	Part Name
49C14638	Antenna Coupler CU-215/APT
49C14639	Stub - Matching
49B14640	Line - R F Transmission
49B14641	Line Section - R F Transmission, Lower
49B14642	Line Section - R F Transmission, Upper
49A14643	Insulator - Line, R F Transmission
49B14644	Rod - Line, R F Transmission
49A14645	Contact - Line, R F Transmission
49C14646	Cavity - Tuned
49B14647	Shell - Connector, Bottom
49B14648	Shell - Connector, Side
49A14649	Contact - Stub, Side
49A14650	Insulator - Stub, Side
49A14651	Insulator - Bead
49C14652	Base
49C14653	Plate -Base
49B14654	Holder - Base
49B14655	Clamp

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