AD 256 554

256554

Technical Report No. AF-87

734 500

THE CUT-OFF WAVELENGTHS AND POWER-VOLTAGE IMPEDANCES OF COMPOSITE WAVEGUIDES FOR THE FUNDAMENTAL MODE

by

G. R. Valenzuela

THE JOHNS HOPKINS UNIVERSITY
RADIATION LABORATORY
BALTIMORE 2, MD.

CONTRACT NO. AF 33(616)-6753

MAY 1961

61-3-2

Copy No. 47

THE JOHNS HOPKINS UNIVERSITY
RADIATION LABORATORY
BALTIMORE, MARYLAND

Technical Report No. AF-87

The Cut-Off Wavelengths and Power-Voltage Impedances of Composite Waveguides for the Fundamental Mode

by

G. R. Valenzuela

Contract AF 33(616)-6753 May, 1961

ACKNOWLEDGEMENT

Acknowledgement is due to Miss Marguerite Velten for performing the numerical calculation and to Mr. Tomos L. apRhys for reviewing the manuscript.

CONTENTS

ABSTRACT

The Rayleigh-Ritz method is used to solve the eigenvalue problem for electromagnetic waves propagating through a waveguide of a non-simple cross section. The method is applied to obtain the cut-off wavelength and the power-voltage impedance for the fundamental mode (that equivalent to the H_{10} mode in rectangular waveguide and the H_{11} mode in circular waveguide) for a waveguide with semicircular side walls and flat top and bottom walls, and for a truncated-circular waveguide.

Numerical results are given for both waveguides, and supporting experimental evidence is adduced for the waveguide with semicircular sides and flat top and bottom walls, for aspect ratios of 0.302 and 0.702. The cut-off wavelengths obtained are within 3 per cent while the power-voltage impedances are within 6 per cent of their respective exact values.

I. INTRODUCTION

Interest in these composite waveguides arises from their possible applications in transition from rectangular to circular waveguides, where they provide convenient intermediate sections.

When electromagnetic waves propagate in waveguides of non-simple cross section no exact solution can be obtained by the conventional method of solving the wave equation by separation of variables. In such cases approximations are available with the aid of perturbation methods and variational methods[1].

The Rayleigh-Ritz method will be used to obtain an approximate solution for the cut-off wavelength and the power-voltage impedance in waveguides with semicircular side walls and flat top and bottom walls, and for truncated-circular waveguides.

The results obtained contradict the results published in Principles of Microwave Circuits[2] on the cut-off wavelength for a waveguide of semicircular side walls and flat top and bottom walls for aspect ratios between 0.3 and 1.0.

II. THEORY

The boundary value problem of electromagnetic waves propagating in a cylindrical waveguide can always be reduced to a simple two dimensional problem. If the longitudinal waveguide axis is in the z direction,

$$\nabla^2 \psi_i (x, y) + k_i^2 \psi_i (x, y) = 0, \tag{1}$$

where $\psi_i (x, y)$ and k_i are the eigenfunction and the propagation constant for the i^{th} mode, respectively.

Kornhauser[3] showed that in any cylindrical waveguide the lowest order mode with non-zero eigenvalue is an H-mode. Now let ψ represent the eigenfunction for the fundamental mode and drop any subscript. The eigenfunction ψ is proportional to the magnetic field component in the direction of propagation.

Since the modes in a waveguide are orthogonal, that is,

$$\int_S \psi_m \psi_n \, d\sigma = \delta_{mn} \quad \text{(kronecker delta)}, \tag{2}$$

where S is the waveguide cross section, the eigenfunction ψ for the fundamental mode can be constructed from[3]

$$\int_S \psi \, d\sigma = 0 \; . \tag{3}$$

Then a legitimate choice for the eigenfunction for the fundamental mode is,

$$\psi(x) = \sum_{n=o}^{N} C_{2n+1} \, x^{2n+1} \; . \tag{4}$$

For simplicity choose N = 1, then

$$\psi(x) = C_1 x + C_3 x^3 \quad . \tag{5}$$

In general it can be easily shown that if ψ satisfies either the Dirichlet or Neumann boundary conditions, its eigenvalue is minimized by the expression.

$$k^2 = \frac{\int |\operatorname{grad} \psi|^2 d\sigma}{\int \psi^2 d\sigma} \quad , \tag{6}$$

the integrals being taken over the waveguide cross section.

By using the trial function (5) for the fundamental mode, Equation (6) takes the following general form,

$$k^2 = \frac{\alpha C_1^2 + \beta C_1 C_3 + \gamma C_3^2}{\delta C_1^2 + \varepsilon C_1 C_3 + \zeta C_3^2} \tag{7}$$

where α, β, γ, δ, ε, and ζ are constants dependent on the dimensions of the waveguide.

Then the parameters C_1 and C_3 are adjusted independently to minimize the eigenvalue k^2.

$$\frac{\partial [k^2]}{\partial C_1} = 0 \qquad \frac{\partial [k^2]}{\partial C_3} = 0 \; .$$

After performing the minimization, we obtain the following system of equations:

$$
\begin{aligned}
(2\delta k^2 - 2\alpha)\, C_1 + (\varepsilon k^2 - \beta)\, C_3 &= 0 \\
(\varepsilon k^2 - \beta)\, C_1 + (2\zeta k^2 - 2\gamma)\, C_3 &= 0 \quad . \qquad (8)
\end{aligned}
$$

The non-trivial solution is found in the conventional way by equating the determinant of the coefficients to zero, which yields

$$k^4 - 2\text{Ⓗ}k^2 + \Phi = 0 \ , \qquad (9)$$

where

$$\text{Ⓗ} = \frac{2\alpha\zeta + 2\delta\gamma - \varepsilon\beta}{4\delta\zeta - \varepsilon^2}$$

and

$$\Phi = \frac{4\alpha\gamma - \beta^2}{4\delta\zeta - \varepsilon^2} \quad .$$

An expression for the power-voltage impedance is obtained next. The power-voltage impedance is defined as the ratio of the maximum mean voltage $V/\sqrt{2}$ across the waveguide squared divided by the total average power W flowing through the waveguide.

$$Z_{WV} = \frac{VV^*}{2W} \quad .$$

The maximum voltage across the waveguide can be found from

$$V = 2 \int_0^b E_y \Big|_{x=o} dy$$

where the electric field $E_y = \frac{\partial\psi}{\partial x} = C_1 + 3C_3x^2$. The maximum voltage then is

$$V = 2bC_1 \quad . \tag{10}$$

The power flowing down the waveguide can be obtained for an H mode from

$$W = \frac{k^2}{2Z_o} \int \psi^2 \, d\sigma \quad , \tag{11}$$

where

$Z_o = 120\pi\lambda_g/\lambda$ is the field impedance, and

as usual,

λ_g = is the waveguide wavelength

and λ = is the free space wavelength.

The expression for the power-voltage impedance for composite waveguides is,

$$Z_{WV} = \frac{b^2 Z_o}{\alpha + \beta\left(\frac{C_3}{C_1}\right) + \gamma\left(\frac{C_3}{C_1}\right)^2} \quad . \tag{12}$$

The ratio $\frac{C_3}{C_1}$ can be obtained from Equation (8).

III. APPLICATION

1. The approximate method was used to obtain the eigenvalue for the fundamental mode of waveguide with semicircular side walls and flat top and bottom walls. See Figure 1.

The coefficients obtained for this composite waveguide are the following:

$$\alpha = ab \left[p + \frac{\pi}{4} r \right]$$

$$\beta = a^3 b \left[2p^3 + \frac{3\pi}{2} p^2 r + 4pr^2 + \frac{3\pi}{8} r^3 \right]$$

$$\gamma = a^5 b \left[\frac{9}{5} p^5 + \frac{9\pi}{4} p^4 r + 12p^3 r^2 + \frac{27\pi}{8} p^2 r^3 + \frac{24}{5} pr^4 + \frac{9\pi}{32} r^5 \right]$$

$$\delta = a^3 b \left[\frac{1}{3} p^3 + \frac{\pi}{4} p^2 r + \frac{2}{3} pr^2 + \frac{\pi}{16} r^3 \right]$$

$$\varepsilon = a^5 b \left[\frac{2}{5} p^5 + \frac{\pi}{2} p^4 r + \frac{8}{3} p^3 r^2 + \frac{3\pi}{4} p^2 r^3 + \frac{16}{15} pr^4 + \frac{\pi}{16} r^5 \right]$$

$$\zeta = a^7 b \left[\frac{1}{7} p^7 + \frac{\pi}{4} p^6 r + 2p^5 r^2 + \frac{15\pi}{16} p^4 r^3 + \frac{8}{3} p^3 r^4 + \frac{15\pi}{32} p^2 r^5 + \frac{48}{105} pr^6 + \frac{5\pi}{256} r^7 \right]$$

where

$r = \frac{b}{a}$ and $p = 1 - r$.

The numerical results are shown in Figure 2.

2. The method was also applied to a truncated-circular waveguide. See Figure 3.

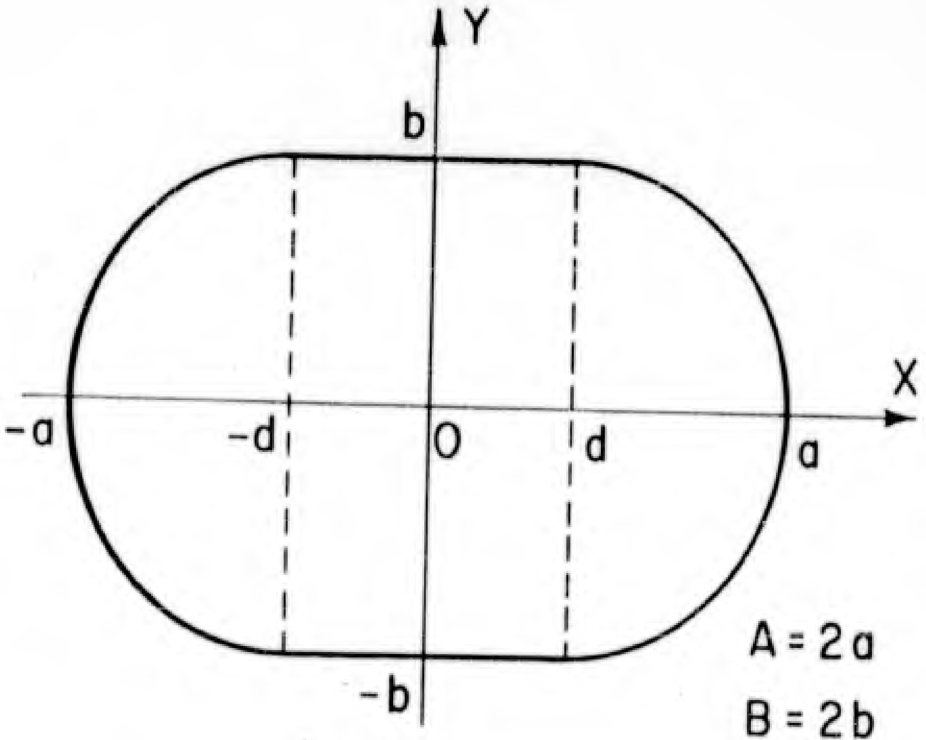

FIGURE 1: COMPOSITE CIRCULAR WAVEGUIDE

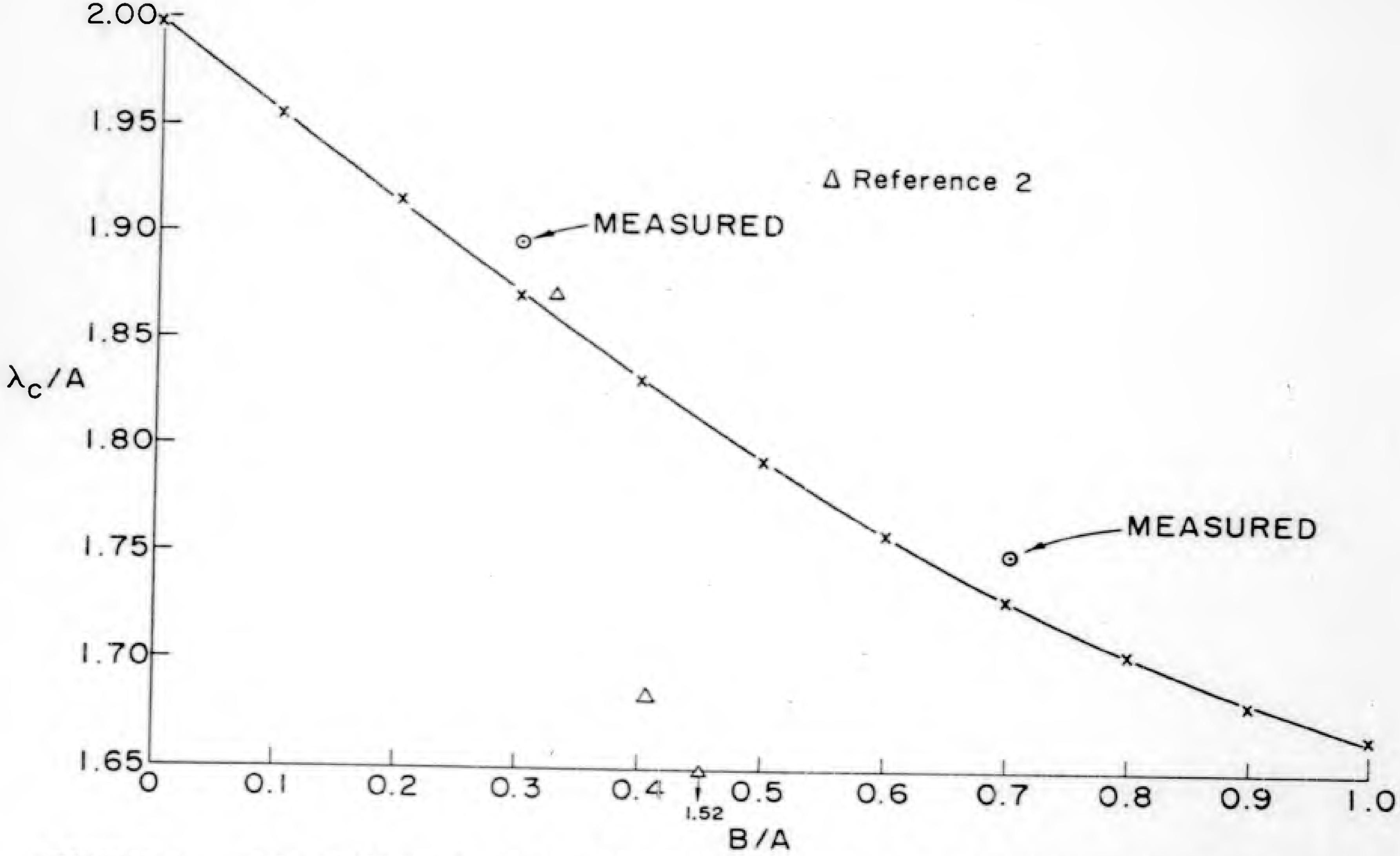

FIGURE 2: SEMI-CIRCULAR SIDE WALLS AND UPPER AND BOTTOM FLAT WALLS WAVEGUIDE CUT-OFF WAVELENGTH PER WIDE DIMENSION AS A FUNCTION OF NARROW TO WIDE DIMENSION RATIO.

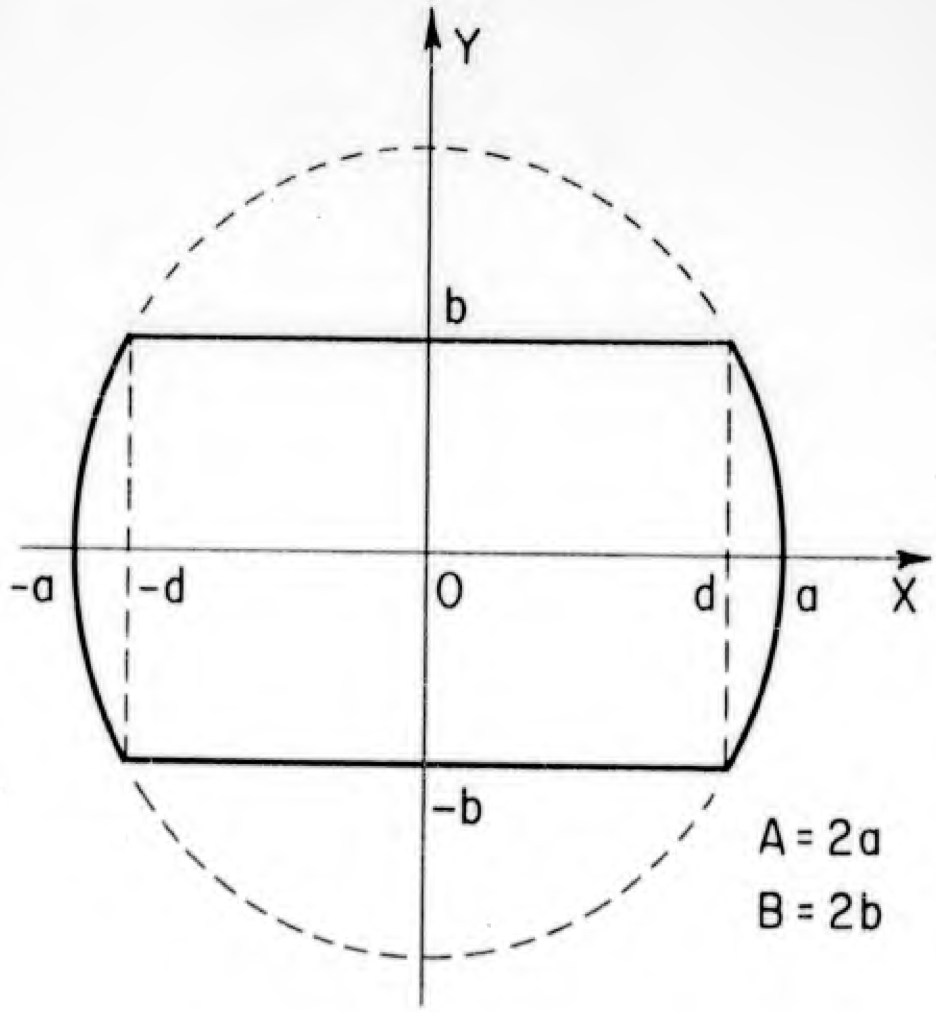

FIGURE 3: TRUNCATED CIRCULAR WAVEGUIDE

For this waveguide the coefficients obtained are the following:

$$\alpha = a^2 \left[qr + \frac{1}{2}\Delta - \frac{1}{4}\sin 2\tau \right]$$

$$\beta = a^4 \left[2q^3 r + \frac{3}{4}\Delta + \frac{3}{16}\sin 4\tau \right]$$

$$\gamma = a^6 \left[\frac{9}{5} q^5 r + \frac{3}{2}\sin^3 \tau \cos^3 \tau + \frac{9}{16}\Delta + \frac{9}{64}\sin 4\tau \right]$$

$$\delta = a^4 \left[\frac{1}{3} q^3 r + \frac{1}{8}\Delta + \frac{1}{32}\sin 4\tau \right]$$

$$\varepsilon = a^6 \left[\frac{2}{5} q^5 + \frac{\sin^3 \tau \cos^3 \tau}{3} + \frac{1}{8}\Delta + \frac{1}{32}\sin 4\tau \right]$$

$$\zeta = a^8 \left[\frac{1}{7} q^7 r + \frac{1}{8}\left\{ \sin^5 \tau \cos^3 \tau + \frac{5}{6}\sin^3 \tau \cos^3 \tau + \frac{5}{16}\Delta + \frac{5}{64}\sin 4\tau \right\} \right]$$

where

$$r = \frac{b}{a};\ q = (1-r^2)^{1/2}\ ; \quad r = \sin^{-1} q; \quad \Delta = \left(\frac{\pi}{2} - \tau\right) .$$

The numerical results are plotted in Figure 4.

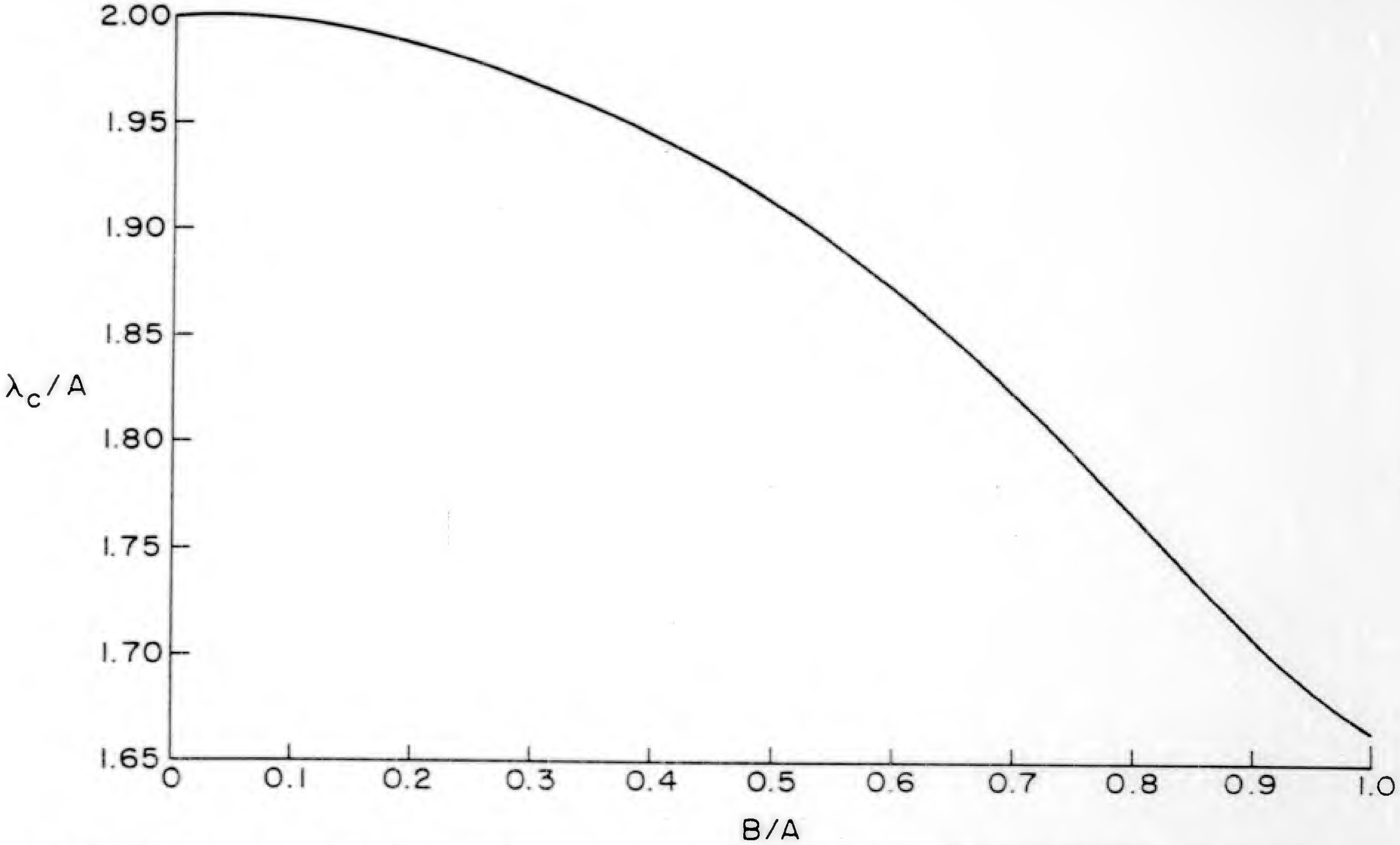

FIGURE 4: TRUNCATED-CIRCULAR WAVEGUIDE CUT-OFF WAVELENGTH PER WIDE DIMENSION AS A FUNCTION OF NARROW TO WIDE DIMENSION RATIO.

IV. EXPERIMENTAL

To assess the accuracy of the results, an experiment was performed. Two 3" waveguide sections with semicircular side walls and flat top and bottom walls of aspect ratios of 0.302 and 0.702 were electroformed. Their wide dimension was 0.622 inch the width of the standard P-band rectangular waveguide. See Figure 5.

The cut-off wavelength was obtained by two independent methods: firstly, by measuring the phase change when the composite waveguide was shortened by about 1 inch; and secondly, by measuring the transmission-versus-frequency characteristic using an electrically-swept backward-wave oscillator (source).

The measured points and the points obtained from reference 2 are also included in Figure 2.

The power-voltage impedance was also measured. For this purpose a termination was developed for the composite waveguide sections, and by using a standard P-band slotted line the impedance was measured at the junction between the rectangular and composite waveguide. The real part accounts for the impedance mismatch while the imaginary part accounts for the junction susceptance.

The measured points are shown in Figure 6.

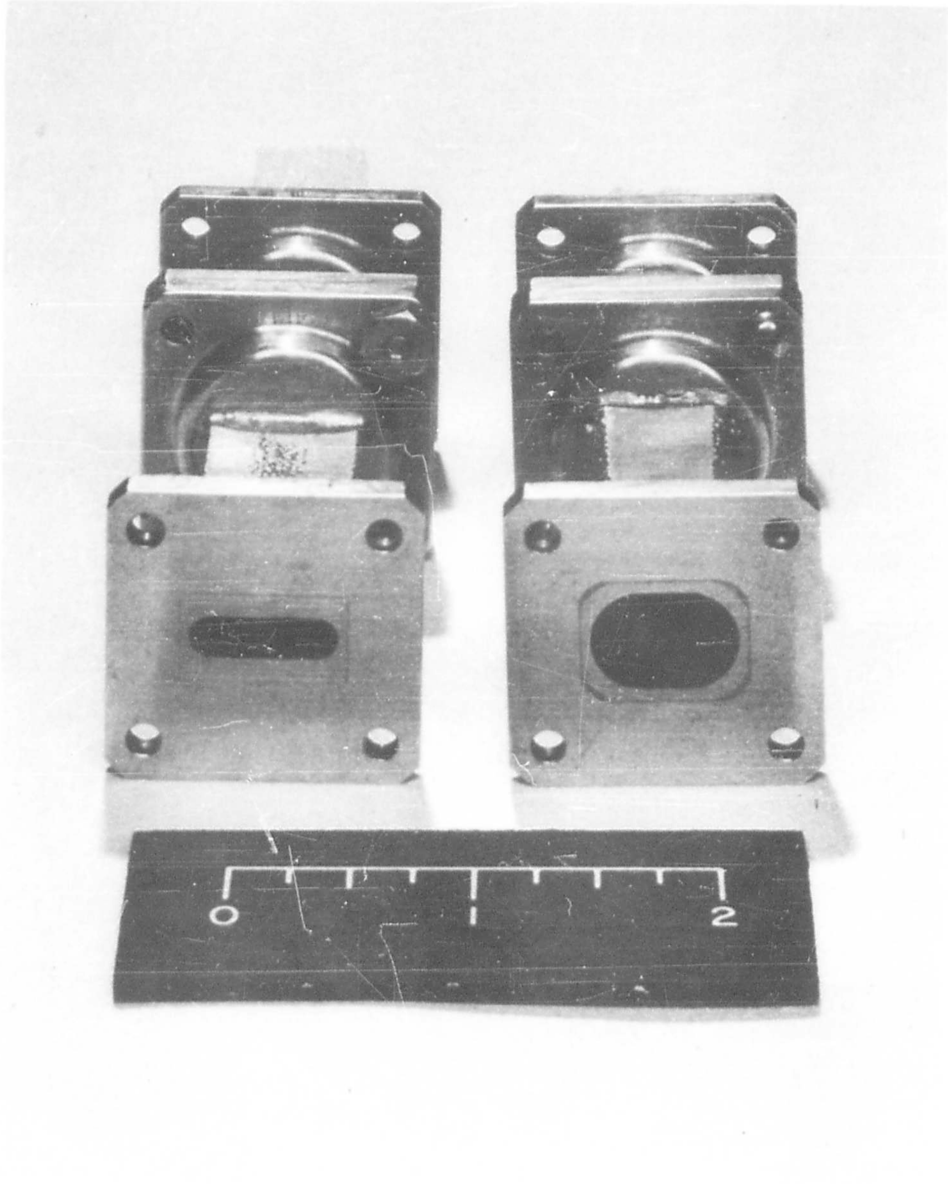

FIGURE 5: WAVEGUIDE WITH FLAT TOPS AND BOTTOMS AND SEMICIRCULAR SIDE WALLS EXPERIMENTAL SECTIONS

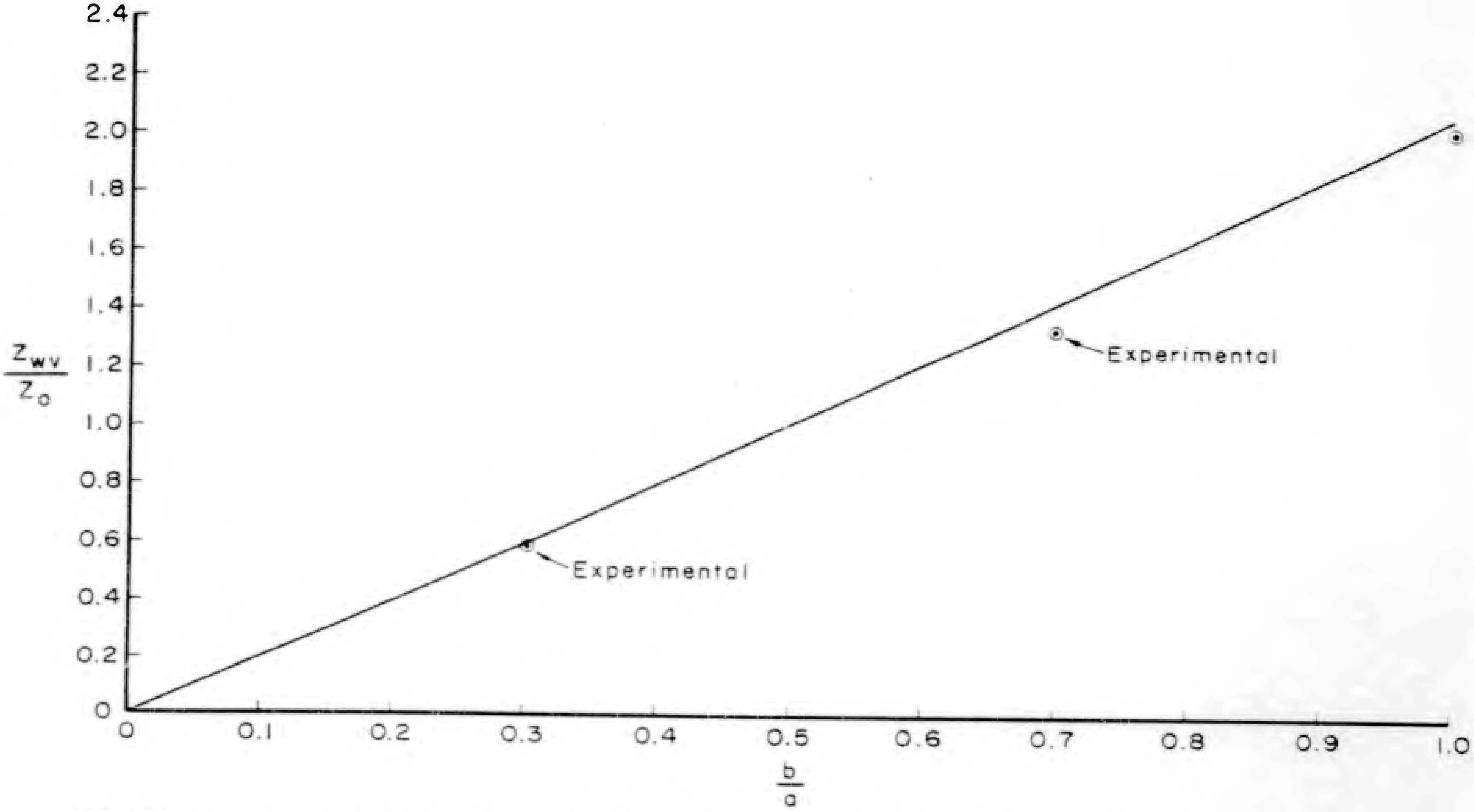

FIGURE 6 THE POWER-VOLTAGE IMPEDANCE AS A FUNCTION OF ASPECT RATIO FOR COMPOSITE WAVEGUIDES.

V. CONCLUSION

The Rayleigh-Ritz method was applied to the eigenvalue problem for the fundamental mode in composite waveguides. Supporting experimental evidence was obtained for the waveguide of semicircular side walls and flat top and bottom walls, which indicates the cut-off wavelengths are within 3 per cent and the power-voltage impedances are within 6 per cent of their exact value.

The cut-off wavelengths obtained by this approximate method are smaller than the exact value, since this is a minimization problem of the eigenvalue k^2.

The cut-off wavelength for the waveguide of semicircular side walls and flat top and bottom walls indicated in Reference 2 for aspect ratios of 0.406 and 0.450 are even smaller than the cut-off wavelengths obtained by this method; therefore their approximation must have been inferior to the one used in this paper.

Surprisingly enough the calculated values for the power-voltage impedance for both composite waveguides came out to be identical for all practical purposes.

The accuracy could be improved by selecting a trial function containing terms in Y^2.

REFERENCES

1. Morse, P. R. and Feshbach, H., Methods in Theoretical Physics II, McGraw-Hill Book Co., Inc., New York, New York, 1953.

2. Montgomery, C. G., Dicke, R. H. and Purcell, E. M., Principles of Microwave Circuits, MIT Rad. Lab. Ser., McGraw-Hill Book, Co., Inc., New York, New York, Vol. 8, p. 45, 1948.

3. Kornhauser, E. T. and Stakgold, Application of Variational Methods to the Equation $\nabla^2 u + \lambda u = 0$, Harvard Univ., Cruft Laboratory, Cambridge, Mass., T.R. No. 117, October 5, 1950.

ELECTRONICS DISTRIBUTION

Wright Air Development Division (WWACC)
Wright-Patterson AFB, Ohio
1 Attn: WWAD
2 WWDPVD-1
1 WWDPVD-2
1 WWRDM
1 WWRDS
1 WWRNA
1 WWRNE
1 WWRNEA
3 WWRNGW-1
1 WWRNGW-2
1 WWRNGW-3
2 WWRNR
1 WWRNRS
1 WWZB
1 AFCIN-4B1a
1 AFCIN-4C3

Commander
Rome Air Development Center
Griffiss Air Force Base
Rome, New York
1 Attn: RCEMSA
1 RCERHS
1 RCSST
1 RCU
1 RCWE
1 RCWEA
2 RCWEC
1 RCWED
1 RCWEE
1 RCWES

1 Air Force Cambridge Research Labs.
AFRD (ARDC) CRREL-R
Scientific Library Branch
L. G. Hanscom Field
Bedford, Massachusetts

1 Commander, HQ, ARDC
Air Force Ballistic Missile Division
5760 Arbor Vitae Avenue
Inglewood, California
Attn: WDSOT

1 Director, Development Planning
HQ, USAF
Washington 25, D. C.
Attn: AFDAP-T

1 Director, Research and Technology
HQ, USAF
Washington 25, D. C.
Attn: AFDRT-ER

1 Commander, HQ
Air Defense Command
Ent AFB, Colorado
Attn: ADOOA

1 Commander-in-Chief
Strategic Air Command
Offutt AFB, Nebraska
Attn: Operations Analysis

1 Tactical Air Command
Directorate of Operations Analysis
Langley AFB, Virginia

1 HQ, Ninth Air Force
Shaw AFB, South Calolina

1 HQ, Air Force Missile Development Center
Holloman AFB, New Mexico
Attn: MDTXT

1 Director
Air University Library
Maxwell AFB, Alabama
Attn: AUL-6234

1 HQ, USAF Security Service
Kelly AFB
San Antonio, Texas
Attn: CLR, Russell Watson

5 National Aeronautics and Space Administration
1520 H Street, N. W.
Washington 25, D. C.
Attn: Bertram A. Mulcahy
Assistant Director for
Technical Information

1 Director
Weapons Systems Ecaluation Group
Room 1 E 880, The Pentagon
Washington 25, D. C.

1 Office of Secretary of Defense
Office of Asst. Secretary (R. and D.)
W. Pentagon
Washington 25, D. C.

1 Commander, Fort Monmouth
Red Bank, New Jersey
Attn: Countermeasures Branch

1 Director, Coles Signal Laboratory
Fort Monmouth, New Jersey

1 Commanding General
Countermeasures Division, DST
Fort Monmouth, New Jersey
Attn: USASCS, Mr. H. Allen

Chief, Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.
1 Attn: EL-45
1 EL-411

1 Chief, Bureau of Ships, Code 335
Room 1532, Main Navy Building
18th and Constitution Ave., N. W.
Washington 25, D. C.

1 Commander
U. S. Naval Missile and Astronautics Center
Point Mugu, California
Attn: Technical Library

1 New York Naval Shipyard
Brooklyn 1, New York
Attn: Material Laboratory

1 Commanding Officer
U. S. Naval Air Development Center
Engineering Development Department
Johnsville, Pennsylvania
Attn: J. M. McGlone

1 Commanding Officer (Code 74)
Naval Ordnance Laboratory
Corona, California

2 Director
Naval Research Laboratory
Washington 25, D. C.

1 Director
National Security Agency
Ft. George G. Meade, Md.
Attn: CREF-332 (Room 2C087)

1 U. S. Army Signal Electronic Research Unit
P. O. Box 205
Mountain View, California

1 Commanding General
Army Rocket and Guided Missile Agency
Redstone Arsenal, Alabama
Attn: ORDXR-RF

1 Commanding General
White Sands Missile Range
New Mexico
Attn: ORDBS-OM-Tech. Library-403

Missile Electronics Laboratories
Ordnance Missile Laboratory
Army Rocket and Guided Missile Agency
Redstone Arsenal, Alabama
1 Attn: J. P. Hallowes, Jr. Bldg. 5429
1 P. S. Birman

1 Office, Chief Signal Officer
Room 2# - 258
The Pentagon
Washington 25, D. C.

10 ASTIA
Arlington Hall Station
Arlington 12, Virginia
Attn: TIPDR

1 Airborne Instruments Laboratory
Walt Whitman Road
Melville, Long Island, New York
Attn: Cont. AF 33(616)-2143

1 Bjorksten Research Labs., Inc.
P. O. Box 265
Madison, Wisconsin
Attn: Security Office

1 Boeing Airplane Company
Pilotless Aircraft Division
P. O. Box 3925
Seattle 24, Washington
Attn: Library Supervisor

1 Boeing Airplane Company
Mailstop 18-47
Seattle 14, Washington
Attn: Cont. AF 33(038)-19589

1 Laboratories for Applied Sciences
University of Chicago
Museum of Science and Industry
Chicago 37, Illinois
Attn: Library-W-305

1 Convair
Fort Worth, Texas
Attn: Chief Librarian

1 Cook Research Laboratories
6401 Oakton Street
Morton Grove, Illinois
Attn: Cont. NOrd-16369

1 Cornell Aeronautical Laboratory
4455 Genesee Street
P. O. Box 235
Buffalo 21, New York
Attn: Dr. Carl Miller
Cont. AF 33(616)-6307

1 Electronic Communications, Inc.
1830 York Road
Timonium, Maryland

1 Fairchild Astrionics Division
Fairchild Engine and Airplane Corporation
Wyandanch, Long Island, New York

1 General Electric Advanced Electronics
Center
Cornell University
Ithaca, New York
Attn: Librarian

1 General Electric Company
B-278, 901 Broad Street
Utica, New York
Attn: Cont. AF 33(600)-30632

1 Grumman Aircraft Engineering Corp.
Bethpage, Long Island, New York
Attn: Engineering Library
Plant 5

1 HRB-Singer, Inc.
P. O. Box 60
Science Park
State College, Pennsylvania

1 Hallicrafters Company
4401 W. Fifth Avenue
Chicago 24, Illinois
Attn: Cont. AF 33(600)-26117

1 Hughes Aircraft Company
c/o Plant Representative
Florence and Teal Streets
Culver City, California
Attn: Company Technical Document Center,
Bldg. 6, Room C2048

1 University of Illinois
Coordinated Science Laboratory
264 Engineering Research Laboratory
Urbana, Illinois

1 Jansky and Bailey, Inc.
Systems Engineering Dept.
1339 Wisconsin Ave., N. W.
Washington 7, D. C.
Attn: Cont. AF 33(616)-6740

1 Radio Corporation of America
Delaware and Cooper
Camden, New Jersey
Attn: Mr. Jack J. Rudnick
Cont. AF 33(600)-39608

1 Radio Corporation of America
Talos Equipment Projects
Moorestown, New Jersey
Attn: H. D. Albrecht
Coordinator, Bldg, 108-2

1 Radio Corporation of America
Missile Electronics and Controls Division
Box 588
Burlington, Massachusetts
Attn: W. Ramsey

1 Radio Corporation of America
WCM + SRD Eng. Library 306/2
Attn: L. R. Hund, Librarian
8500 Balboa Blvd.
Van Nuys, California

1 Ramo Wooldridge, a Division of
Thompson Ramo Wooldridge, Inc.
8433 Fallbrook Avenue
Canoga Park, California

1 RAND Corporation
1700 Main Street
Santa Monica, California
Attn: Cont. AF 18(600)-1600

1 Raytheon Company
Santa Barbara Operation
P. O. Box 636
Santa Barbara, California
Attn: Cont. AF 33(600)-28016

1 Raytheon Company Equipment Division
Surface Radar and Navigation Operations
State Road West
Wayland, Massachusetts
Attn: Librarian

1 Revere Copper and Brass, Inc.
196 Diamond Street
Brooklyn 22, New York
Attn: Cont. AF 33(616)-5672
V. Lane, Security Officer

1 Space Technology Laboratories, Inc.
P. O. Box 95001
Los Angeles 45, California
Attn: Technical Information Center,
Document Procurement

1 Sperry Gyroscope Company
Great Neck, Long Island
New York
Attn: Cont. AF 33(038)-14524

1 Stanford Electronics Laboratories
Stanford University
Stanford, California
Attn: Applied Electronics Laboratory
Document Library

1 Sylvania Electric Products, Inc.
100 First Avenue
Waltham 54, Massachusetts
Attn: Dr. L. S. Sheingold
Cont. AF 33(600)-24208

1 Sylvania Electronic Systems
Sylvania Electric Products, Inc.
P. O. Box 188
Mountain View, California
Attn: Roger Battie
Supervisor, Technical Liaison

1 University of Illinois
Ultramicrowave Group
Electrical Engineering Research
Urbana, Illinois

1 International Telephone and Telegraph
Corp.
500 Washington Avenue
Nutley 10, New Jersey
Attn: Cont. W33-038-ac-15012

1 The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland
Attn: Cont. NOrd-7386

1 Litton Industries, Inc.
4900 Calvert Road
College Park, Maryland
Attn: Jack Giles

1 Lockheed Aircraft Corporation
Missile and Space Division
3251 Hanover Street
Palo Alto, California
Attn: Technical Information Center

1 Lockheed Aircraft Corporation
Georgia Division
Marietta, Georgia
Attn: Dept. 72-15
Cont. AF 34(601)-4852

1 The Martin Company
Baltimore 3, Maryland
Attn: Engineering Librarian
Cont. AF 33(600)-21703

2 Lincoln Laboratory
Mass. Inst. of Technology
P. O. Box 73
Lexington 73, Massachusetts
Attn: Library D-224

1 Electronic Systems Laboratory
Mass. Inst. of Technology
Cambridge, Massachusetts
Attn: Cont. AF 33(616)-5477

1 Melpar, Inc.
3000 Arlington Blvd.
Falls Church, Virginia
Attn: Cont. AF 33(038)-21250

1 University of Michigan
Willow Run Research Center
Ypsilanti, Michigan
Attn: Cont. AF 33(616)-3153

1 Radiation Laboratory
The University of Michigan
201 Catherine Street
Ann Arbor, Michigan
Attn: Keeve M. Siegel

1 Electronics Defense Group
Dept. of Electrical Engineering
Eng. Research Institute
University of Michigan
Ann Arbor, Michigan
Attn: Cont. DA-36-038-sc-15358

1 The Mitre Corporation
P. O. Box 208
Bedford, Massachusetts

1 Motorola, Inc.
Riverside, California

1 North American Aviation, Inc.
International Airport
Los Angeles 45, California
Attn: Cont. AF 33(600)-36599
J. W. Schwartz

1 Northrup Corporation
Norair Division
1001 E. Broadway
Hawthorne, California
Attn: Technical Information

1 The Ohio State University
Research Foundation
1314 Kinnear Road
Columbus 12, Ohio
Attn: Dr. T. E. Tice

1 University of Texas
Defense Research Laboratory
Box 8029 University Station
Austin, Texas
Attn: Cont. AF 33(616)-313

1 Westinghouse Electric Corp.
Air Arm Division
Engineering Library
P. O. Box 746
Baltimore 3, Maryland
Attn: A. E. Battaglia
Librarian