APPENDIX II

MEASUREMENTS

MEASUREMENTS

X-Ray Measurements

Figure 65, illustrates the Bravais-Miller nomenclature system for the atomic planes most commonly used in checking AT-cut quartz plates. Either the $01\cdot\bar{1}$ plane, or the $02\cdot\bar{2}$ plane which is parallel to it but has a different Bragg angle, is used to find the angular displacement of a quartz plate from these atomic planes, which intersect the quartz Z-axis at an angle of 38°13'. If the plates are not definitiely known to be AT-cuts, the sense of their displacement from the $01\cdot\bar{1}$ or $02\cdot\bar{2}$ planes may be determined by comparison with the $02\cdot\bar{3}$ plane, which is located 49°45' from the Z-axis. (A 35°15' AT-cut must not only lie 2°58' from the $01\cdot\bar{1}$ or $02\cdot\bar{2}$ planes, but must also lie 14°30' from the $02\cdot\bar{3}$ plane.)

Figure 66* shows a quartz crystal as seen from an X-direction; the radial lines indicate the atomic planes which are parallel to the X-direction. Each such plane is identified by Miller indices, Bragg angle, angular displacement from the Z-direction, and relative reflection intensity. Also indicated are the relative orientations of several well-known cuts.

X-ray intensity curves, in Figures 67, 68, and 69, show the effects upon reflection intensity of double crystal vs. single crystal goniometry, choice of atomic reference plane, and various surface conditions of the quartz plate being tested.

Figures 70, 71, 72 show how the accuracy of a ZZ' angle measurement depends upon unwanted rotations of an AT-cut plate with respect to the atomic reference plane and/or the goniometer instrument. It is to be noted from Figures 70 and 71, that the use of the $01\cdot\bar{1}$ plane is somewhat safer than the $02\cdot\bar{2}$ plane, since the ZZ' errors are smaller for a given accidental rotation about the Y' or Z' axes. Figure 72 contains the same kind of information given in Figure 70, but includes the effects of variation in Bragg angle θ_B for other cuts than the AT. In either case the rotation of the reflecting plane is around the Z' axis.

* Catherine Barclay, and Leland T. Sogn, "Reference Data for Orienting Quartz Plates by X-ray Diffraction," National Bureau of Standards Circular 543.

FIGURE 65

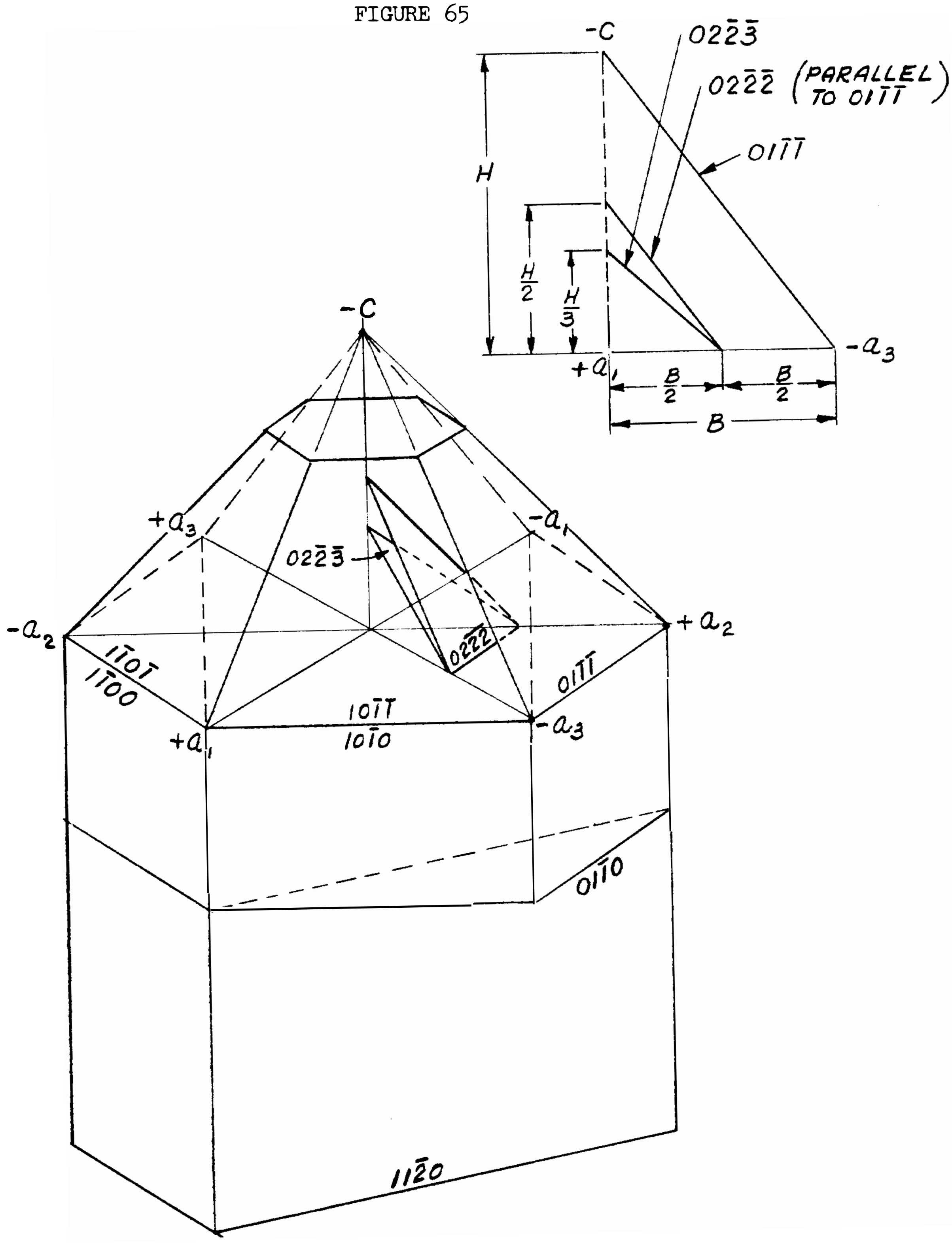
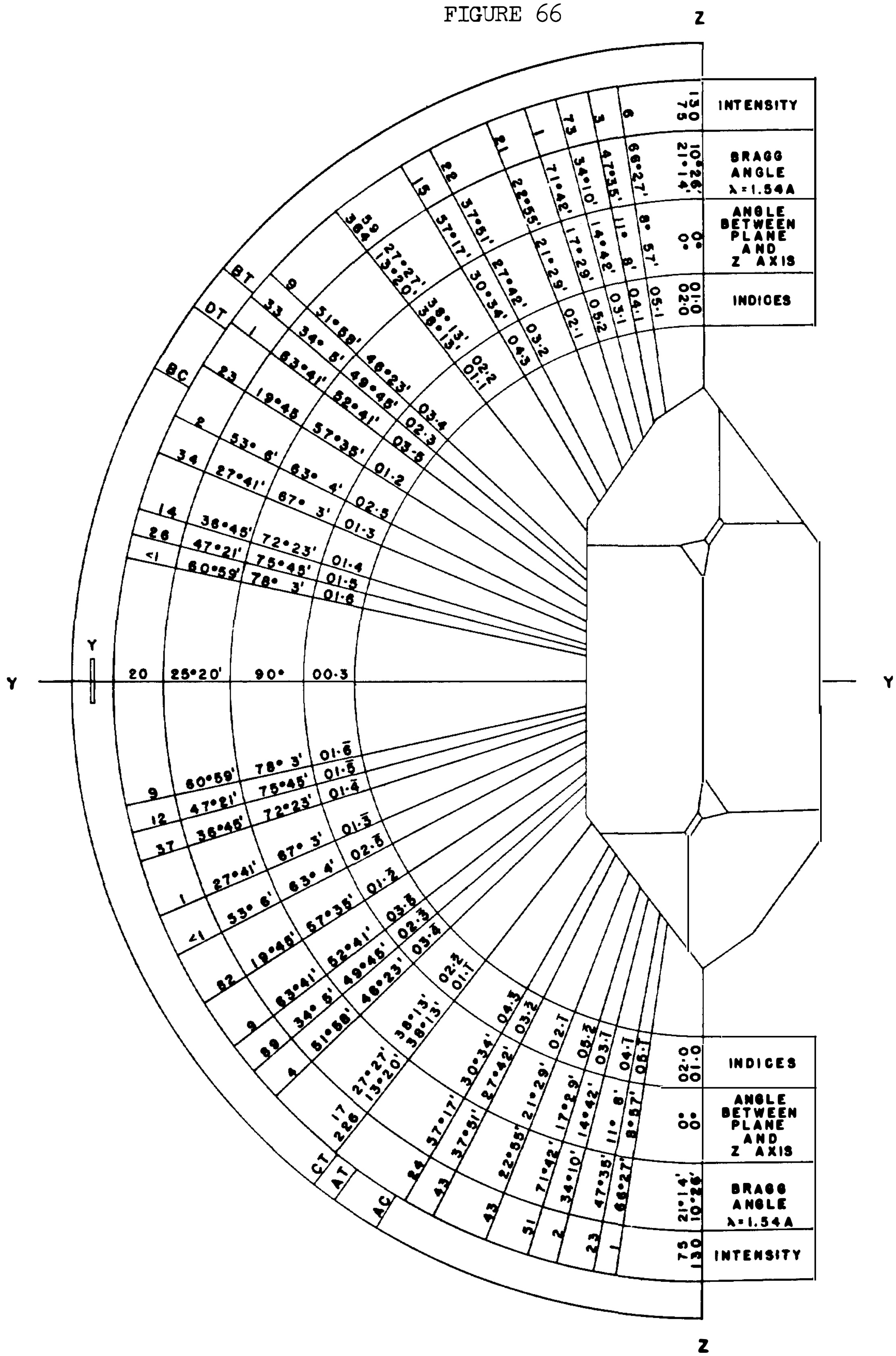

-C
$02\bar{2}\bar{3}$
$02\bar{2}\bar{2}$ (PARALLEL TO $01\bar{1}\bar{1}$)
$01\bar{1}\bar{1}$
H
$\frac{H}{2}$
$\frac{H}{3}$
$-a_3$
$+a_1$
$\frac{B}{2}$
$\frac{B}{2}$
B
-C
$+a_3$
$-a_1$
$02\bar{2}\bar{3}$
$-a_2$
$+a_2$
$02\bar{2}\bar{2}$
$1\bar{1}0\bar{1}$
$1\bar{1}00$
$01\bar{1}\bar{1}$
$10\bar{1}\bar{1}$
$10\bar{1}0$
$+a_1$
$-a_3$
$01\bar{1}0$
$11\bar{2}0$

FIGURE 66



ATOMIC PLANES PARALLEL TO X-AXIS

Catherine Barclay and Leland T. Sogn
NBS Circular 543 (July 24, 1953)

FIGURE 67

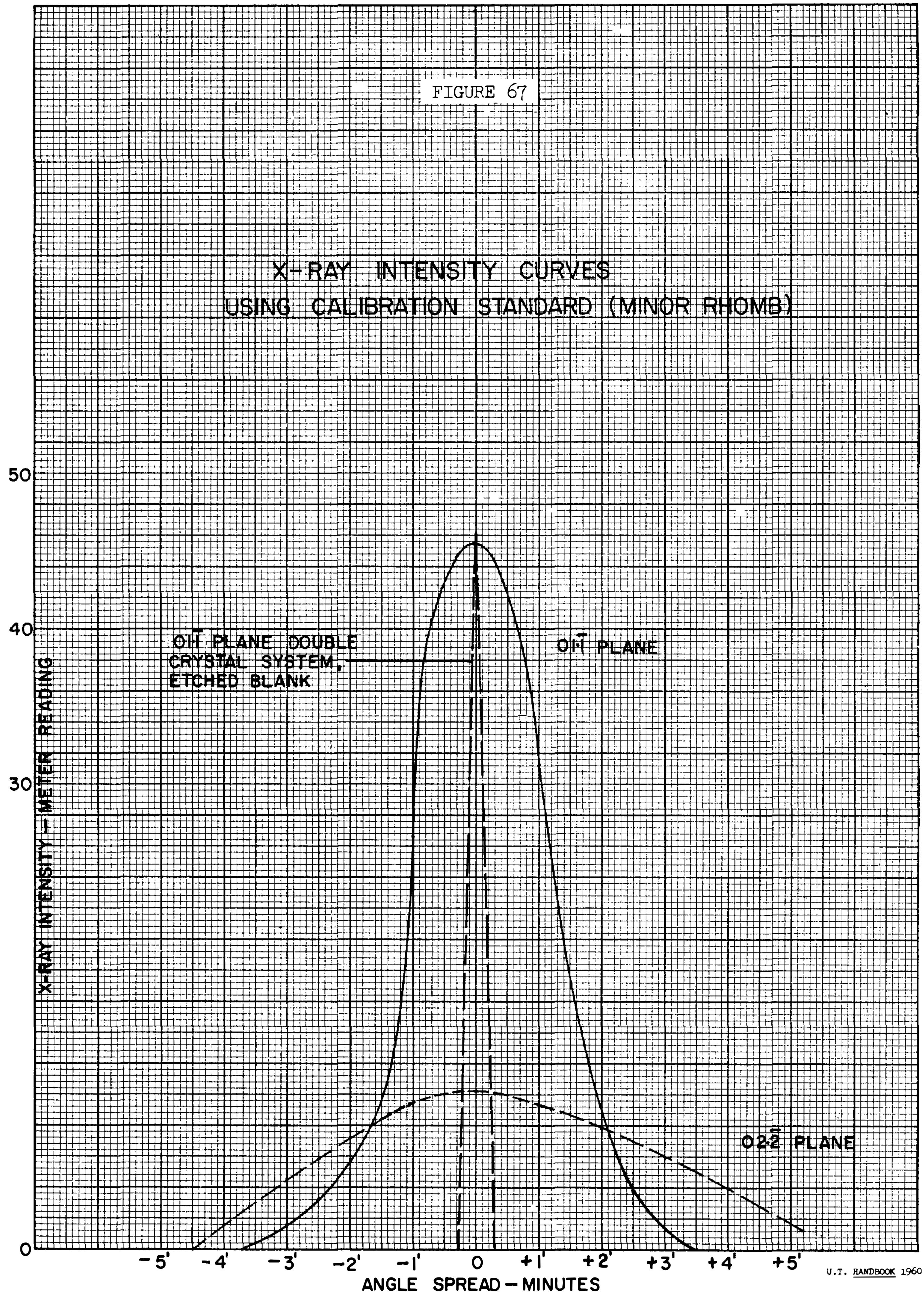
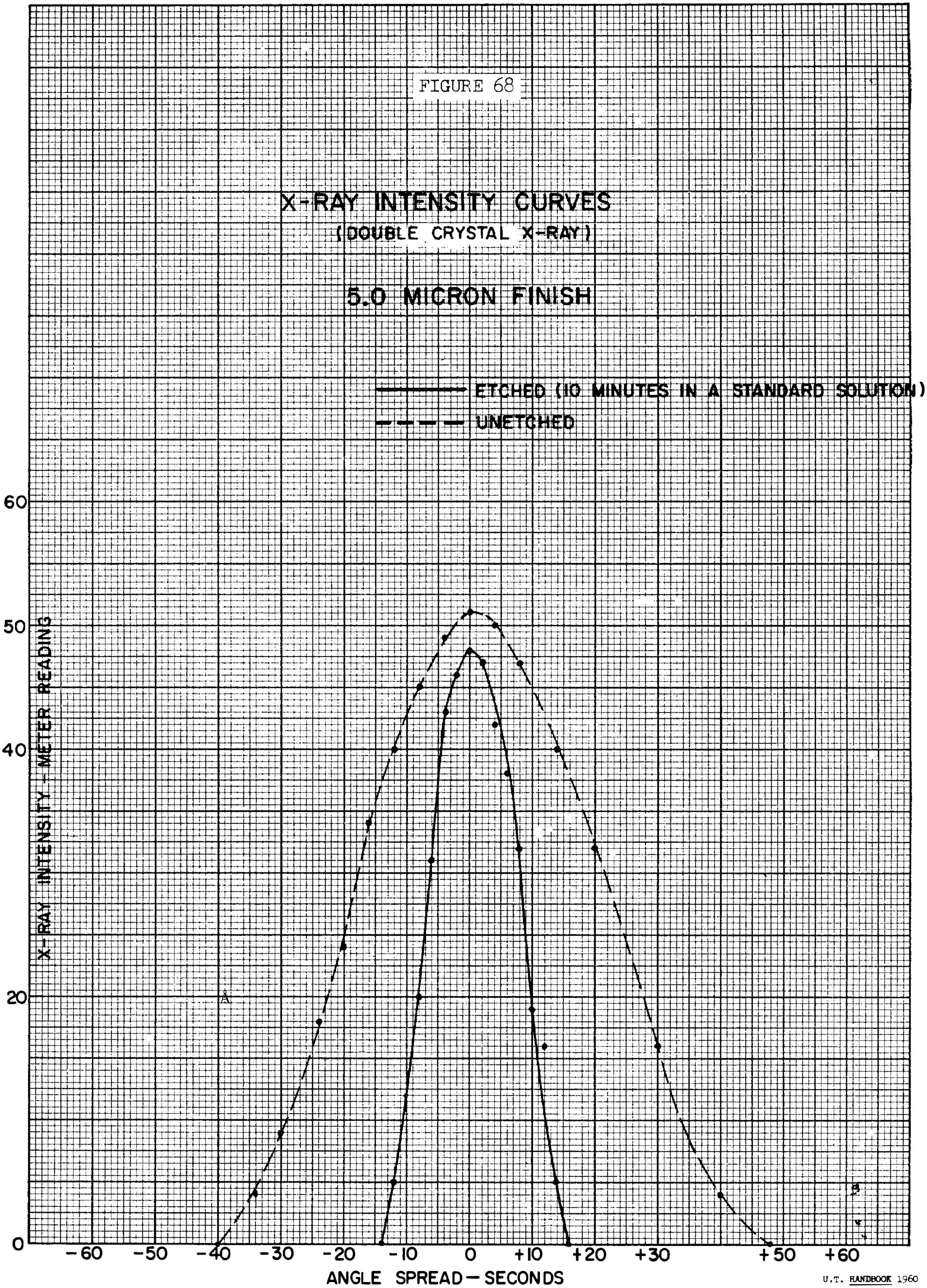

X-RAY INTENSITY CURVES
USING CALIBRATION STANDARD (MINOR RHOMB)
50
40
30
0
X-RAY INTENSITY — METER READING
OI1̄ PLANE DOUBLE
CRYSTAL SYSTEM,
ETCHED BLANK
OI1̄ PLANE
02 2̄ PLANE
−5' −4' −3' −2' −1' 0 +1' +2' +3' +4' +5'
ANGLE SPREAD — MINUTES

FIGURE 68


X-RAY INTENSITY CURVES
(DOUBLE CRYSTAL X-RAY)
5.0 MICRON FINISH
ETCHED (10 MINUTES IN A STANDARD SOLUTION)
UNETCHED
X-RAY INTENSITY - METER READING
60
50
40
20
0
-60
-50
-40
-30
-20
-10
0
+10
+20
+30
+50
+60
ANGLE SPREAD — SECONDS

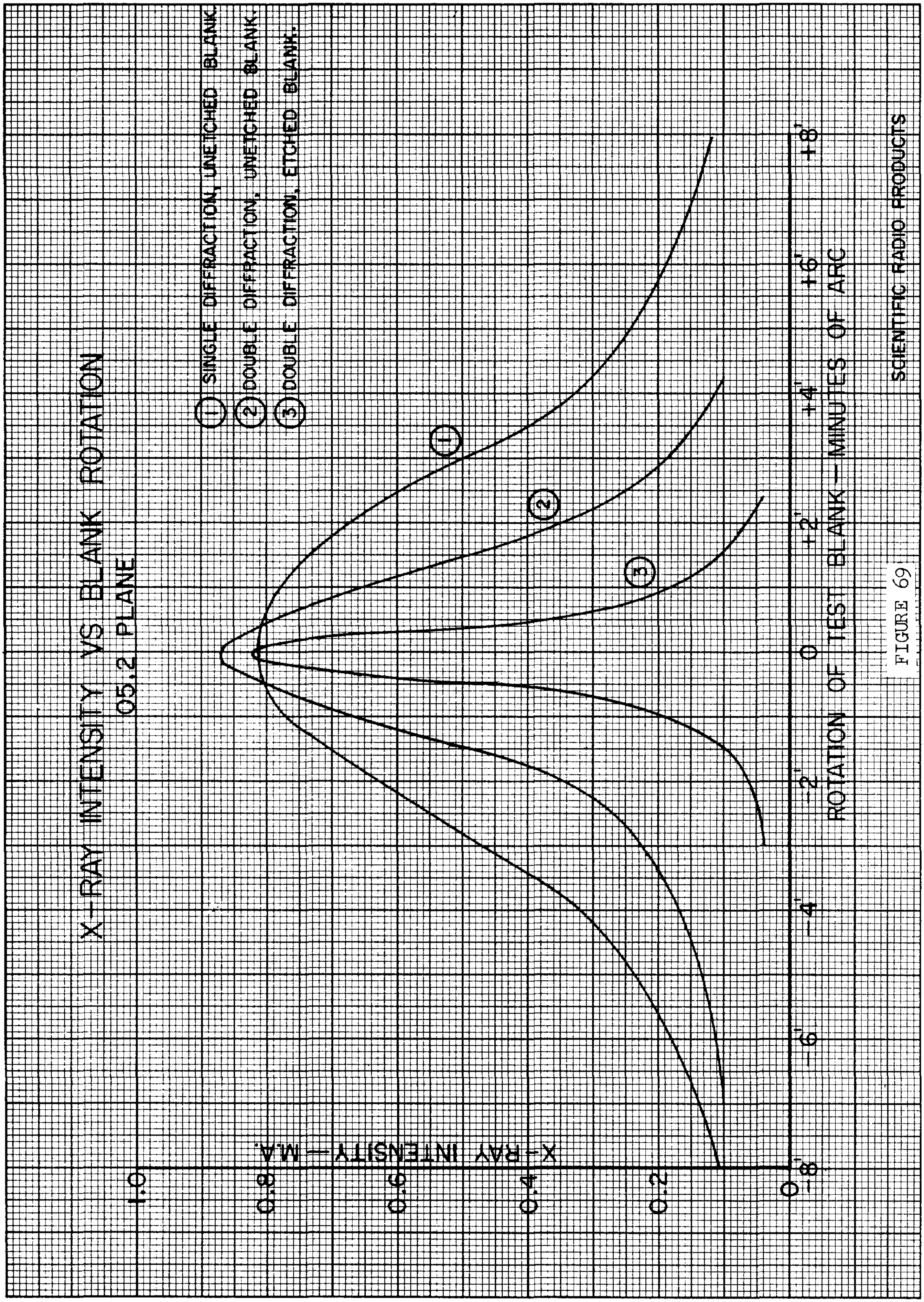

X-RAY INTENSITY VS BLANK ROTATION
05.2 PLANE
(1) SINGLE DIFFRACTION, UNETCHED BLANK.
(2) DOUBLE DIFFRACTION, UNETCHED BLANK.
(3) DOUBLE DIFFRACTION, ETCHED BLANK.
X-RAY INTENSITY — M.A.
1.0
0.8
0.6
0.4
0.2
0
−8'
−6'
−4'
−2'
0
+2'
+4'
+6'
+8'
ROTATION OF TEST BLANK — MINUTES OF ARC
SCIENTIFIC RADIO PRODUCTS

FIGURE 69

FIGURE 70

ZZ' ANGLE MEASUREMENT ERRORS DUE TO A ROTATION β ABOUT Z' FOR A 35° 15' AT CUT

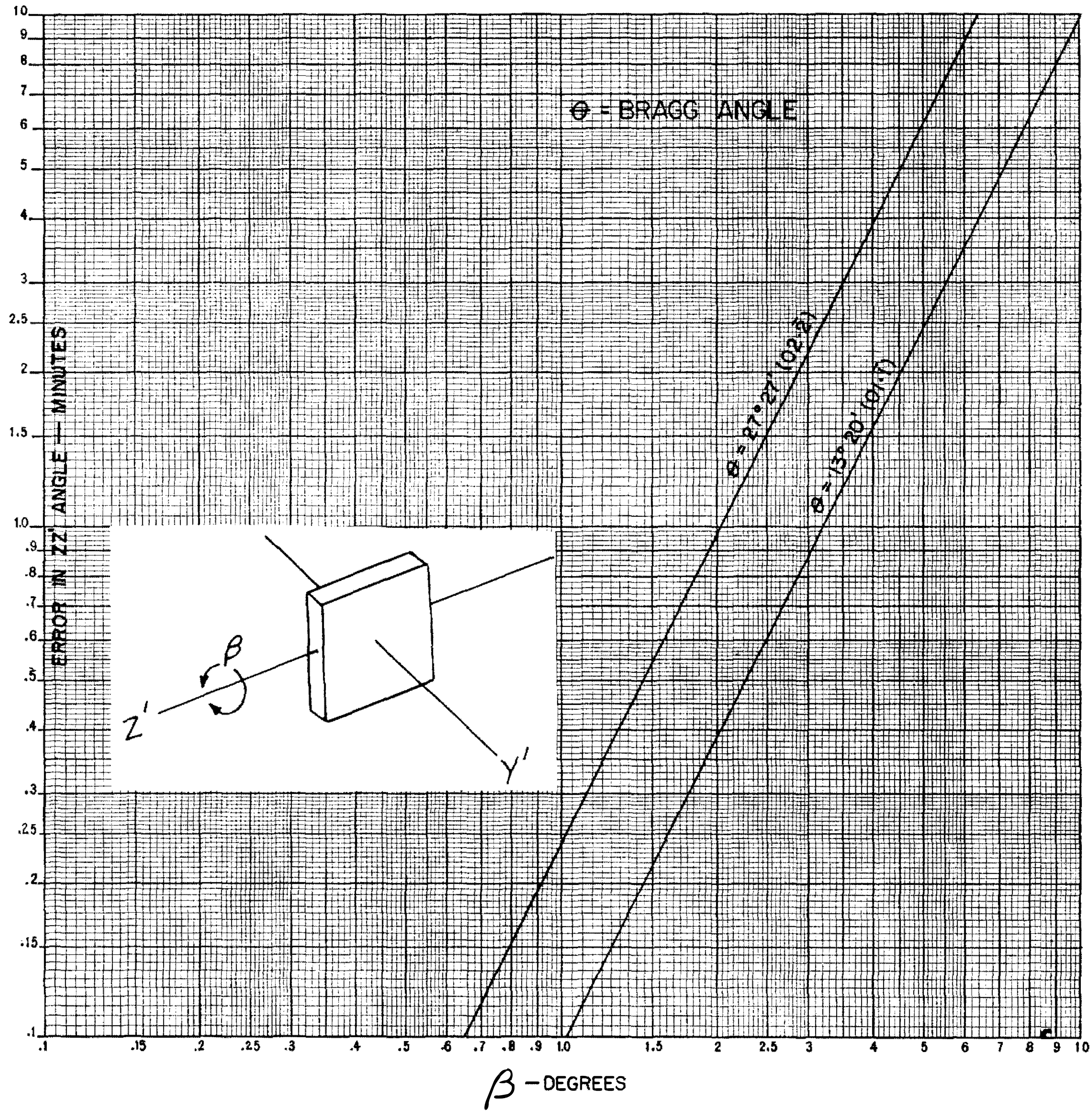


FIGURE 71

ZZ' ANGLE MEASUREMENT ERRORS DUE TO
A ROTATION α ABOUT Y' FOR A 35°15' AT CUT

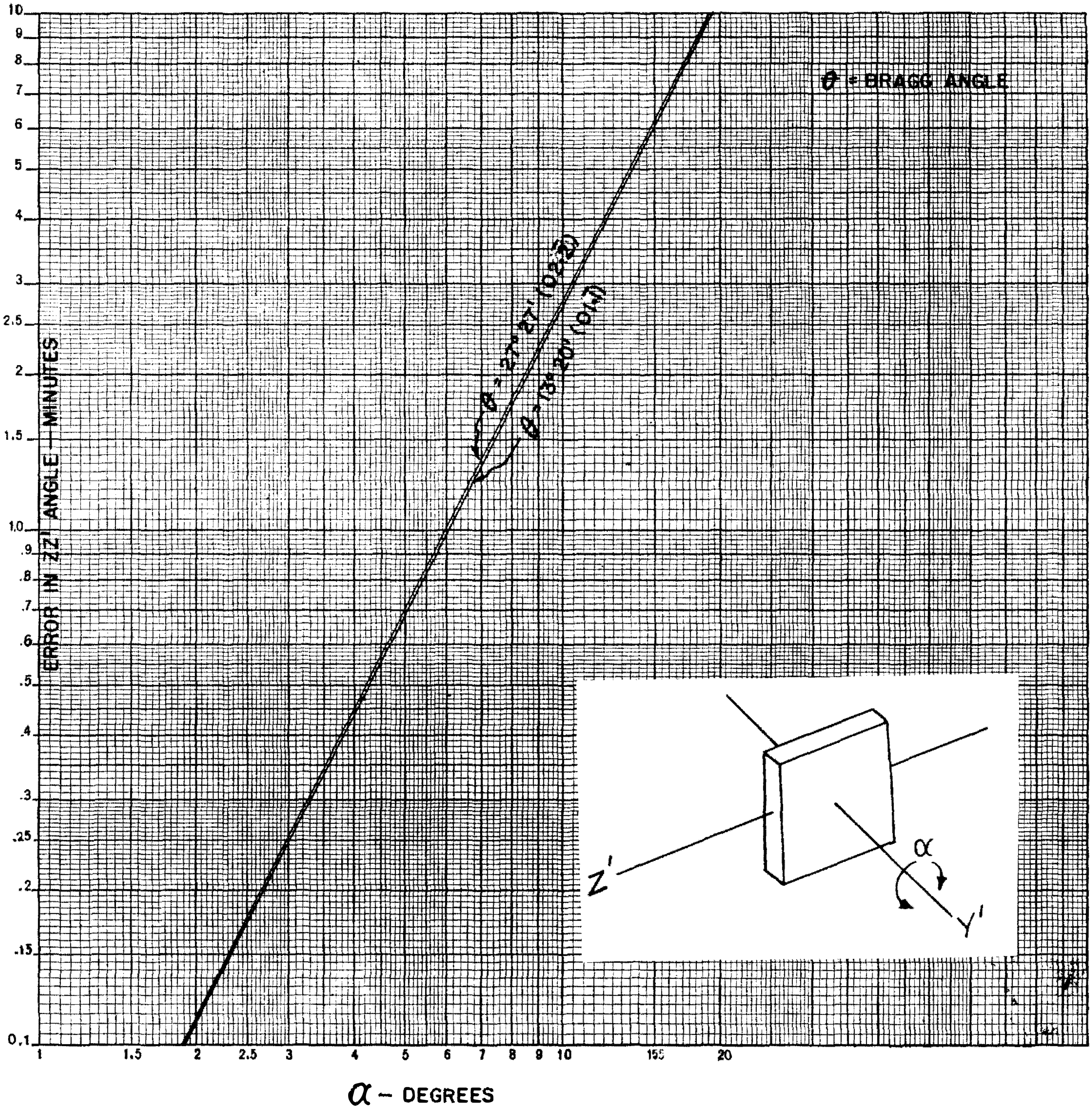
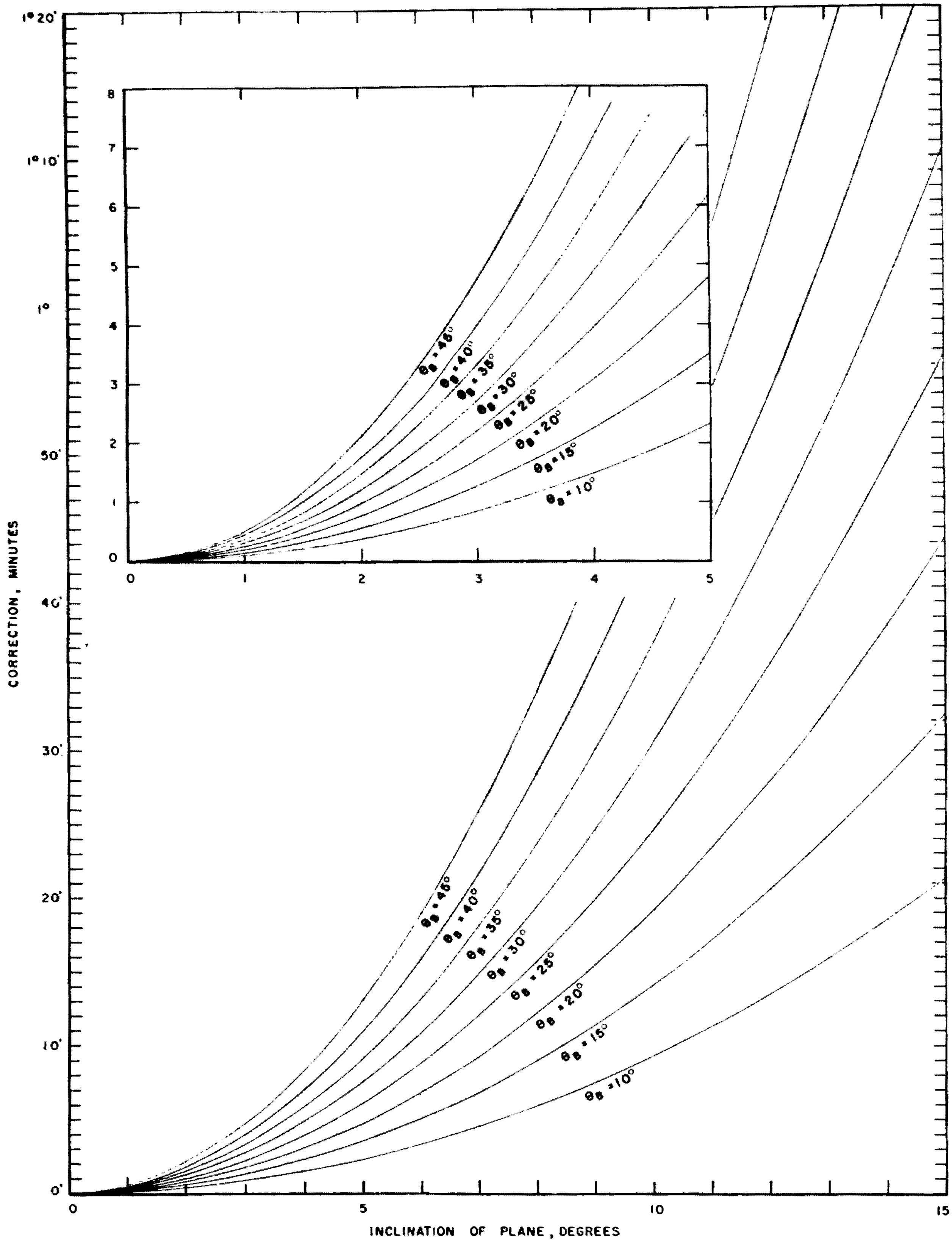


FIGURE 72



Graph showing the amount to be added to the angular reading when the reflecting plane is inclined.

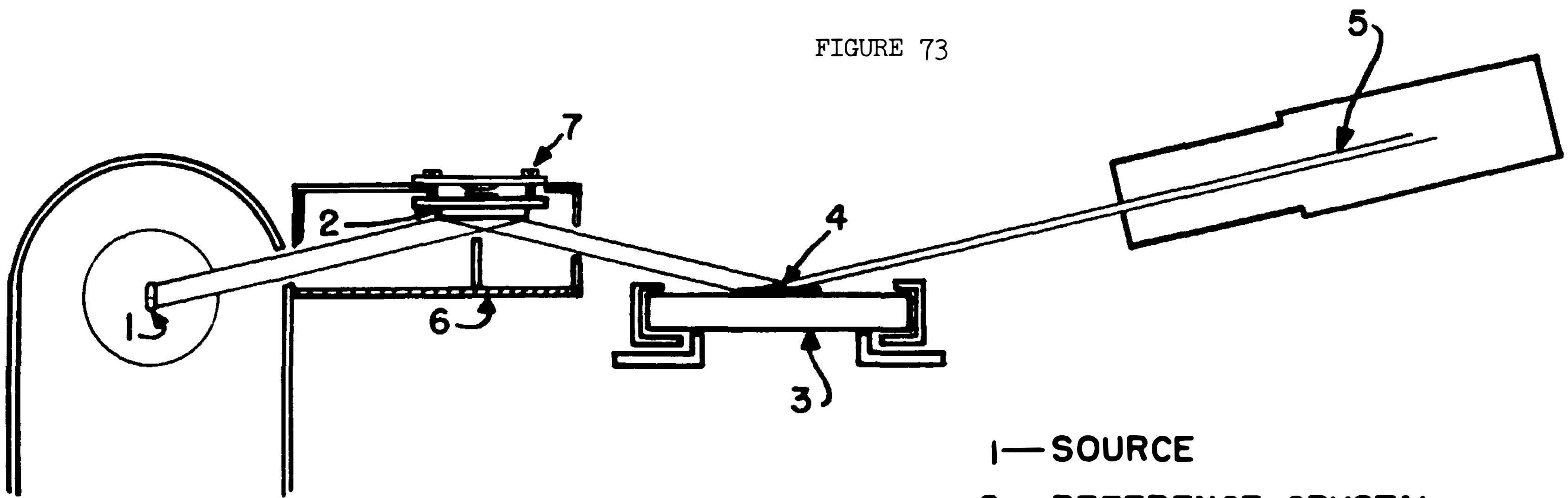
This graph is for the same rotation as Figure 70, but covers a larger range. From Catherine Barclay and Leland T. Sogn, "Reference Data for Orienting Quartz Plates by X-Ray Diffraction," National Bureau of Standards Circular 543 (July 24,1953).

The advantages of a double-crystal X-ray system were discussed by W. L. Bond, "A Double-Crystal X-Ray Goniometer for Accurate Orientation Determination," Proceedings of the I.R.E., vol.38 (August, 1950), pp. 886-889, and by D. L. Hammond, Double Crystal X-Ray Goniometer for Precise Orientation Measurement of Polished Crystalline Plates, Engineering Report Nr. E 1212, U. S. Army Signal Research and Development Laboratories, (15 August 1957). For the application of the double crystal system to standard General Electric X-Rays see James T. Lavan and others, Two Double Crystal X-Ray Diffraction Systems for Sorting Quartz Oscillator Blanks by Angle, Special Report of Union Thermoelectric Corporation, (15 July, 1958) on Contract DA36-039-sc-71061. For a similar adaptation of a standard Phillips X-ray by Mr. Jack Saunders and Mr. D. L. Hammond, see the first quarterly or final report of Scientific Radio Products on Contract DA36-039-sc-73007. The Union Thermoelectric Supplement to Interim Report 11, X-Ray Double Crystal Prepositioning System, (15 October, 1959) on Contract DA36-039-sc-71061 describes the use of double-diffraction on an X-ray used in a prepositioning orientation system. Another pre-positioning system, involving several novel features is described by Mr. E. M. Shideler and Mr. D. L. Hammond in the "Completion Report Step" of Scientific Radio Products on Contracts DA36-039-sc-70287 and DA36-039-sc-70280. Also see A. W. Warner, "Design and Performance of Ultraprecise 2.5 mc Quartz Crystal Units," Bell System Technical Journal, vol.39 (Sept.1960), pp. 1200-1202.

Both Union Thermoelectric and Scientific Radio Products employed in connection with these systems, three-point vacuum chucks to hold the crystal plate being measured. The three points, for resistance to wear, should be drilled sapphire or ruby. This method of holding the plate minimizes distortion of the plate and also errors resulting from grains of dust between the plate and its supports.

Figure 73 is a schematic of a double-crystal system developed by the Signal Corps Engineering Laboratories, in which the plate being measured rests on an optical flat. Figure 74 is the assembly drawing for a system, built on a General Electric XRD-4, and employing a three-point vacuum chuck. Figure 75 is a similar system employed for the orientation of a stone on a transfer jig. Figure 76 is a more elaborate system of a similar kind, employing two reference crystals.

FIGURE 73



1—SOURCE

2—REFERENCE CRYSTAL

3—OPTICAL FLAT REFERENCE SURFACE

4—CRYSTAL UNDER TEST

5—DETECTOR

6—LEAD SHIELD

7—ZERO ADJUSTING SCREW

DOUBLE CRYSTAL X-RAY
OPTICAL SYSTEM

FIGURE 74

ASSEMBLY, DOUBLE CRYSTAL SYSTEM ON
GENERAL ELECTRIC X-RAY MODEL XRD-4

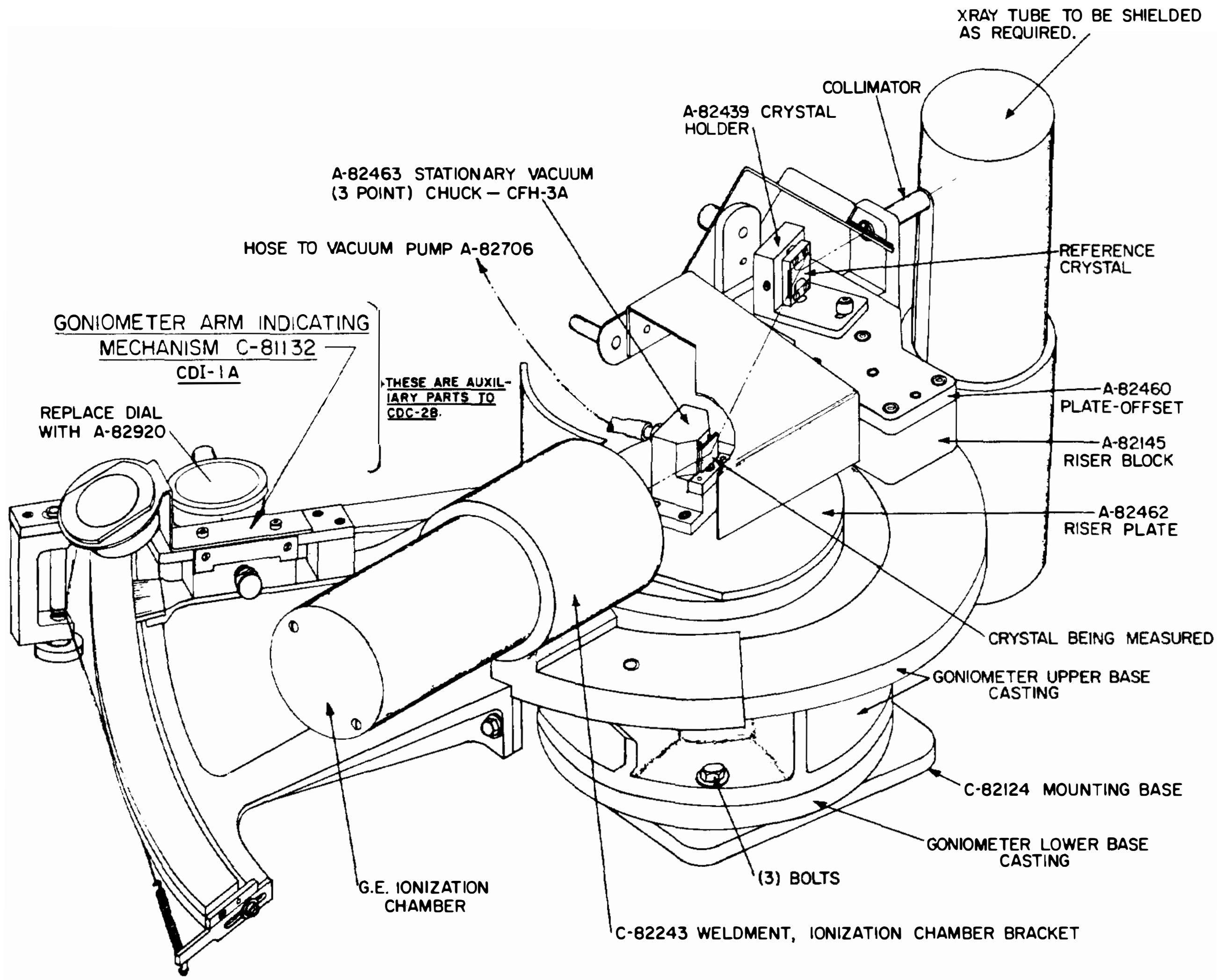


FIGURE 75

ASSEMBLY, DOUBLE CRYSTAL SYSTEM
USING PREPOSITIONING SYSTEM ON
GENERAL ELECTRIC X-RAY MODEL XRD-4

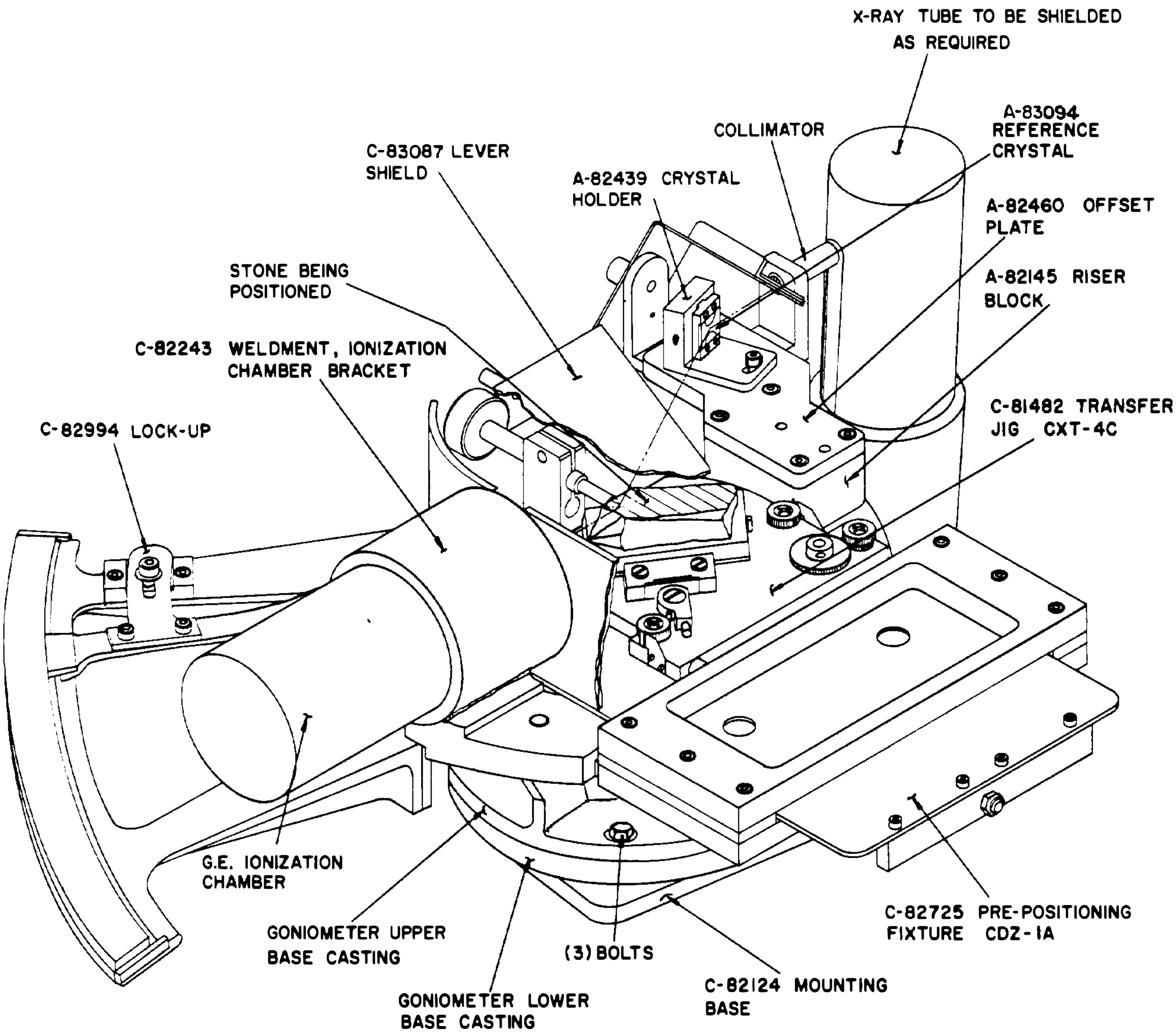
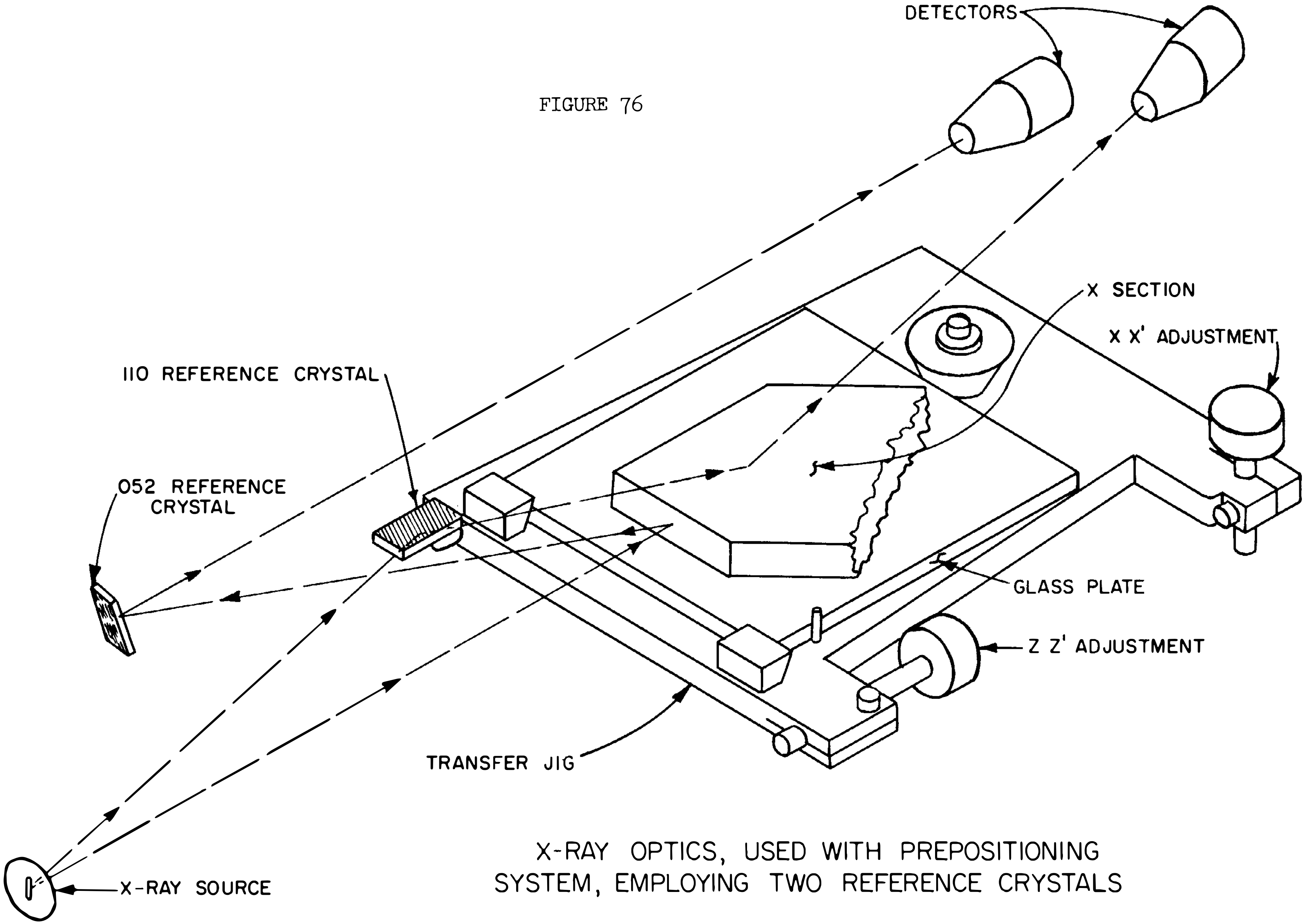


FIGURE 76



X-RAY OPTICS, USED WITH PREPOSITIONING
SYSTEM, EMPLOYING TWO REFERENCE CRYSTALS

Scientific Radio Products, Inc.

Measurements of the Geometry of Quartz Resonator Plates

Measurement of Parallelism

As the frequency is increased it becomes increasingly important that the two main surfaces of a resonator plate be parallel. Deviations from parallelism result in increased motional resistance. In practice very thin blanks tend to be meniscus shaped, that is convex-concave, like a spectacle lens (first drawing in Figure 77). Excessive values of "h" indicate poor process control, but in the 60 to 100 mc range, at least, the effect upon the performance of the resonator is negligible if the thickness remains uniform. If a quartz plate is examined by interferometry (Figure 78), the interference lines will be indicative of "h" unless the plate is wrung to an optical flat so as to distort its natural shape.

The evaluations in Figure 77 refer only to 5th harmonic units in the 60 to 100 mc range, with large diameter to thickness ratios.

Parallelism can be measured by a mechanical comparator, or by placing the polished quartz plate under a monochromatic light in such a way that one surface is the reference for the other. A rule of thumb for high frequency fifth harmonic blanks is that not more than two light bands should be clearly visible.

Figure 79 is an interpretation of interferometer patterns produced by examining various shapes with reference to an optical flat. The important fact in interferometry is that the interference bands indicate the relative spacing between two surfaces. When a polished quartz plate is placed under a monochromatic light the two surfaces are the major surfaces of the quartz plate. They are not adjustable with reference to each other. Both are the surfaces being measured. Neither is a true reference surface in the usual sense. The situation is that of Position 3 in Figure 79, except that the upper as well as the lower surface can be spherical, cylindrical, etc.

Measurement of Contour

If the manufacturers' designation of a spherical lap were sufficiently accurate, it would, nevertheless, be necessary to measure the contours produced after the spherical lap had been distorted by use.

FIGURE 77

NOMENCLATURE FOR DESCRIBING GEOMETRY OF A VERY THIN BLANK

CROSS SECTIONS

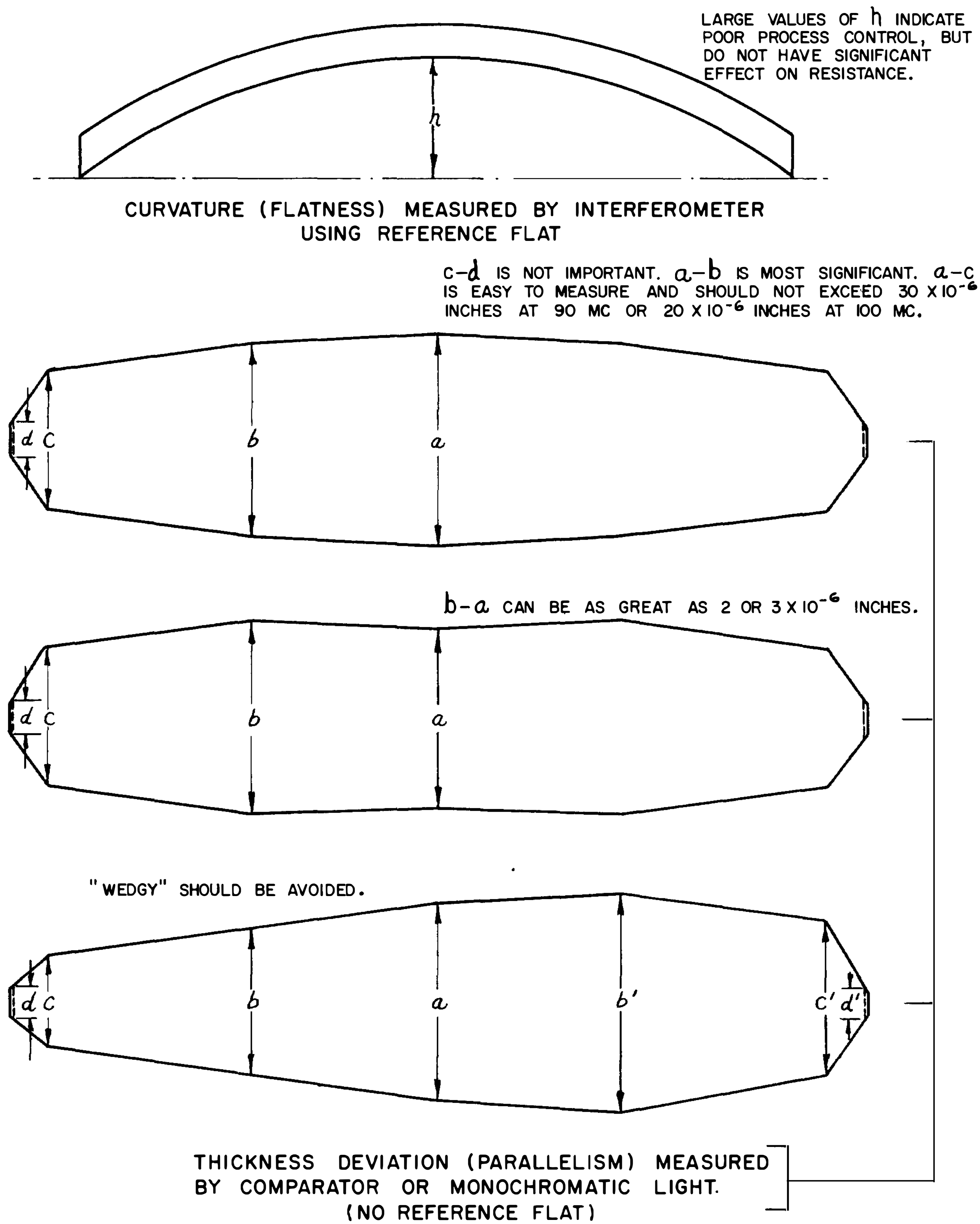
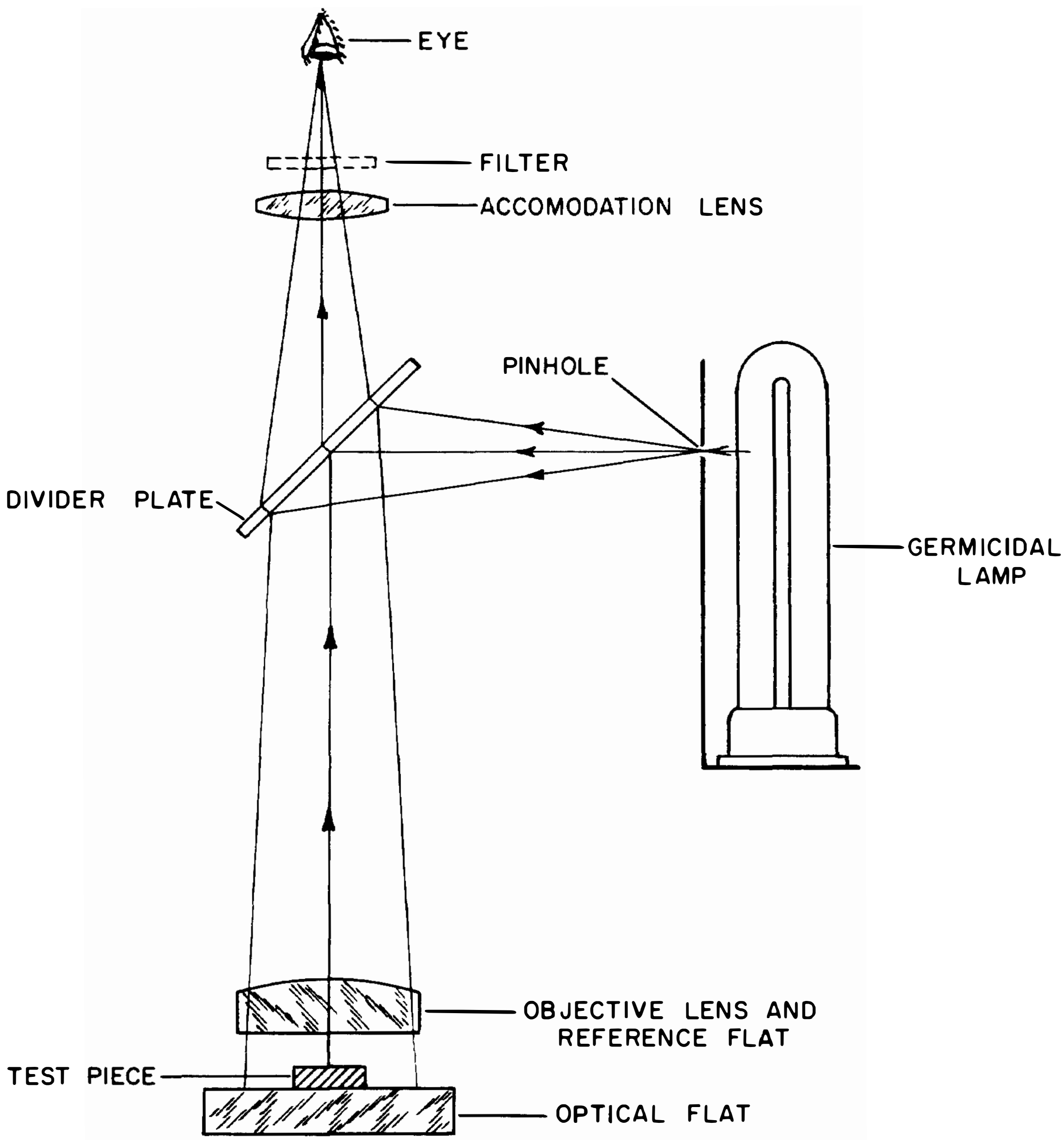


FIGURE 78

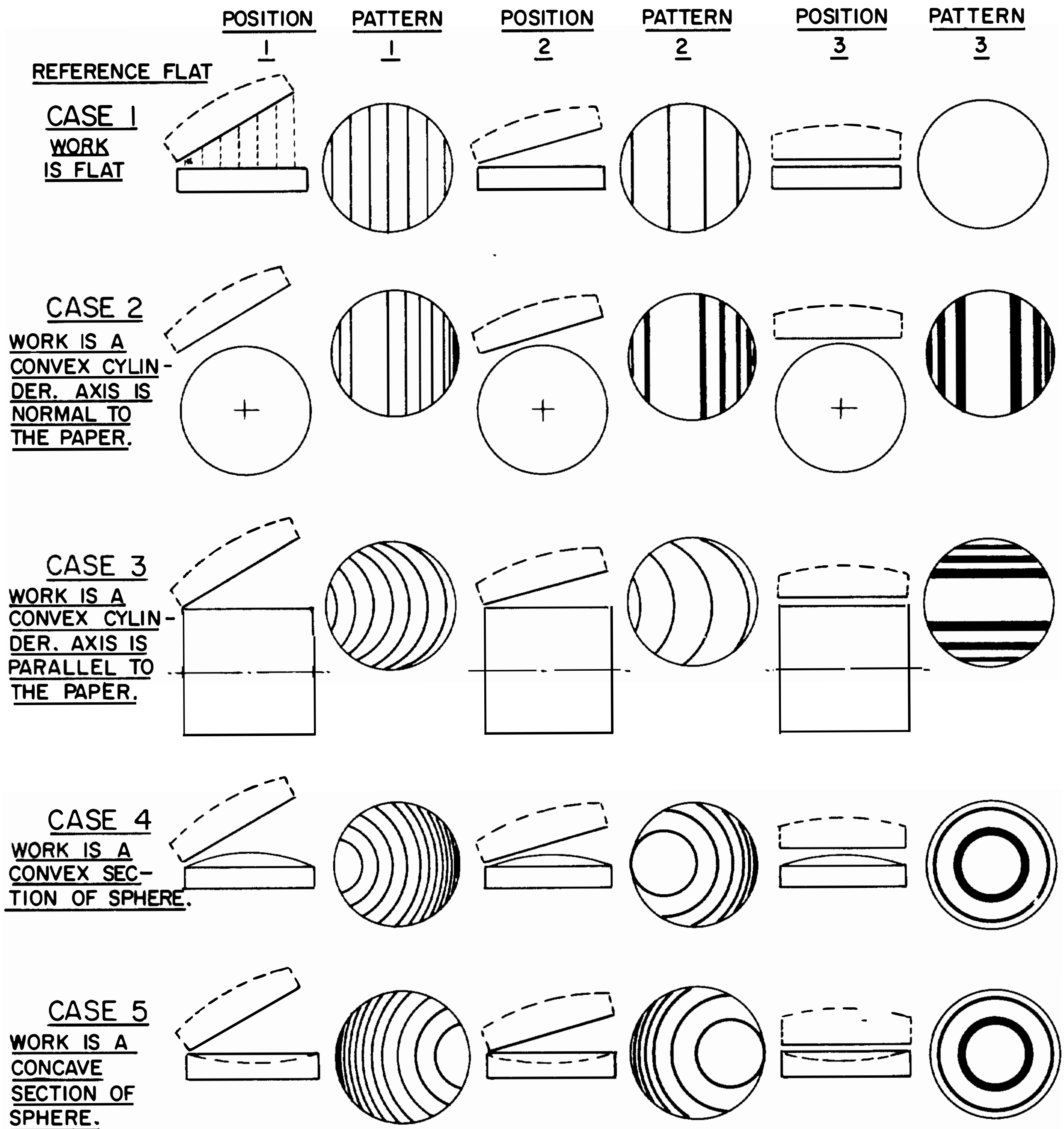


INTERFEROMETER

DRAWING COURTESY OF BAUSCH & LOMB

FIGURE 79

INTERFEROMETER PATTERNS

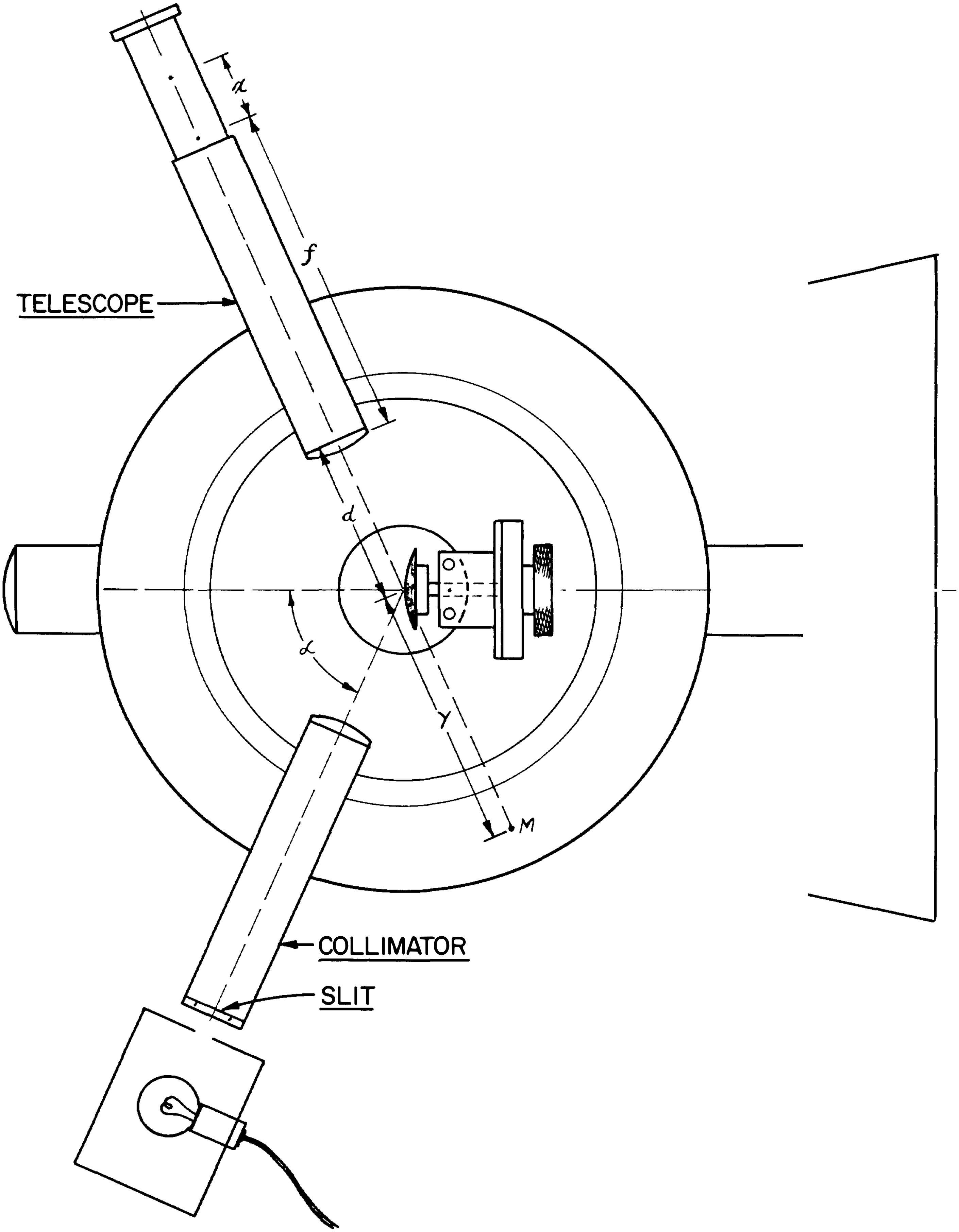


EFFECT OF ANGLE BETWEEN SURFACE BEING MEASURED AND REFERENCE FLAT

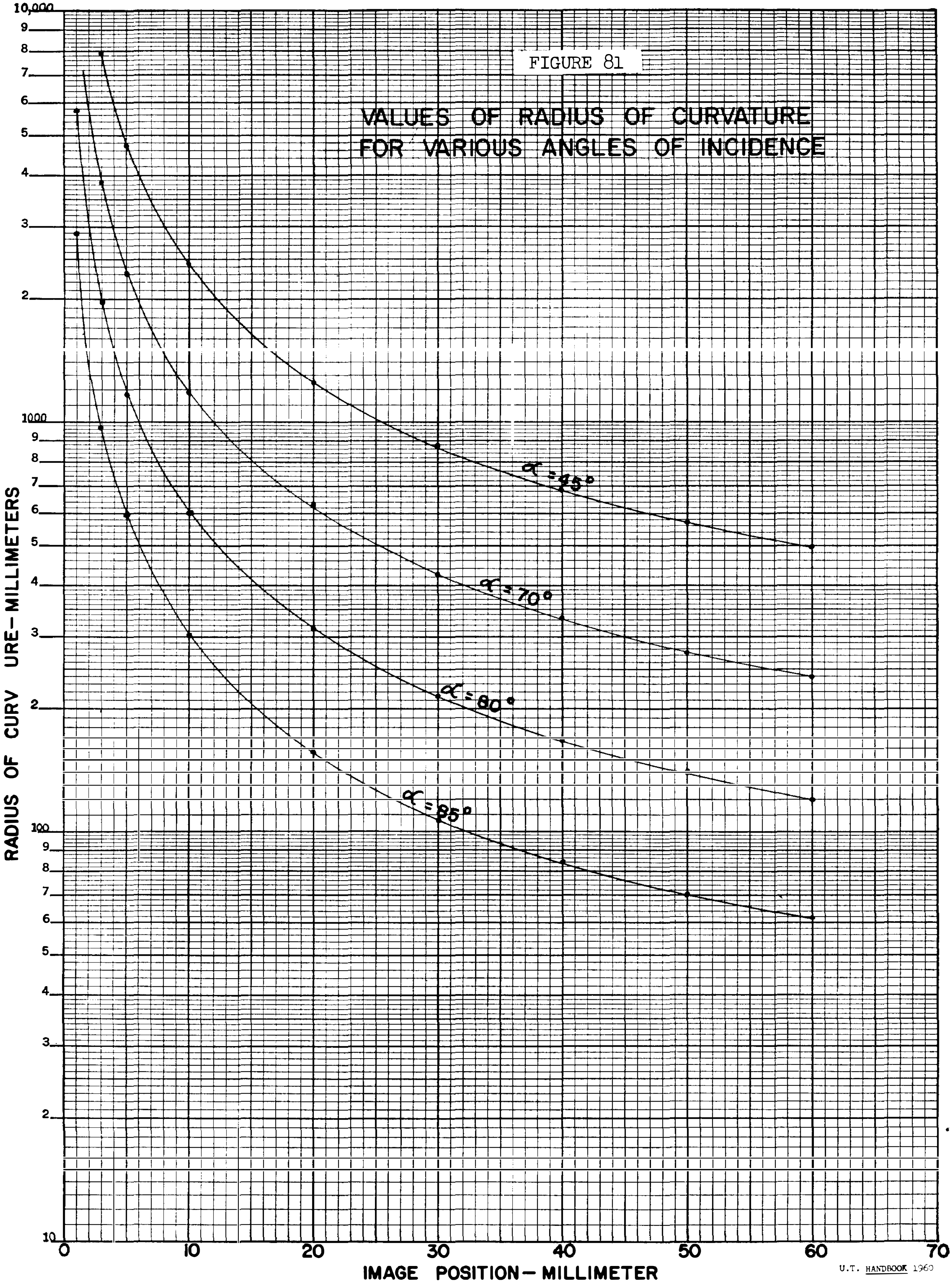
Of the two methods of measuring contour, a modified spectrometer, and a microscope with suitable graduations, the microscope method (Figure 83) is the more precise. The spectrometer method (Figures 80, 81, 82) is inaccurate if the contour departs from the spherical.

The microscope method measures the height of curvature of plano-convex plates. It can be very accurate, but is too time-consuming for production checks. A suitable microscope would have about 430 x magnification, a stage calibrated in tenths of a millimeter, and a focus adjustment calibrated in 2 micron increments.

Figure 83 translates height of curvature into diopters. The maximum curvature for any specified thickness and diameter can be read from the figure where the thickness of the plate is equal to h.



MODIFIED
OPTICAL SPECTROMETER



U.T. HANDBOOK 1960

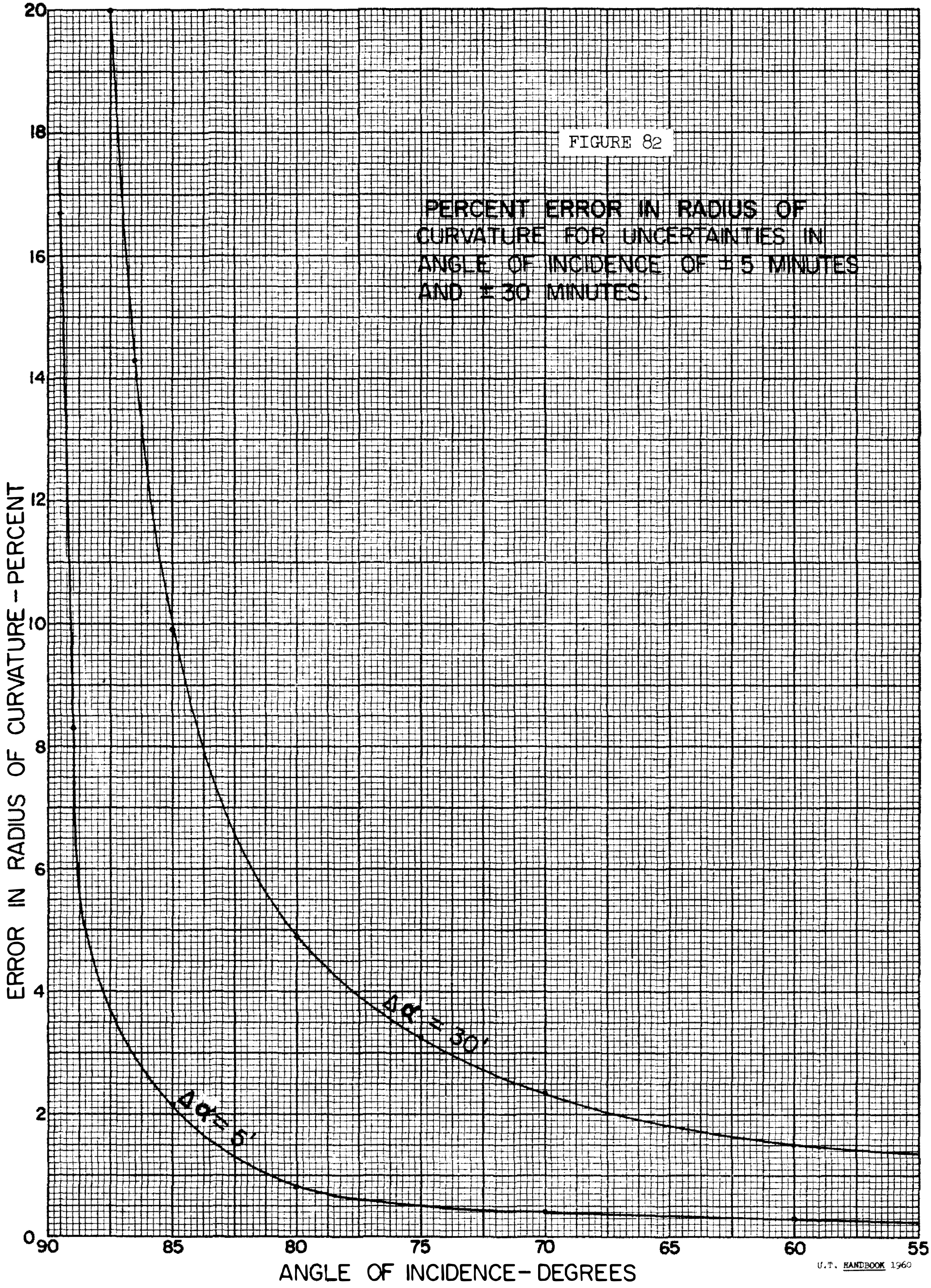
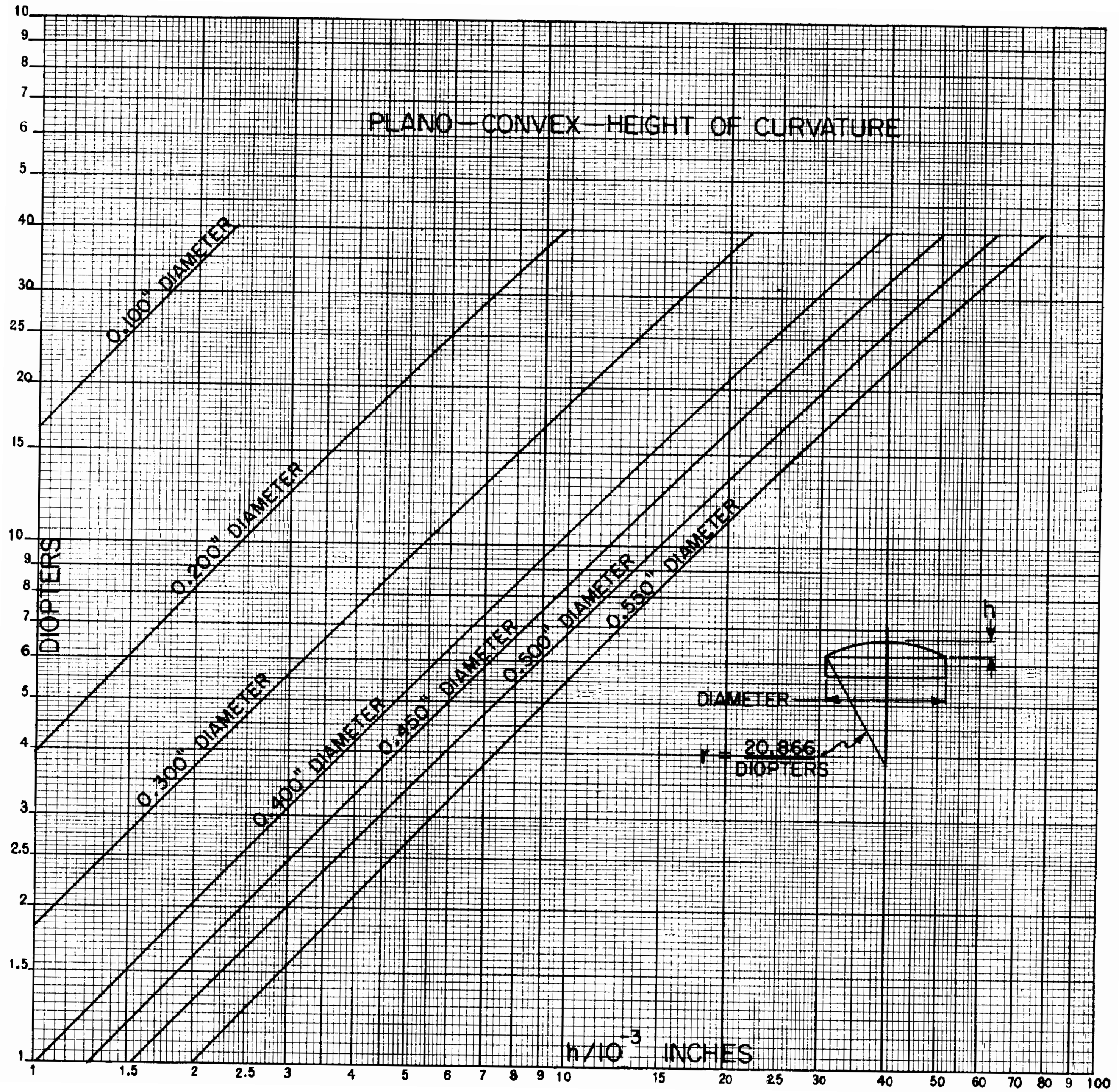


FIGURE 82
PERCENT ERROR IN RADIUS OF CURVATURE FOR UNCERTAINTIES IN ANGLE OF INCIDENCE OF ± 5 MINUTES AND ± 30 MINUTES.
Δα = 30'
Δα = 5'
ERROR IN RADIUS OF CURVATURE - PERCENT
ANGLE OF INCIDENCE - DEGREES
0
2
4
6
8
10
12
14
16
18
20
90
85
80
75
70
65
60
55

FIGURE 83



PLANO—CONVEX—HEIGHT OF CURVATURE
0.100" DIAMETER
0.200" DIAMETER
0.300" DIAMETER
0.400" DIAMETER
0.450" DIAMETER
0.500" DIAMETER
0.550" DIAMETER
DIOPTERS
h/10^-3 INCHES
DIAMETER
h
r = 20.866 / DIOPTERS

Measurement of Electrical Parameters

Crystal Impedance Meters

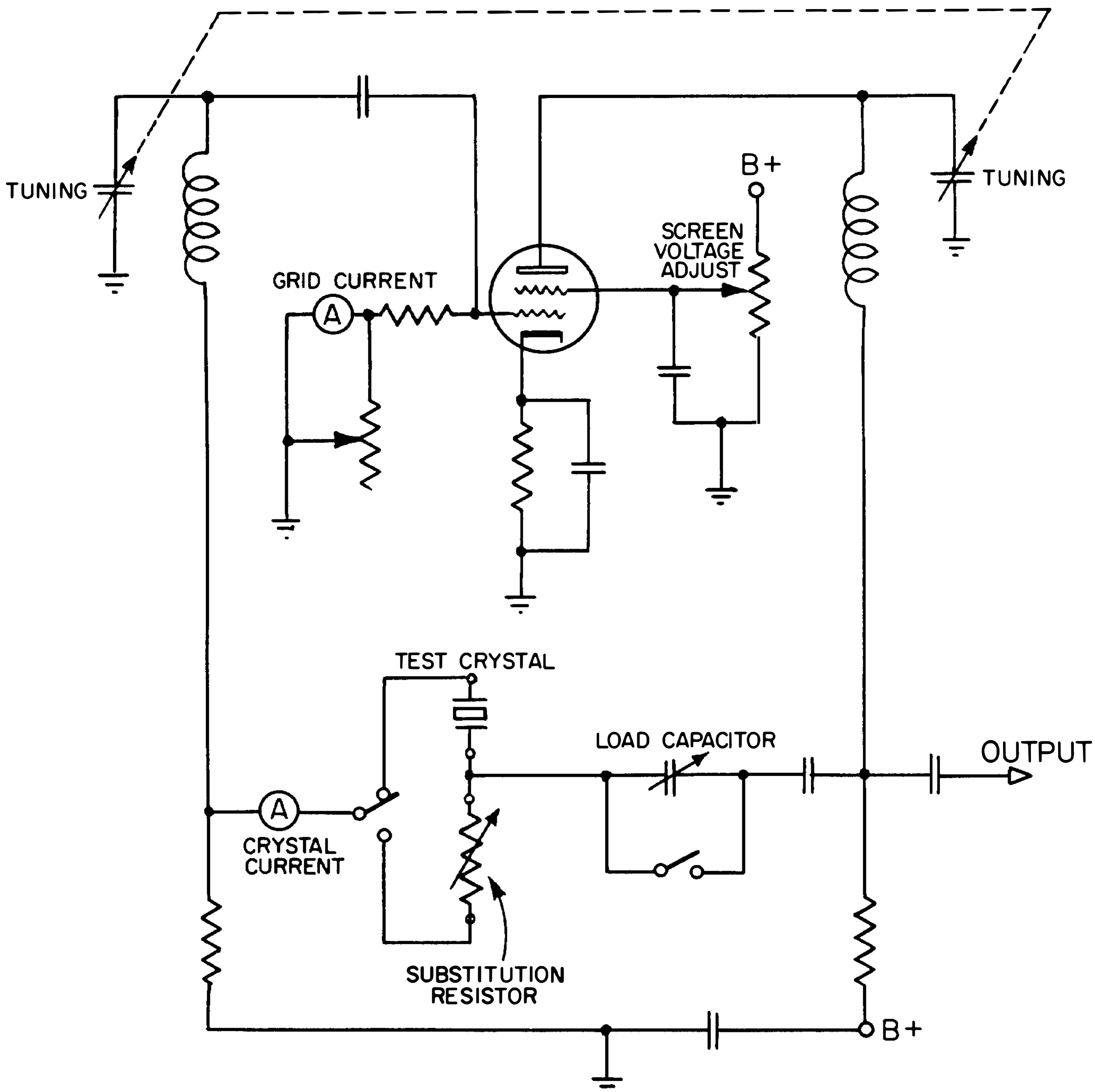
The crystal impedance meter is used primarily as a standard instrument for correlating production test instruments. It is also used occasionally for production measurements on tight-tolerance crystal units.

The crystal impedance meter is a special type of tuned-plate, tuned-grid variable frequency oscillator in which the crystal to be tested is inserted in the feedback path. The crystal unit, together with other elements in the feedback path, develops low impedance over certain ranges of frequency, thereby satisfying the necessary conditions for circuit oscillation at a frequency corresponding to a mechanical resonant frequency of the crystal.

The effective resistance of the crystal unit is measured at a particular frequency by application of the following principle of substitution:

> If, in any oscillating system, an element or combination of elements is replaced by a substitute element in such a way as to leave the amplitude, frequency, and wave form of the periodically-fluctuating variable unchanged, the substitute element of the system is operationally equivalent to the original. Thus, if a crystal unit is removed from a crystal impedance meter and is replaced by a combination of electrical impedance elements without changing the frequency of oscillation or the control grid current amplitude, then the substituted element or elements are the electrical equivalent of the crystal unit. The crystal unit in a crystal impedance meter may be operated at any frequency for which its effective resistance is low enough to permit the passage of sufficient feedback current between the plate and grid circuits of the amplifier tube to sustain oscillation. The crystal may thus be measured at or below its resonant frequency or at some higher frequency which is usually referred to as an anti-resonant frequency.

FIGURE 84



SIMPLIFIED SCHEMATIC DIAGRAM OF CRYSTAL IMPEDANCE METER

The practical upper limit of usefulness of the type of CI meter circuit represented by TS-683 (TM-11-2652) is between 100 and 120 mc. Above this limit the VHF crystal impedance meter circuit is used, as in AN/TSM-15, described in U. S. Army Signal Engineering Laboratory Engineering Report E-1170. In this circuit the reactance of the shunt capacitance (C_0) is cancelled by means of a neutralizing inductance across the quartz resonator unit.

In either type of crystal impedance meter the reactive characteristics of standard substitution resistors introduce significant errors in measurements in the neighborhood of 100 mc and above (Figure 85). Construction of non-reactive substitution resistors is described by Georgia Institute of Technology, reports on Contract DA36-039-sc-56730, and by Union Thermoelectric, Compensated Calibrating Resistors, Special Report, 15 Dec., 1957, Contract DA36-039-sc-71061.

Sometimes when measurements have been made according to specifications for resistance at anti-resonance, it is desired to estimate the resistance at series resonance, and vice-versa. Figure 86 gives the theoretical ratio of resistance at antiresonance to resistance at series resonance, as a function of static capacitance (C_0), for two different values of external shunt capacitance.

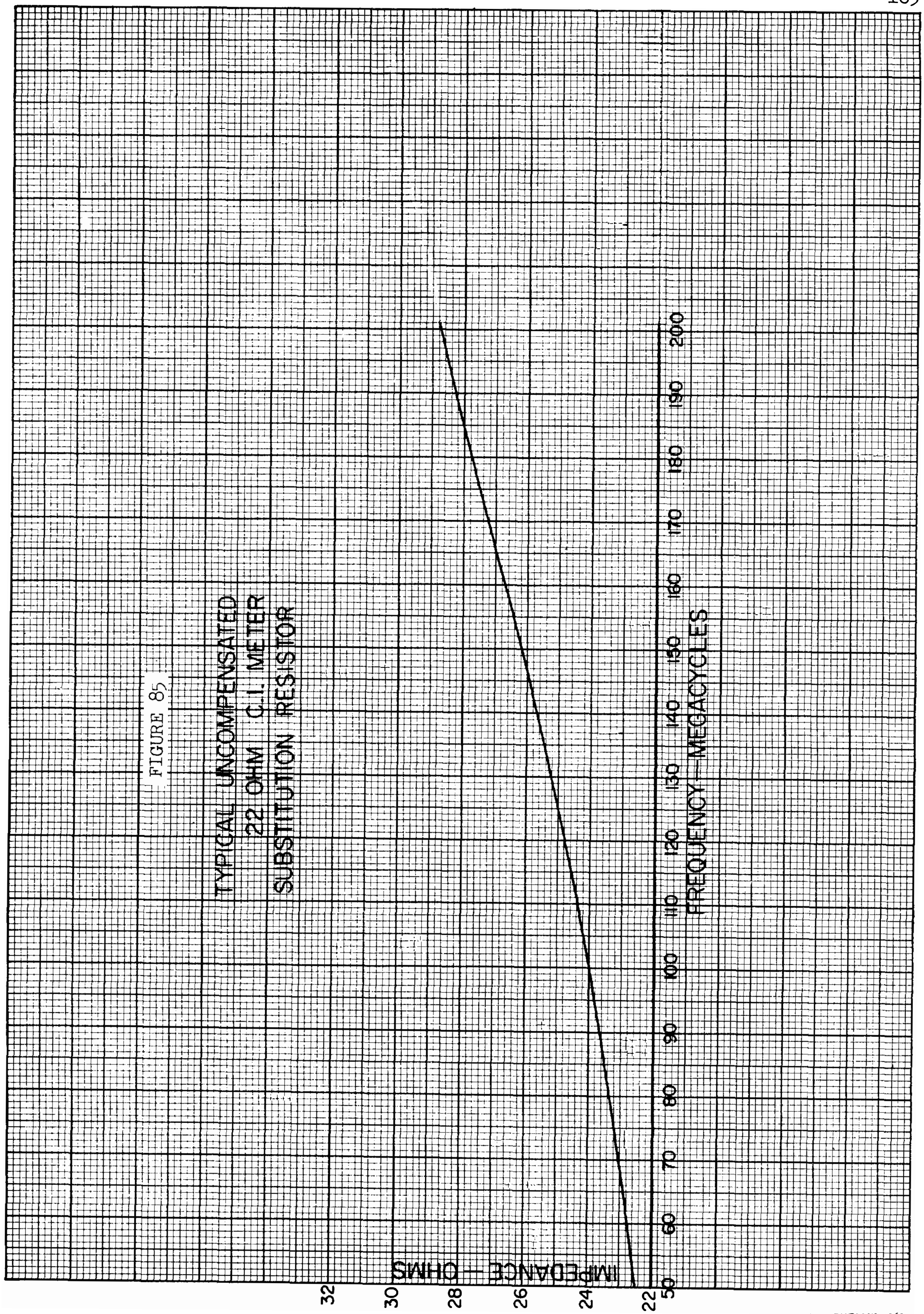


FIGURE 85
TYPICAL UNCOMPENSATED
22 OHM C.I. METER
SUBSTITUTION RESISTOR
FREQUENCY—MEGACYCLES
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
IMPEDANCE — OHMS
22
24
26
28
30
32

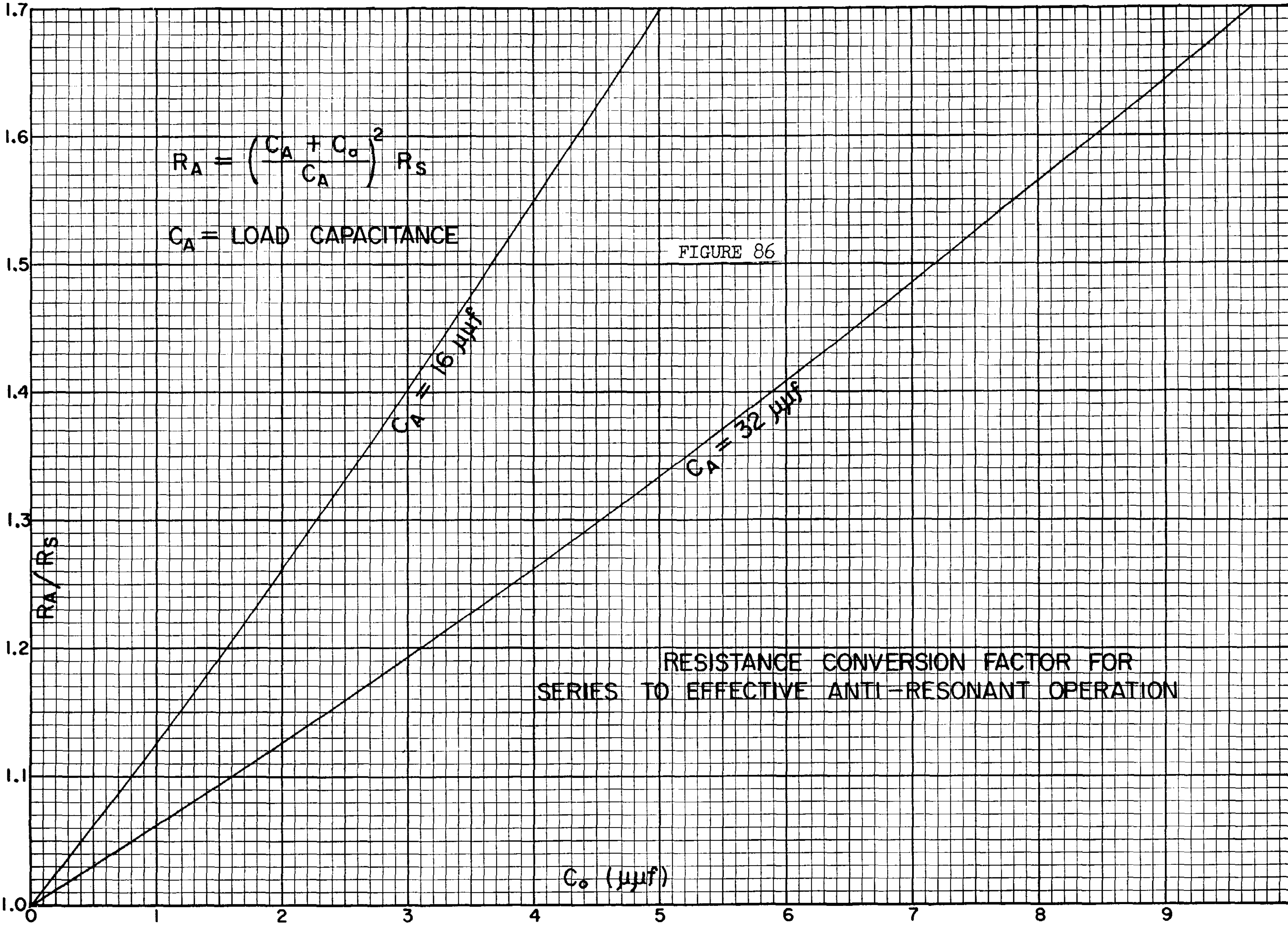


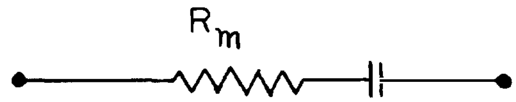
FIGURE 86

STATIC CAPACITANCE OF CRYSTAL UNIT

Metallic Resistance

When the specified maximum resistance is low it is desirable to know how much of the measured resistance of a crystal unit results from the holder, mount, etc.

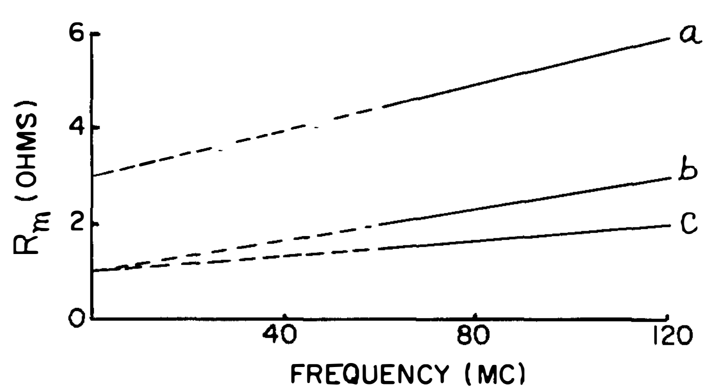
Metallic resistance (R_m) is the resistance of a unit as a capacitor, and includes resistance of the mount, of the bonding cement or solder, and of the plated electrodes, as well as dielectric losses.



It is measured by a reactance bridge, Q meter, or similar instrument, at a frequency sufficiently below or above the resonant frequency that the quartz plate appears only as a dielectric. At high frequencies, skin effect is a major factor in R_m.

R_m is not to be confused with "mounting losses" resulting from the mechanical damping of the plate's vibration by the mounting supports. Such mounting losses can be very large in small low frequency blanks, whereas R_m is the more significant factor at very high frequencies.

The figure shows typical measurements of R_m, made between 60 and 120 mc and extrapolated downward. Line a shows the metallic resistance of an 108 mc 5th harmonic unit, using a music wire mount bonded with a bakelite-silver mixture. The slope is largely the result of skin effect resistance of the wires. Lines b and c represent bonding with an epoxy cement to larger supports: the "RCA rigid type" (b) and the "tab-clip" (c). The plating was gold over aluminum.



References on Measurement of Electrical Parameters

E.A. Gerber, "A Review of Methods for Measuring the Constants of Piezoelectric Vibrators," Proc. I.R.E., vol. 41(Sept.,1953).

A.C. Prichard and M. Bernstein, "Crystal Impedance Meters Replace Test Sets," Electronics, vol. 26 (May, 1953).

L. F. Koerner, "Progress in the Development of Test Oscillators," Proc. I.R.E., vol. 39 (Jan. 1951).

G. K. Guttwein, "VHF Test Circuits," paper presented at 9th Annual Frequency Control Symposium, May 1955.

"VHF Crystal Measurements," Proceedings of the 10th Annual Symposium on Frequency Control (May 1956), pp.310-312.

John P. Buchanan, Handbook of Piezoelectric Crystals for Radio Equipment Designers, Wright Air Development Center Technical Report 56-156 (Oct. 1956), pp. 86-90.

Georgia Institute of Technology, reports on Contracts DA36-039-sc-74948, DA36-039-sc-56730, DA36-039-sc-71191.

E. A. Gerber and L. F. Koerner, "Methods of Measurement of the Parameters of Piezoelectric Vibrators," Proc. I.R.E., vol. 46 (Oct. 1958).

The following cover additional refinements:

Armour Research Foundation, Final Report on Contract DA36-039-sc-74896 (null bridge, external regulated power supply).

Scientific Radio Products, Final Report on Contract DA36-039-sc-73007 (frequency multiplier).