Naval Research Laboratory
Washington, DC 20375-5000

NRL Memorandum Report 6531

Cold Tests of Quasi-Optical Gyrotron Resonators

R.P. FISCHER, T.A. HARGREAVES* AND A.W. FLIFLET

Beam Physics Branch
Plasma Physics Division

**Mission Research Corp.*
Newington, VA 22122

September 7, 1989

Approved for public release; distribution unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 6531	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Research Laboratory 6b. OFFICE SYMBOL (If applicable) Code 4794	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION DOE 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20545	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. DN780-307

11. TITLE (Include Security Classification)
Cold Tests of Quasi-Optical Gyrotron Resonators

12. PERSONAL AUTHOR(S)
Fischer, R.P., Hargreaves,* T.A. and Fliflet, A.W.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM ______ TO ______	1989 September 7	31

16. SUPPLEMENTARY NOTATION
*Mission Research Corp., Newington, VA 22122

17. COSATI CODES			
FIELD	GROUP	SUB-GROUP	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Quasi-optical gyrotron; Open resonator; Cold tests; Scalar diffraction theory; Quality factor

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Cold tests are performed on a number of quasi-optical gyrotron resonators at 94 and 120 GHz to determine the variation of cavity Q with mirror separation. The separation between the resonator mirrors is varied between 15 and 35 cm, with measured quality factors ranging from 10,000 to 100,000. Good agreement is obtained between the measured data and values calculated from scalar diffraction theory. The effect of misaligning the mirrors is also examined experimentally.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Richard P. Fischer	22b. TELEPHONE (Include Area Code) (202) 7673765 22c. OFFICE SYMBOL Code 4794

CONTENTS

COLD TESTS OF QUASI-OPTICAL GYROTRON RESONATORS

I. Introduction

Gyrotrons are currently under development as efficient, high-power sources of millimeter waves. The trend is toward higher power (> 1 MW average) and higher frequency (submillimeter wavelengths). Waveguide cavity gyrotrons are presently the leading candidate for electron cyclotron heating of fusion plasmas.[1] However, these conventional cavity gyrotrons suffer from large ohmic heating, transverse mode competition, and electron beam collection problems as power and frequency are increased. The quasi-optical gyrotron (QOG) was proposed by Sprangle, Vomvoridis, and Manheimer in 1980[2,3,4,5] and has the potential to overcome each of these difficulties.

The quasi-optical resonator is comprised of a pair of spherical mirrors separated by many wavelengths. The QOG operates in a series of TEM_{00l} modes, where $l > 100$ for cw relevent configurations. Higher order transverse modes can be made to suffer from large diffraction losses due to the finite size of the mirrors. The diffraction of the TEM_{00l} modes around one or both of the mirrors is collected as output.

Typical round-trip diffraction losses are several percent. This output coupling sensitively depends upon the mirror size, radius of curvature, and separation. For a given pair of mirrors, output coupling is increased by increasing the separation between the mirrors. However, the radiation waist near the center of the cavity is relatively insensitive to changes in separation. Thus, the output coupling can be varied independently with respect to the interaction length. This is a unique feature of the QOG, and is quite advantageous experimentally.

The electron beam direction is perpendicular to the axis of the resonator, which allows the beam to be collected separately from the radiation. This is an important feature for high-power devices and eases restrictions on the collector. It also facilitates the use of depressed collector technology. The cavity mirrors are well removed (> 10 cm) from the wave/beam interaction region, which reduces the ohmic heating density at the mirrors.

The quality factor (Q) of a resonator is an important parameter which describes how well the cavity stores energy and is closely related to the output coupling. The Q for a

Manuscript approved July 25, 1989.

Fabry-Perot-type resonator can be very large. Quality factors on the order of 100,000 are typical for resonators used in recent experiments at the Naval Research Laboratory. Since the balance between ohmic effects and diffraction is very important in the QOG, a detailed experimental study is called for.

Fabry-Perot resonators have been used for years to measure the microwave properties of solids, liquids, and gases.[6] These cavitites have proven to be quite useful. For permittivity and loss measurements, the design goal is to make the Q as large as possible. This is accomplished by making the mirrors large so that diffraction losses are negligible. Energy is typically coupled into the cavity through coupling holes or a dielectric beam splitter.

Cold tests of gyrotron cavities are difficult to perform in practice. Most cold-test schemes involve drilling coupling holes into the cavity walls,[7] which can perturb the cavity mode severely. It is also difficult to couple efficiently to the mode of interest, which is frequently a high-order mode. Woskoboinikow *et al.*[8] radiated their conventional gyrotron cavities in the far field and analyzed the reflected signal. This technique has the advantage of being nondestructive, so that the hot test cavity may be used for the cold test. It is difficult to test a QO cavity this way because little energy is coupled into the resonator mode.

Although the QOG is an advanced concept, it operates in the fundamental Gaussian mode. This makes coupling to the correct mode very easy. This study uses the method of Perrenoud *et al.*[9] where a small hole is used to couple energy into the resonator and diffracted power is collected with a standard gain horn as output. This technique has a distinct advantage in that there is no background radiation pattern on the oscilloscope trace, which increases the accuracy of the measurment. The majority of the measurements in this article concern the variation of Q with separation for various cavities. Good agreement is obtained between measured values and calculations based on scalar diffraction theory. The effect of misaligning the mirrors is also examined experimentally.

II. Quasi-Optical Resonators

The Q of a Fabry-Perot-type resonator can be written

$$Q = \frac{4\pi L}{\lambda f_L} \tag{1}$$

where L is the separation between mirrors, λ is the free-space wavelength, and f_L is the fractional round-trip loss. In practice, this loss factor includes ohmic losses, diffraction losses, and losses due to coupling holes. These are the three loss mechanisms which are important in this study. The total Q of the resonator can be expressed as

$$\frac{1}{Q} = \frac{1}{Q_\Omega} + \frac{1}{Q_{d,c}} \tag{2}$$

where Q_Ω is the ohmic Q, and $Q_{d,c}$ is the Q due to diffraction and coupling losses. The ohmic Q is calculated using the formula

$$Q_\Omega = \frac{L}{4}(f\pi\mu_0\sigma)^{\frac{1}{2}}. \tag{3}$$

In this expression, μ_0 is the permeability of free space and σ is the conductivity of the mirrors. Silver- and gold-plated mirrors are used in the cold tests, with conductivities 6.15×10^7 and 4.5×10^7 Siemens/m, respectively. The ohmic Q increases linearly with separation and is unimportant for large output coupling.

The diffraction/coupling Q is calculated separately from the ohmic Q. This is accomplished by a computer code which is based on a scalar Huygen's formulation.[10] Inputs to the code include the wavelength of the radiation, the mirror radius, the radius of curvature of the mirrors, the separation between the mirrors, and the dimensions of a coupling hole. Some of these parameters are illustrated in Figure 1. The program also models cavities where the mirrors are not identical. Outputs from the code include $Q_{d,c}$, the balance between Q_d and Q_c , and the electric field distribution along the surface of each mirror for the TEM_{00} and TEM_{01} modes. Other modes may also be analyzed.

A chief obstacle to performing cold tests of millimeter-wave resonators is coupling power into the cavity without perturbing the Q too seriously. In this study, a small coupling hole is drilled through the center of one mirror. The size of the hole is chosen to minimize degradation of Q while coupling a meaningful amount of power into the cavity. The radius of the coupling hole is 0.38 mm. The calculated effect of the coupling hole can be seen in Figure 2. For separations greater than 20 cm, there is practically no difference between the two resonators. In the present Naval Research Laboratory QOG experiment, the separation can be varied between 20 and 28 cm. This resonator lies well within the confocal instability point at 38.7 cm separation and the concentric stability limit at 77.4 cm separation. Thus, this cold test cavity should be a good model for the experiment. Below 20 cm, any change in the round-trip losses results in a large change in the total Q, due to the small output coupling. Figure 3 shows the round-trip transmission loss due to diffraction as a function of separation for the cavity analyzed in Figure 2. The transmission varies between 2.5% to 6% in the range of interest.

III. Cold Test Apparatus

The experimental set-up is similar to that adopted by Perenoud *et al.*[9] A schematic diagram is shown in Figure 4. The entire arrangement is located on an optical table, with the quasi-optical mirrors mounted on six-inch diameter optical mounts which can be translated by hand on a rail.

A 0.76-mm diameter coupling hole pierces the left mirror. It is counterbored from behind, leaving a .005- to .010-inch wall. A WR-8 waveguide is inserted from the back of the coupling mirror for input, while a standard gain horn intercepts a small amount of the diffracted signal as output. In practice, the pick-up horn is placed next to the coupling mirror so that it may remain stationary while the far mirror is translated.

Two millimeter-wave sources are used for the measurements. The first is a 94 GHz IMPATT which produces 20 mW of power. Its frequency is swept by applying a 1-volt ramp to the FM port. The second source is a 120 GHz reflex klystron with a power output of several milliwatts. It is also swept with a low-voltage ramp, which is amplified in the klystron power supply/modulator and applied to the reflector. It is desirable to have a linear frequency sweep versus time for the millimeter-wave source. This allows for direct measurement of the full width at half maximum (FWHM) from the oscillocope with no corrections. Typical sweeps are 20 MHz for this work and are linear over the range of interest for most resonators.

A detector/amplifier manufactured by Millitech Corp., which has a sensitivity of 50 V/mW, is used to observe the small signals collected by the radiation pick-up. The detector and its power supply are shielded, which reduces the noise on the oscilloscope to 0.1 mV. Typical resonances observed on the oscilloscpe are 1-2 mV. The horizontal trace is calibrated using the interferometer in Figure 4. The interferometer is comprised of two six-inch diameter mirrors and has a Q of approximately 70,000. The separation can be varied between 32 and 43 cm, with fine adjustments facilitated by a micrometer graduated to 0.0001 inches. The interferometer would not be required if the quasi-optical cavity was mounted with a precision micrometer.

The resonator mirrors are made of oxygen-free, high-conductivity (OFHC) copper. They are machined, polished, and then plated with either silver or gold. The surface finish is $\lambda/20$ for $\lambda = 10\mu m$. Thus, surface scattering of millimeter waves should be negligible. The mirrors have a 0.5-mm bevel at the mirror's edge, which decreases the effective diameter by 1.0 mm.

A unique feature of the cold test arrangement is that the resonator mirrors are aligned with an HeNe laser. The incident beam defines the axis of the resonator, so that the mirror angle can be optimized by aligning the reflected and incident beams. The coupling hole is used to full advantage by passing the beam through the hole for centering and alignment. The resonator mirrors can be quickly aligned to better than $\frac{1}{10}^\circ$.

IV. Results

Figure 5 shows measured and calculated values of Q versus separation for a resonator with 4.6-cm diameter mirrors. The coupling hole is 0.76 mm in diameter and the frequency is 120 GHz. The radius of curvature is 38.7 cm for each of the mirrors used in this work.

The agreement between data and theory is quite good for separations greater than 20 cm, which is the region of operation the QOG. Measured values are somewhat higher than predicted at closer separations. This discrepancy may be due to the coupling hole.

A second set of measurements is shown in Figure 6. The frequency is 94 GHz, the resonator mirrors are 5.6 cm in diameter, and the coupling hole is 0.76 mm in diameter. The agreement between measured and calculated values is quite good. This resonator is similar to the resonator in Figure 5 in terms of Q.

Figure 7 shows data obtained with the 4.6-cm mirrors measured at 94 GHz. The values for Q are much lower due to increased diffraction losses at the longer wavelength. A Q of $7,000$ corresponds to a round-trip transmission coefficient of 18% for a separation of 26 cm.

The present QOG utilizes a symmetric cavity; the mirrors are identical. Future configurations may include asymmetric resonators which couple power from one side only. Figures 8 and 9 show measured and calculated Q's for slightly asymmetric cavitites. There is diffraction around both mirrors, with more loss from the smaller mirror. The code accurately predicts the properties of these asymmetric cavities.

Another valuable measurement is the effect of misaligned mirrors on the Q. Perrenoud *et al.*[9] found that 0.5° tilt resulted in a 50% degradation of Q for their configuration. This information is important because the mirrors must be attached to the magnet dewar, and it is difficult to estimate how well the dewar flanges are aligned. Figure 10 shows the effect of mirror misalignment on Q for one of the asymmetric cavities. The mirror separation is 15.8 cm and the frequency is 94 GHz. The Q begins degrading after 1° of misalignment. By 2°, the Q is reduced by 20%. The small scatter of the data for tilts less than 1° is indicative of the reproducibility of the measurement. In general, the sensitivity of the resonator to misalignment depends upon mirror size and separation. Increasing the separation to 25 cm has little effect on sensitivity to alignment for this cavity.

There are several sources of error in these measurements of Q versus separation. If the frequency sweep is not perfectly linear in time, a systematic error will be present. Secondly, there is a random error in reading the FWHM from the oscilloscope. A third source of error is due to the slightly asymmetric shape of the resonance on the oscilloscope. Adjusting the pick-up horn usually corrects this problem. Hence, the measured values should be accurate to better than ±10%. This error can be lowered to below ±5% with calibration and careful technique.

Acknowledgements

This work was supported by the Office of Fusion Energy of the Department of Energy and the Office of Naval Research.

References

[1] "CW Operation of a 140 GHz Gyrotron," K. Felch, B. Bier, L.J. Cragi, H. Huey, L. Ives, H. Jory, N. Lopez, and S. Spang, Int. J. Elec. **61**, 701 (1986).

[2] "Theory of the Quasi-Optical Electron Cyclotron Maser," P. Sprangle, J. Vomvoridis and W. Manheimer, Phys. Rev. A **23**, 3127 (1981).

[3] "Multimode Time Dependent Analysis of Quasi-Optical Gyrotrons and Gyroklystrons," A. Bondeson, W.M. Manheimer and E. Ott, Phys. Fluids **26**, 285 (1983).

[4] "Multimode Analysis of Quasi-Optical Gyrotrons and Gyroklystrons," A. Bondeson, B. Levush, W. Manheimer and E. Ott, Int. J. of Electronics **53**, 547 (1982)

[5] "Cavity Design for Quasi-Optical Gyrotron or Gyroklystron Operation at Harmonics of the Cyclotron Frequency," B. Levush and W. Manheimer, Intl. J. Infrared and Millimeter Waves **4**, No. 6, 877 (1983)

[6] "Fabry-Perot and Open Resonators at Microwave and Millimeter Wave Frequencies, 2-300 GHz," R.N. Clark and C.B. Rosenberg, J. Phys. E **15**, 9-24 (1982).

[7] "Loaded Q's and Field Profiles of Tapered Axisymmeteric Gyrotron Cavities," H. Derler, T.J. Grant, and D.S. Stone, IEEE Trans. Electron Devices, Vol **ED-29**, pp 1917-1929 (1982).

[8] "Nondestructive Gyrotron Cold Cavity Measurements," P. P. Woskoboinikow and W. J. Mulligan, IEEE Trans. Microwave Th. and Tech., Vol **MTT 35**, No. 2, pp 96-100 (1987).

[9] "Low Power Measurements of the Quality Factor of an Open Resonator with Stepped Mirrors," A. Perrenoud, M.Q. Tran, B. Isaak, A. Alberti, and P. Muggli, Intl Jour. of Infrared and Millimeter Waves **7**, No. 11, pp 1813-1822 (1986).

[10] Code written by K. Yoshioka, with a formulation similar to that found in "Open Resonator for Quasi-Optical Gyrotrons: Structure of the Modes and Their Influence," A. Perrenoud, T.M. Tran, M.Q. Tran, C. Rieder, M. Schlepipen, and A. Bondeson, Int. Journal of Electronics **57**, No. 6, pp 985-1001 (1984).

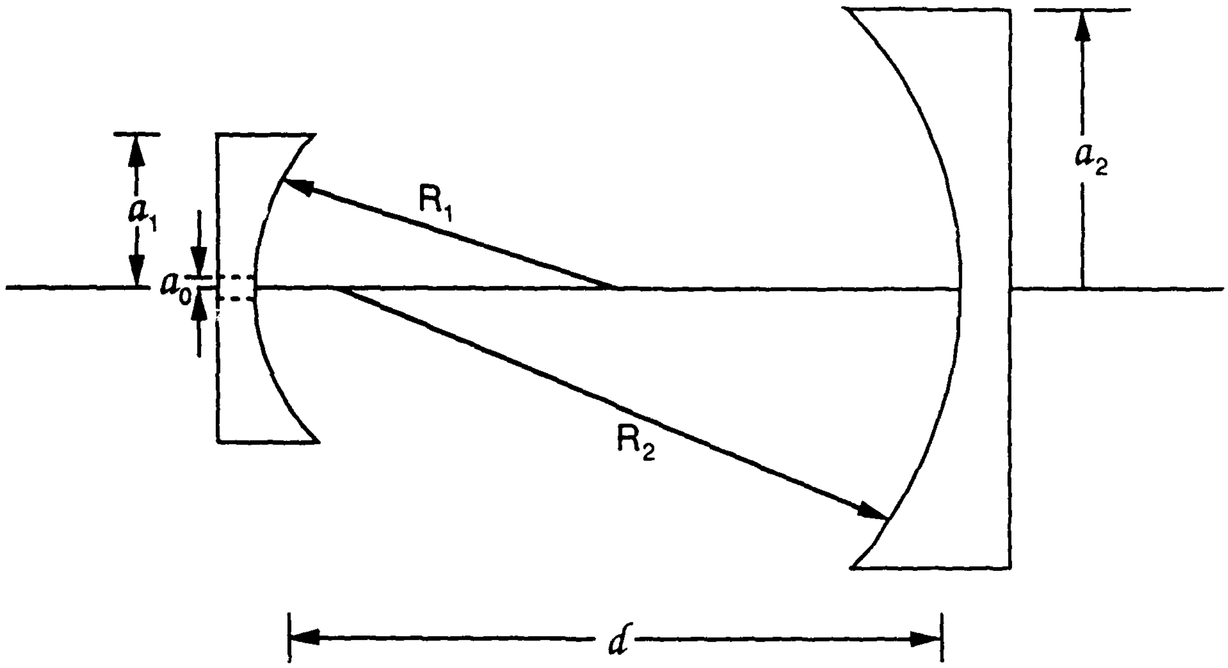

Figure 1 Cross section of a quasi-optical resonator showing two different sized mirrors with a hole for input coupling.

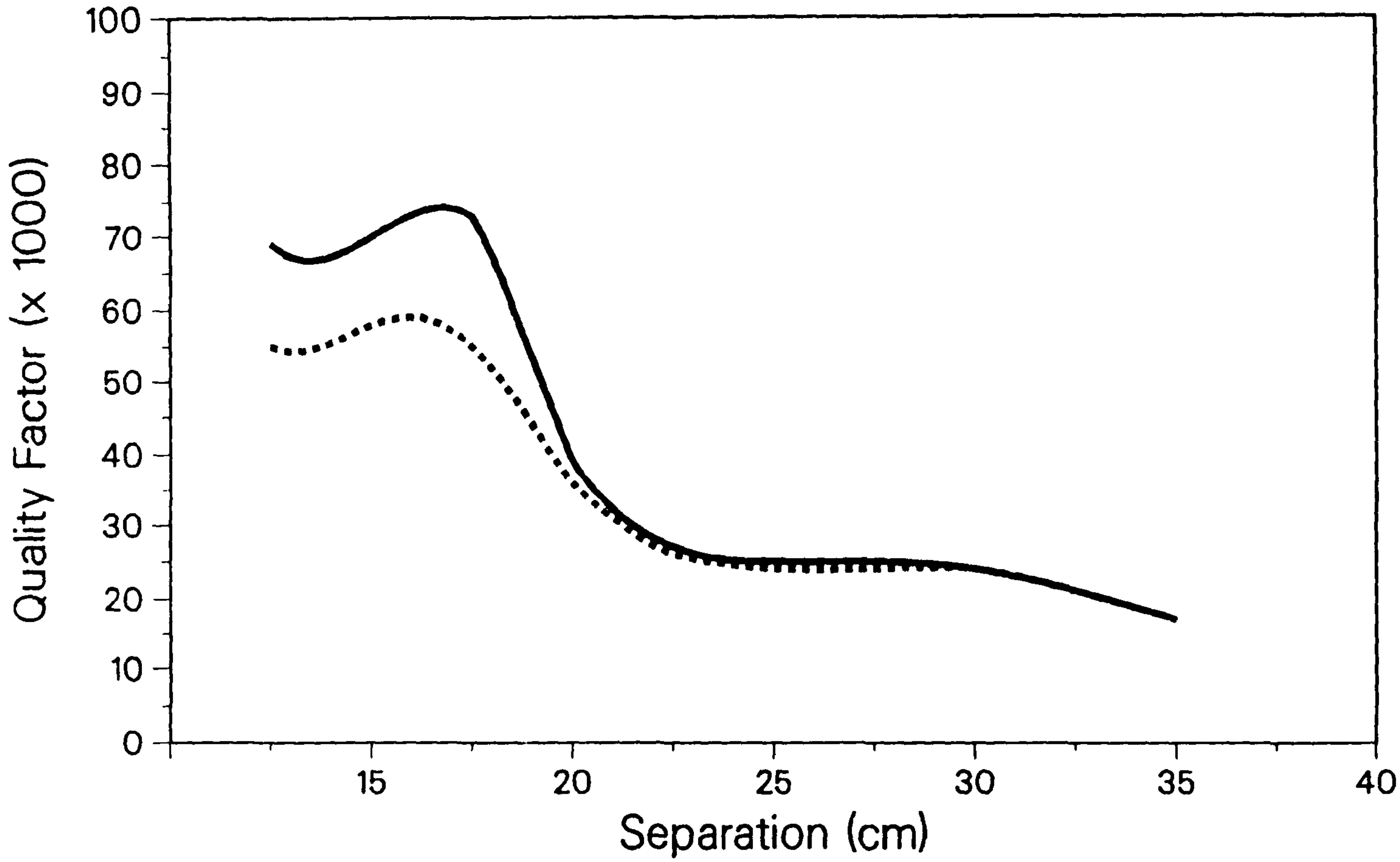

Figure 2 The calculated effect of a coupling hole on the cavity Q. The solid curve is the resonator without the hole; the dashed curve is for a cavity with a 0.76-mm diameter coupling hole (frequency =120 GHz, mirror diameter = 4.6 cm, radius of curvature = 38.7 cm).

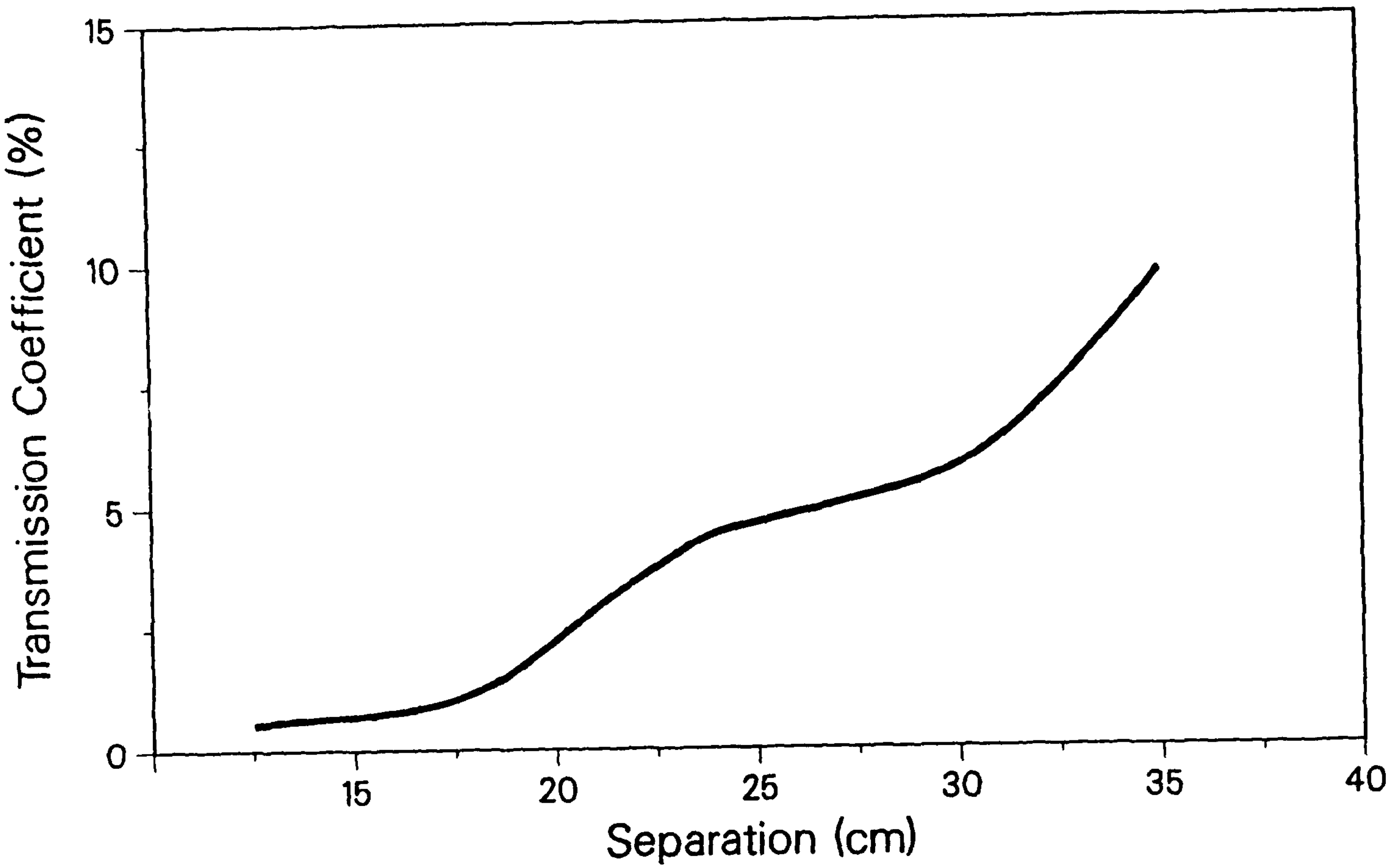

Figure 3 Round-trip transmission coefficient versus mirror separation (frequency = 120 GHz, mirror diameter = 4.6 cm, radius of curvature = 38.7 cm). The separation is typically varied between 20 and 28 cm in the QOG.

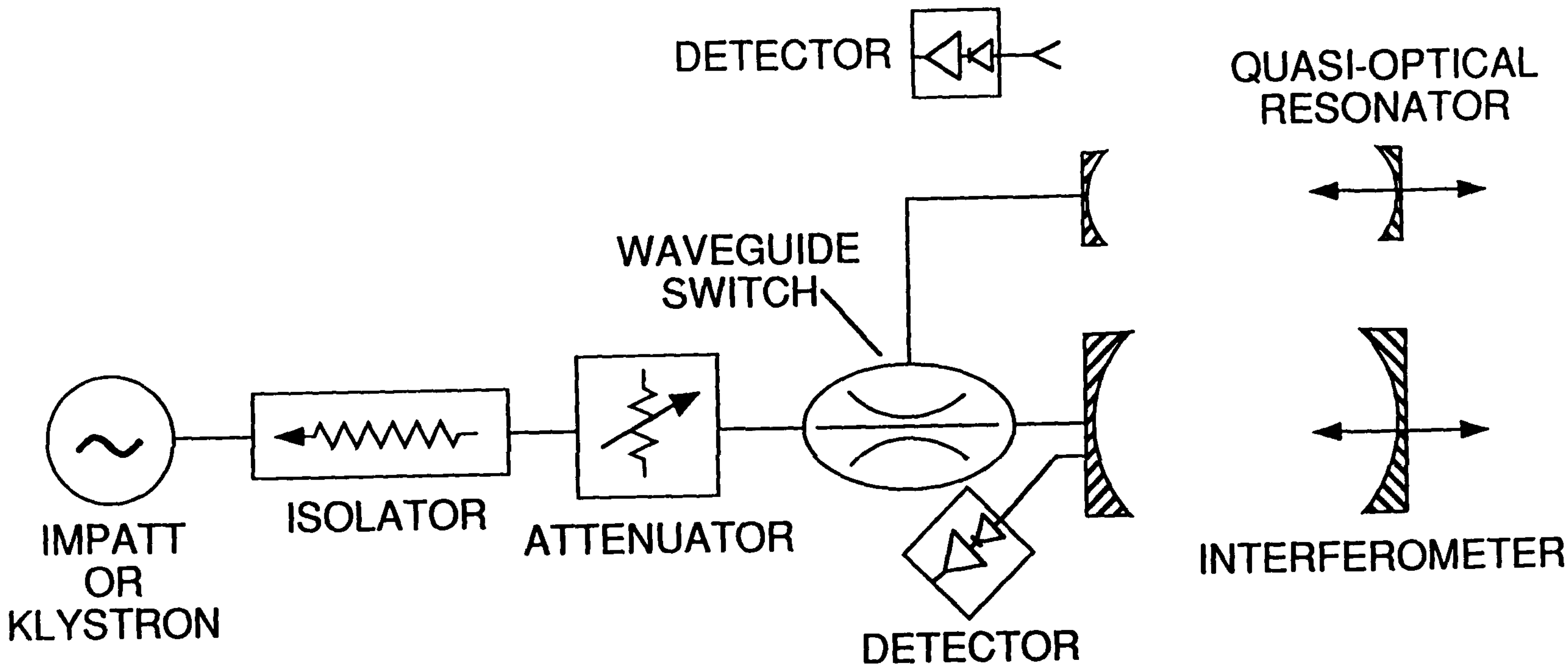

Figure 4 Schematic diagram of the cold-test apparatus. Output is collected as diffraction around one of the quasi-optical mirrors.

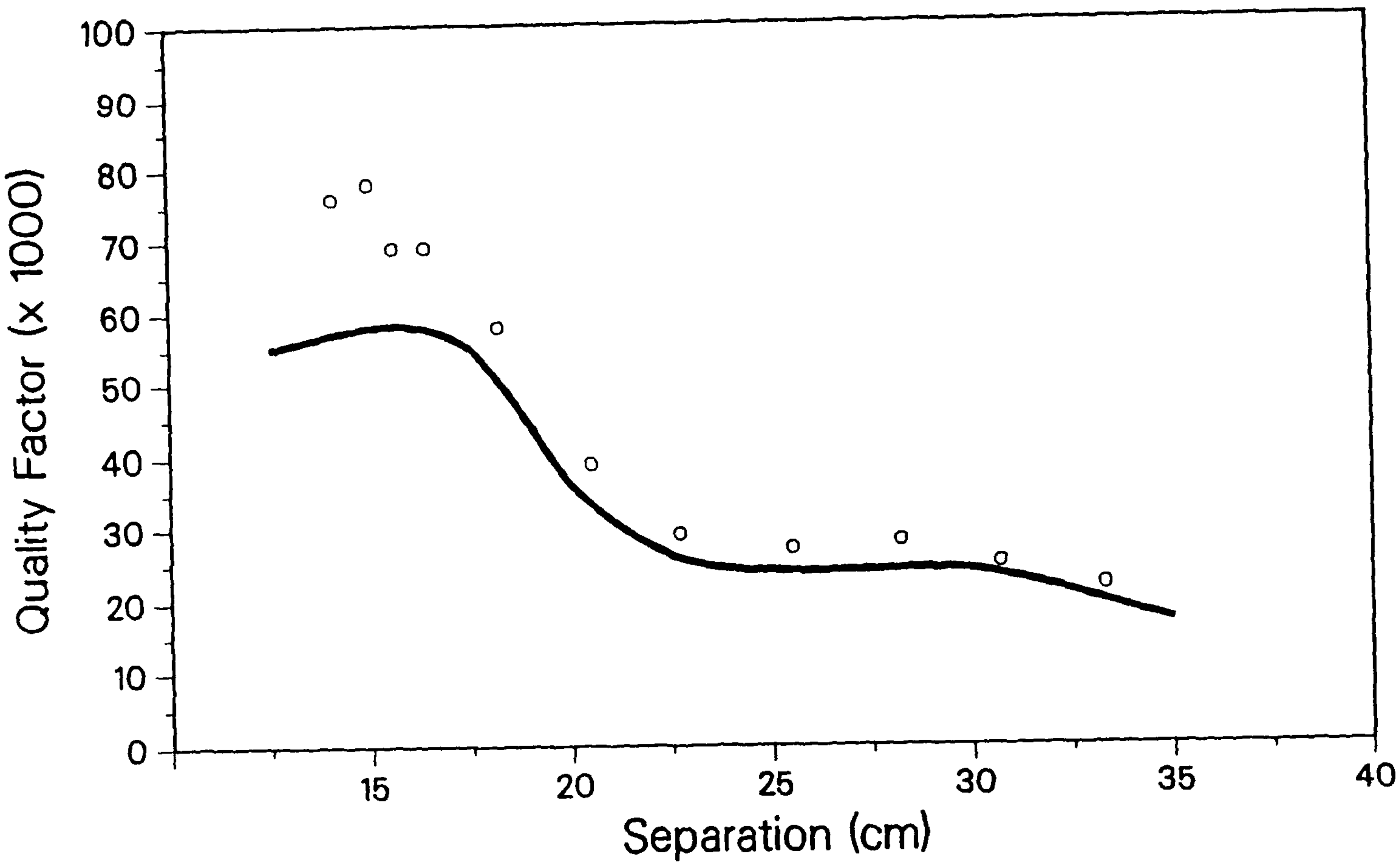

Figure 5 Measured (open dots) and theoretical values (solid curve) of cavity Q versus mirror separation (frequency = 120 GHz, mirror diameter = 4.6 cm, radius of curvature = 38.7 cm, hole diameter = 0.76 mm).

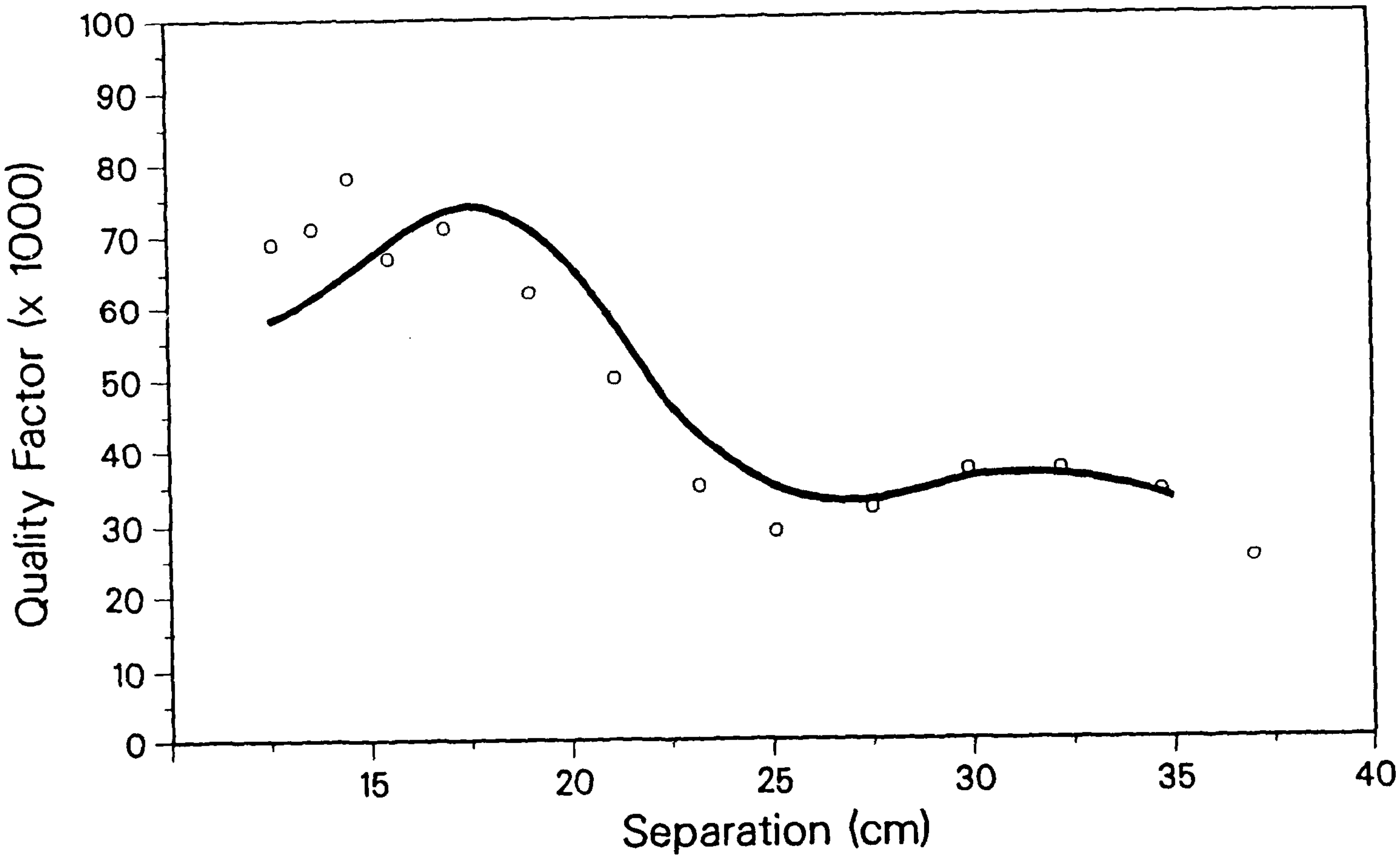

Figure 6 Measured (open dots) and theoretical values (solid curve) of cavity Q versus separation (frequency = 94 GHz, mirror diameter = 5.6 cm, radius of curvature = 38.7 cm, hole diameter = 0.76 mm).

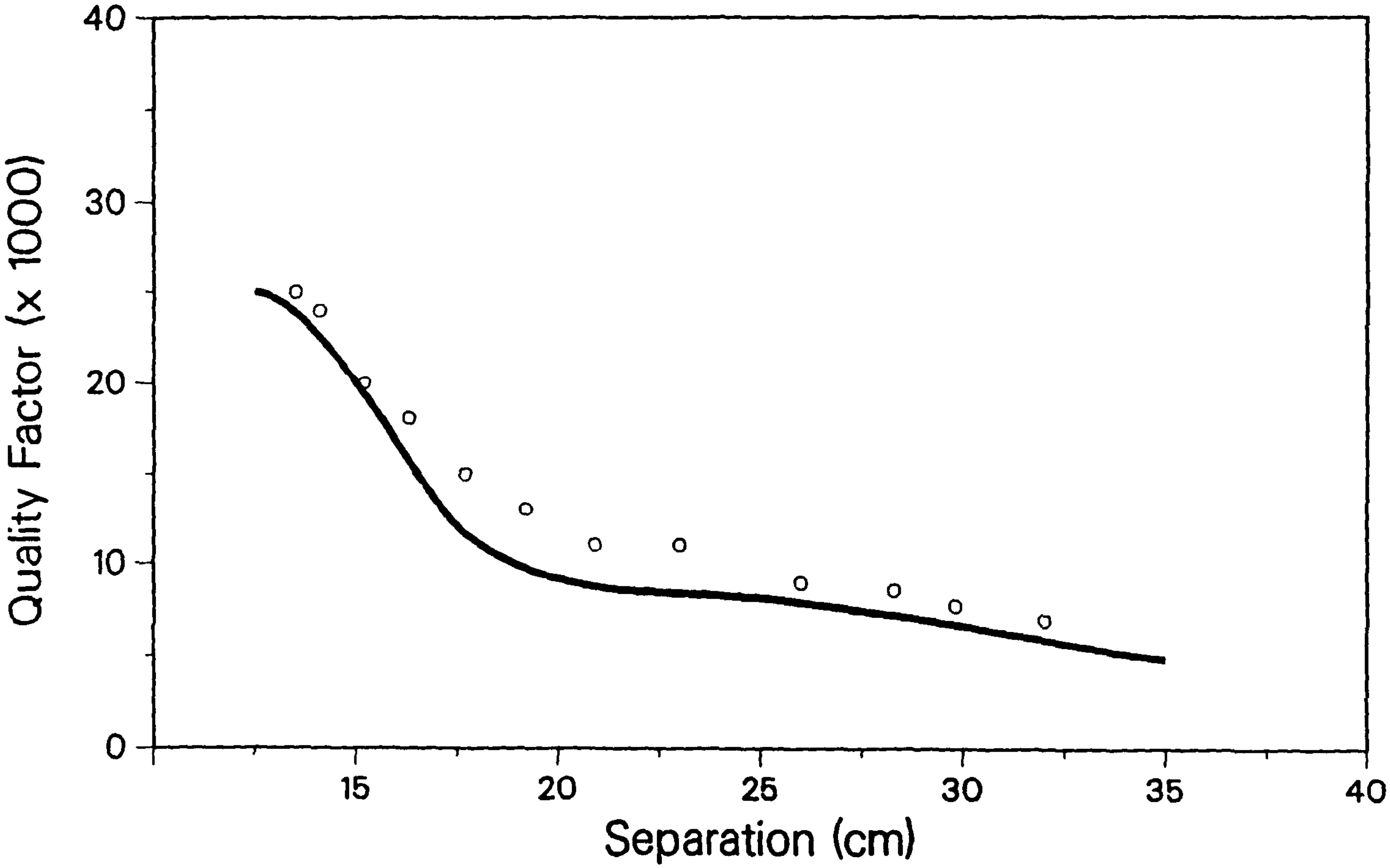

Figure 7 Measured (open dots) and theoretical values (solid curve) of cavity Q versus separation (frequency = 94 GHz, mirror diameter = 4.6 cm, radius of curvature = 38.7 cm, hole diameter = 0.76 mm).

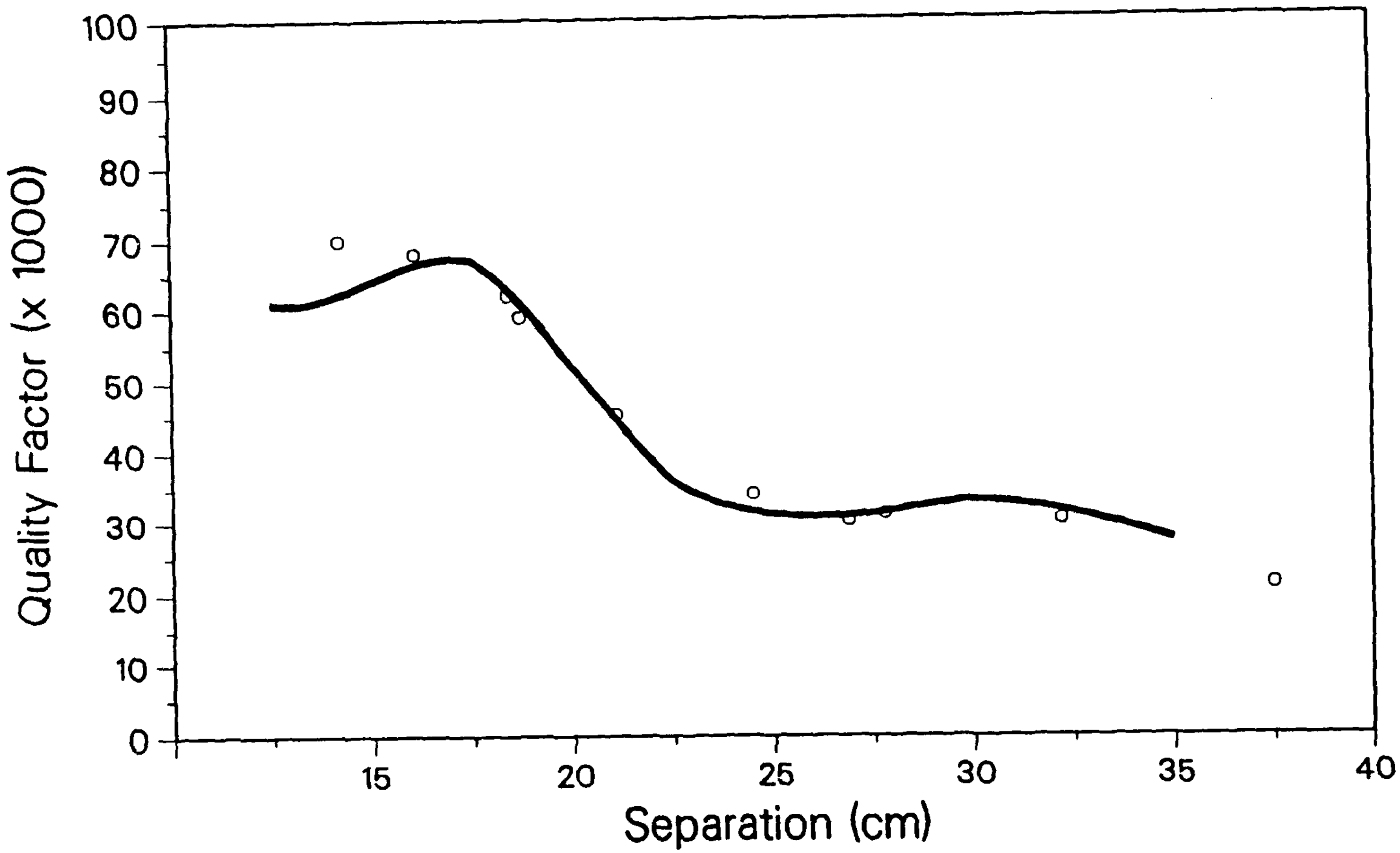

Figure 8 Measured (open dots) and theoretical values (solid curve) of cavity Q versus separation for an asymmetric resonator (frequency = 120 GHz, mirror 1(2) diameter = 4.6(5.0) cm, radius of curvature = 38.7 cm, hole diameter = 0.76 mm).

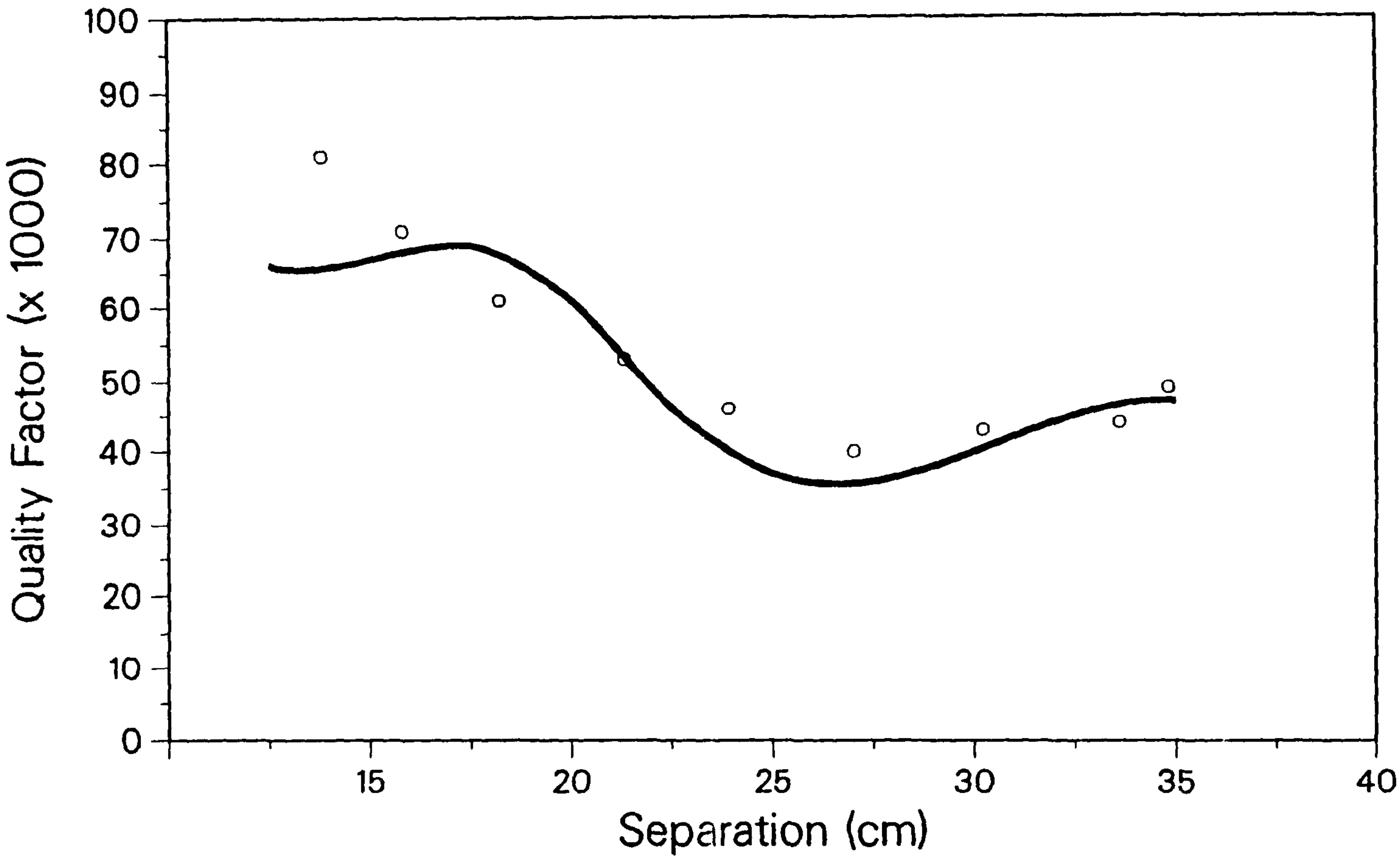

Figure 9 Measured (open dots) and theoretical values (solid curve) of cavity Q versus separation for an asymmetric resonator (frequency = 120 GHz, mirror 1(2) diameter = 4.6(5.6) cm, radius of curvature = 38.7 cm, hole diameter = 0.76 mm).

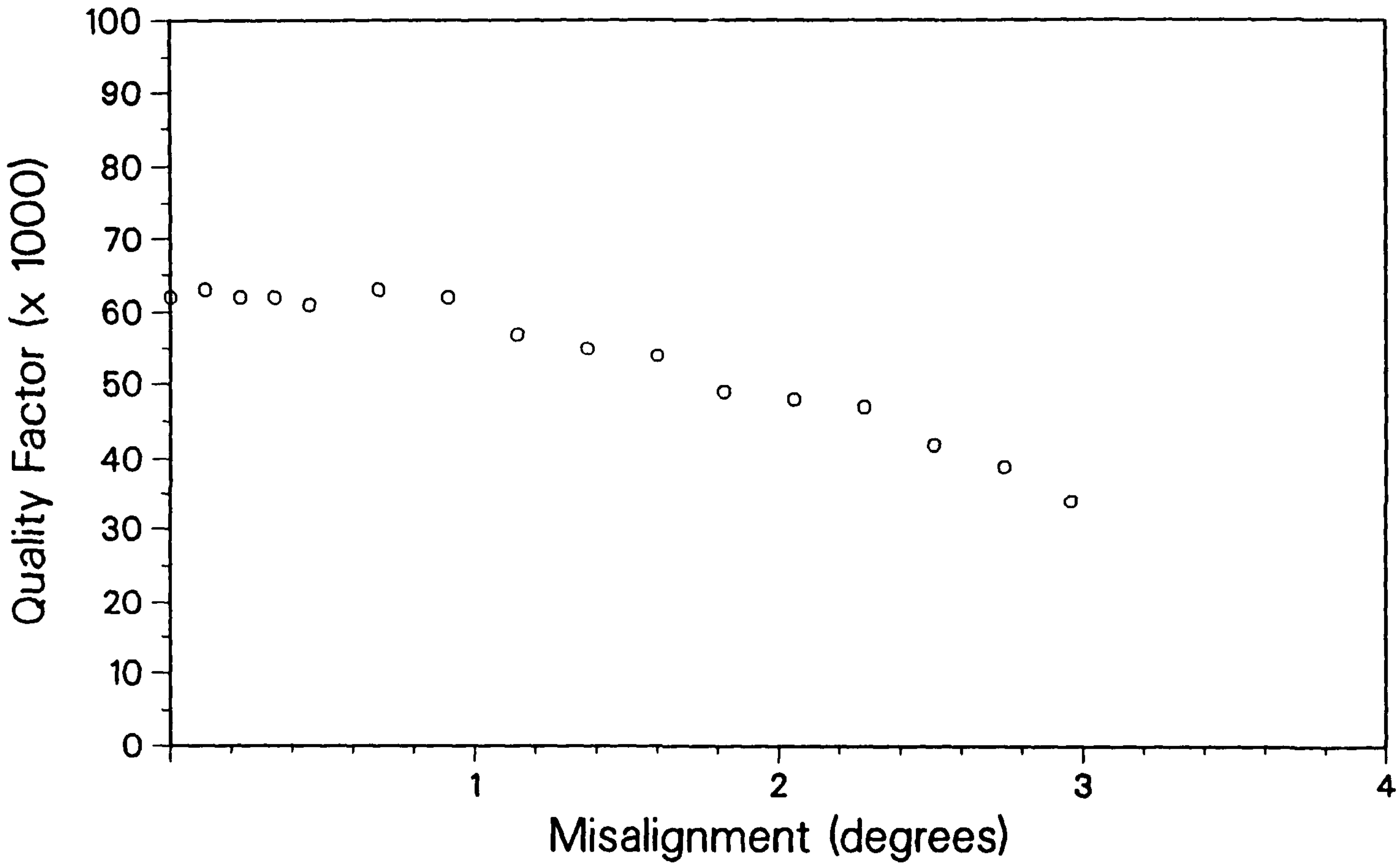

Figure 10 Cavity Q versus mirror misalignment (frequency = 94 GHz, mirror 1(2) diameter = 5.0(5.6) cm, radius of curvature = 38.7 cm, hole diameter = 0.76 mm).

4793/4 DISTRIBUTION LIST

Air Force Avionics Laboratory AFWAL/AADM-1 Wright/Patterson AFB, OH 45433 Attn: Walter Friez	1 copy
Air Force Office of Scientific Research Bolling AFB Washington, D.C. 20332 Attn: H. Schlossberg	1 copy
Air Force Weapons Lab Kirkland AFB Albuquerque, NM 87117 Attn: Dr. William Baker	2 copies
Dr. A.H. Guenter	1 copy
Bhabha Atomic Research Center Laser Division Bombay, India 400085 Attn: T.S. Shirsat	1 copy
Columbia University 520 West 120th Street Department of Electrical Engineering New York, NY 10027 Attn: Dr. S.P. Schlesinger	1 copy
A. Sen	1 copy
Columbia University 520 West 120th Street Department of Applied Physics and Nuclear Engineering New York, NY 10027 Attn: T.C. Marshall	1 copy
R. Gross	1 copy
Cornell University School of Applied and Engineering Physics Ithica, NY 14853 Attn: Prof. Hans H. Fleischmann	1 copy
John Nation	1 copy
R. N. Sudan	1 copy
Creol-FEL Research Pavillion 12424 Research Parkway, Suite 400 Orlando, FL 32826 Attn: Dr. Luis R. Elias	1 copy
Dr. I. Kimel	1 copy

Dartmouth College
18 Wilder, Box 6127
Hanover, NH 03755
Attn: Dr. John E. Walsh 1 copy

Defense Advanced Research Project Agency/DEO
1400 Wilson Blvd.
Arlington, VA 22209
Attn: Dr. L. Buchanan 1 copy

Defense Communications Agency
Washington, D.C. 20305
Attn: Dr. Pravin C. Jain
Assistant for Communications
Technology 1 copy

Defense Nuclear Agency
Washington, D.C. 20305
Attn: Mr. J. Farber 1 copy
Dr. Leon Wittwer (RAAE) 5 copies

Defense Technical Information Center
Cameron Station
5010 Duke Street
Alexandria, VA 22314 2 copies

Department of Energy
Div. of Advanced Energy Projects
Washington, DC 20545
Attn: Dr. R. Gajewski 1 copy

Department of Energy
Office of Energy Research
Washington, D.C. 20545
Attn: C. Finfgeld/ER-542, GTN 1 copy
T.V. George/ER-531, GTN 1 copy
D. Crandall/ER-54, GTN 1 copy
Dr. David F. Sutter/ER-224, GTN 1 copy

Director of Research
U. S. Naval Academy
Annapolis, MD 21402-5021 1 copy

General Atomics
13-260
Box 85608
San Diego, CA 92138
ATTN: Dr. J. Doane 1 copy
Dr. C. Moeller 1 copy

Georgia Tech. EES-EOD
Baker Building
Atlanta, GA 30332
Attn: Dr. James J. Gallagher — 1 copy

Hanscomb Air Force Base
Stop 21, MA 01731
Attn: Lt. Rich Nielson/ESD/INK — 1 copy

Hughes Aircraft Co.
Electron Dynamics Division
3100 West Lomita Boulevard
Torrance, CA 90509
Attn: J. Christiansen — 1 copy
J. Tancredi — 1 copy

Hughes Research Laboratory
3011 Malibu Canyon Road
Malibu, CA 90265
Attn: Dr. R. Harvey — 1 copy
Dr. R.W. Schumacher — 1 copy

KMS Fusion, Inc.
3941 Research Park Dr.
P.O. Box 1567
Ann Arbor, MI 48106
Attn: S.B. Segall — 1 copy

Lawrence Berkeley Laboratory
University of California
1 Cyclotron road
Berkeley, CA 94720
Attn: Dr. A.M. Sessler — 1 copy

Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550
Attn: Dr. D. Prosnitz — 1 copy
Dr. T.J. Orzechowski — 1 copy
Dr. J. Chase — 1 copy
Dr. W.A. Barletta — 1 copy
Dr. D.L. Birx — 1 copy
Dr. R. Briggs — 1 copy
Dr. E.T. Scharlemann — 1 copy

Litton Electron Devices
960 Industrial Road
San Carlos, CA 94070
Attn: Library — 1 copy

Los Alamos National Scientific Laboratroy P.O. Box 1663, MSJ 564 Los Alamos, NM 87545 Attn: Dr. Brian Newman	1 copy
Los Alamos Scientific Laboratory P.O. Box 1663, AT5-827 Los Alamos, NM 87545 Attn: Dr. T.J.T. Kwan	1 copy
Dr. L. Thode	1 copy
Dr. C. Brau	1 copy
Dr. R. R. Bartsch	1 copy
Massachusetts Institute of Technology Department of Physics Cambridge, MA 02139 Attn: Dr. G. Bekefi/36-213	1 copy
Dr. M. Porkolab/NW 36-213	1 copy
Dr. R. Davidson/NW 16-206	1 copy
Dr. A. Bers/NW 38-260	1 copy
Dr. K. Kreischer	1 copy
Dr. B. Danby	1 copy
Dr. G.L. Johnston	1 copy
Massachusetts Institute of Technology 167 Albany St., N.W. 16-200 Cambridge, MA 02139 Attn: Dr. R. Temkin/NW 14-4107	1 copy
Mission Research Corporation 8560 Cinderbed Road, Suite 700 Newington, VA 22122 Attn: Dr. M. Bollen	1 copy
Dr. Tom Hargreaves	1 copy
Dr. J. Pasour	1 copy
Naval Research Laboratory Addressee: Attn: Name/Code Code 0124 - ONR	1 copy
Code 1000 - Commanding Officer	1 copy
Code 1001 - T. Coffey	1 copy
Code 1003.9A - Computer Resources Architect	1 copy
Code 1005 - Head, Office of Mgt. & Admin.	1 copy
Code 1005.1 - Deputy Head, Off. of Mgt. & Admin.	1 copy
Code 1005.6 - Head, Directives Staff	1 copy
Code 1200 - Capt. M.A. Howard	1 copy
Code 1201 - Deputy Head, Command Support Division	1 copy
Code 1220 - Security	1 copy
Code 2000 - J. Brown	1 copy
Code 2604 - NRL Historian	1 copy
Code 2628 - TID Distribution	22 copies
Code 2634 - Cindy Sims	1 copy
Code 3000 - R. Doak	1 copy

Code 4000 - W. Ellis	1 copy
Code 4000 - D. Nagel	1 copy
Code 4700 - S. Ossakow	26 copies
Code 4700.1 - A. Ali	1 copy
Code 4790 - Branch Office	25 copies
Code 4790 - W. Black	1 copy
Code 4790 - G. Cooperstein	1 copy
Code 4790 - A. Fliflet	1 copy
Code 4790 - S. Gold	1 copy
Code 4790 - C. Hui	1 copy
Code 4790 - C. Kapetanakos	1 copy
Code 4790 - A. Kinkead	1 copy
Code 4790 - Y. Lau	1 copy
Code 4790 - W. Manheimer	1 copy
Code 4790 - M. Rhinewine	1 copy
Code 4790 - P. Sprangle	1 copy
Code 5700 - L. Cosby	1 copy
Code 6840 - S. Ahn	1 copy
Code 6840 - A. Ganguly	1 copy
Code 6840 - R. Parker	1 copy
Code 6840 - N. Vanderplaats	1 copy
Code 6850 - L. Whicker	1 copy
Code 6875 - R. Wagner	1 copy

Naval Sea Systems Command
Department of the Navy
Washington, D.C. 20362
Attn: Commander, PMS 405-300 — 1 copy

Northrop Corporation
Defense Systems Division
600 Hicks Rd.
Rolling Meadows, IL 60008
Attn: Dr. Gunter Dohler — 1 copy

Oak Ridge National Laboratory
P.O. Box Y
Mail Stop 3
Building 9201-2
Oak Ridge, TN 37830
Attn: Dr. A. England — 1 copy

Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217
Attn: Dr. C. Roberson — 1 copy

Office of Naval Research
1012 W 36th Street, Childs Way Bldg.
Los Angeles, CA 90089-1022
Attn: Dr. R. Behringer — 1 Copy

Optical Sciences Center
University of Arizona
Tucson, AZ 85721
Attn: Dr. Willis E. Lamb, Jr. — 1 copy

Physical Science Inc.
603 King Street
Alexandria, VA 22314
ATTN: M. Read — 1 copy

Physics International
2700 Merced Street
San Leandro, CA 94577
Attn: Dr. J. Benford — 1 copy

Princeton Plasma
Plasma Physics Laboratory
James Forrestal Campus
P.O. Box 451
Princeton, NJ 08544

Attn: Dr. H. Hsuan	2 copies
Dr. D. Ignat	1 copy
Dr. H. Furth	1 copy
Dr. P. Efthimion	1 copy
Dr. F. Perkins	1 copy

Raytheon Company
Microwave Power Tube Division
Foundry Avenue
Waltham, MA 02154
Attn: N. Dionne — 1 copy

Sandia National Laboratories
ORG. 1231, P.O. Box 5800
Albuquerque, NM 87185

Attn: Dr. Thomas P. Wright	1 copy
Mr. J.E. Powell	1 copy
Dr. J. Hoffman	1 copy
Dr. W.P. Ballard	1 copy
Dr. C. Clark	1 copy

Science Applications, Inc.
1710 Goodridge Dr.
McLean, VA 22102

Attn: Adam Drobot	1 copy
P. Vitello	1 copy
D. Bacon	1 copy
C. Menyuk	1 copy

Science Research Laboratory
15 Ward Street
Somerville, MA 02143
Attn: Dr. R. Shefer — 1 copy

SPAWAR
Washington, D.C. 20363
Attn: E. Warden, Code PDE 106-3113 — 1 copy
Capt. Fontana, PMW 145 — 1 copy

Spectra Technologies
2755 Northup Way
Bellevue, WA 98004
Attn: Dr. J.M. Slater — 1 copy

Stanford University
Dept. of Electrical Engineering
Stanford, CA 94305
Attn: Dr. J. Feinstein — 1 copy

Stanford University
High Energy Physics Laboratory
Stanford, CA 94305
Attn: Dr. T.I. Smith — 1 copy

Stanford University
SLAC
Stanford, CA 94305
Attn: Dr. Jean Labacqz — 1 copy

TRW, Inc.
One Space Park
Redondo Beach, CA 90278
Attn: Dr. H. Boehmer — 1 copy
Dr. T. Romisser — 1 copy
Dr. Z. Guiragossian — 1 copy

University of California
Physics Department
Irvine, CA 92717
Attn: Dr. G. Benford — 1 copy
Dr. N. Rostoker — 1 copy

University of California
Department of Physics
Los Angeles, CA 90024
Attn: Dr. A.T. Lin — 1 copy
Dr. N. Luhmann — 1 copy
Dr. D. McDermott — 1 copy

University of Maryland
Department of Electrical Engineering
College Park, MD 20742
Attn: Dr. V. L. Granatstein — 1 copy
Dr. W. W. Destler — 1 copy

University of Maryland
Laboratory for Plasma and Fusion
Energy Studies
College Park, MD 20742

Attn:	Dr. Tom Antonsen	1 copy
	Dr. John Finn	1 copy
	Dr. Jhan Varyan Hellman	1 copy
	Dr. W. Lawson	1 copy
	Dr. Baruch Levush	1 copy
	Dr. Edward Ott	1 copy
	Dr. M. Reiser	1 copy

University of New Mexico
Department of Physics and Astronomy
800 Yale Blvd, N.E.
Albuquerque, NM 87131

Attn:	Dr. Gerald T. Moore	1 copy

University of Tennessee
Dept. of Electrical Engr.
Knoxville, TN 37916

Attn:	Dr. I. Alexeff	1 copy

University of Utah
Department of Electrical Engineering
3053 Merrill Engineering Bldg.
Salt Lake City, UT 84112

Attn:	Dr. Larry Barnett	1 copy
	Dr. J. Mark Baird	1 copy

U. S. Army
Harry Diamond Labs
2800 Powder Mill Road
Adelphi, MD 20783-1145

Attn:	Dr. Howard Brandt	1 copy
	Dr. Edward Brown	1 copy
	Dr. Stuart Graybill	1 copy
	Dr. A. Kehs	1 copy
	Dr. J. Silverstein	1 copy

Varian Associates
611 Hansen Way
Palo Alto, CA 94303

Attn:	Dr. H. Huey	1 copy
	Dr. H. Jory	1 copy
	Dr. Kevin Felch	1 copy
	Dr. R. Pendleton	1 copy
	Dr. A. Salop	1 copy

Varian Eimac San Carlos Division
301 Industrial Way
San Carlos, CA 94070

Attn:	C. Marshall Loring	1 copy

WL/CA
Kirtland AFB, NM 87117-6008
Attn: Mr. Brendan B. Godfrey — 1 copy

Yale University
Applied Physics
Madison Lab
P.O. Box 2159
Yale Station
New Haven, CN 06520
Attn: Dr. I. Bernstein — 1 copy

Ken Busby — 1 copy