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VIBRATION RESISTANT QUARTZ CRYSTAL RESONATORS.(U)
JAN 81 B GOLDFRANK, A WARNER DAAK20-79-C-0272
UNCLASSIFIED DELET-TR-79-0272-2 NL

1 OF 2
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LEVEL III

(12)

Research and Development Technical Report

DELET-TR-79-0272-2

AD A094682

VIBRATION RESISTANT QUARTZ CRYSTAL RESONATORS

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A. Warner

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3 Delaware Drive
New Hyde Park, NY 11040

January, 1981
Second Interim Report for period 28 Feb - 27 Aug 80

DISTRIBUTION STATEMENT
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Prepared for:
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

ERADCOM

US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

81 2 06 003

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: DELET-TR-79-0272-2	2. GOVT ACCESSION NO.: AD-A074 682
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Vibration Resistant Quartz Crystal Resonators.	5. TYPE OF REPORT & PERIOD COVERED: 2nd 6 Months 28 Feb 80 to 27 Aug 80
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): B. Goldfrank, A. Warner	8. CONTRACT OR GRANT NUMBER(s): DAAK20-79-C-0272
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Frequency Electronics, Inc. 3 Delaware Drive New Hyde Park, NY 11040	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1L162705AH94101102
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Electronics Technology and Devices Laboratory Attn: DELET-MQ Fort Monmouth, NJ 07703	12. REPORT DATE: January, 1981
	13. NUMBER OF PAGES: 100
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Low "g" Sensitivity Crystal Units and Their Testing By A. Warner, B. Goldfrank, M. Meirs and M. Rosenfeld.
Further Developments on 'SC' Cut Crystals By B. Goldfrank and A. Warner.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Doubly rotated quartz crystals, Low 'g' sensitivity, Fast warm-up crystal resonators, quartz, quartz crystals, quartz resonators, SC cut, acceleration, vibration, pressure sensitivity.

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

The objectives of this investigation are to provide doubly rotated quartz crystal resonators that exhibit fast warm-up and low 'g' sensitivity. Warm-up is to be on the order of 1 PP10^9 in three minutes. The 'g' sensitivity is to be 1 PP10^{10} maximum in any axis.

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INTRODUCTION

This is the second six-month report under Contract DAAK20-79-C-0272, for the development of doubly rotated quartz crystals. Included in the report are the major accomplishments during the second six-month period and detailed results of the aforementioned accomplishments. Also included is a list of proposed objectives for the next six-month period. This report is broken down into sections covering the various categories listed below:

1. Task Objectives
2. Approach
3. Program Progress
4. Test Results and Evaluations
5. Proposed Objectives for Next Six-Month Period.

1. TASK OBJECTIVES

A. General

Modern communications, navigation and surveillance systems require highly stable quartz crystal reference oscillators. These oscillators must be capable of fast warmup, and must possess low acceleration sensitivities.

Currently available quartz crystal resonators exhibit frequency changes of about 2 parts in 10^9 per g of acceleration. Such an acceleration sensitivity, a consequence of stress sensitivity of quartz, has been shown to have serious detrimental consequences in several applications where the resonator must operate in a vibratory environment. It has recently been shown that doubly rotated quartz crystal resonators, particularly the so-called SC cut, have much lower sensitivity to mechanical stresses than the commonly used (singly rotated) AT cut. It therefore seems probable that lower acceleration sensitivities will be achieved by using doubly rotated cuts.

The major objective of this program is to study the properties of doubly rotated cuts, and to develop vibration resistant, high precision resonator designs. The optimized vibration resistant designs shall be selected based on suitability for meeting the performance requirements of the NAVSTAR Global Positioning System Manpack/Vehicular Set. The development effort shall make extensive use of previously published information.

B. Definitions of the Angles of Cut

The angles of cut of doubly rotated plates can be described by the IEEE notation as (YXWl)ϕ/θ. This notation is explained in "Standards of Piezo-electric Crystals, 1949", Proc, IRE, Vol. 37, Dec 1949, pp. 1378-1395, and in IEEE Standard No. 176-1949. An SC cut, for example, may be described as (YXWl) 21.75°/33.91°. For simplicity, a cut may also be specified by stating the two rotation angles only; e.g., ϕ = 21.75°, θ = 33.91° describes the same SC cut.

C. Requirements

1. Resonator Frequencies

Optimized vibration resistant designs shall be developed for three resonator frequency ranges as follows:

a. 5 MHz
b. 10 MHz
c. 20 MHz

2. Properties to be Studied and Objectives

The properties of quartz crystal resonators whose angles of cut are located on the bulk wave C-mode zero temperature coefficient locus shall be studied as functions of: (a) the angles of cut of the resonator plates, (b) the plate geometries, (c) the mounting configurations, (d) the overtone number, and (e) any other variables which may affect vibration resistance.

The primary objectives of this study shall be to achieve a vibration sensitivity of 1×10^{-10} per g, and to define the design parameters and tolerances which will permit the achievement of such acceleration sensitivity, in a reproducible manner, for the vibration levels specified in MIL-STD-810C.

3. Secondary Objectives

a. 1×10^{-9} warmup in three minutes after application of power.

b. 1×10^{-9} retrace.

c. 1×10^{-11} per day aging at 100°C, after two weeks stabilization.

d. - 120 dB per Hz spectral purity at 1 Hz away from carrier.

e. 1 x 10^{-12} short term stability for 0.2 to 100 seconds.

f. To correlate vibration sensitivity with static acceleration sensitivity.

g. To investigate optimal enclosure for vibration resistant crystal resonators, including the ceramic flatpacks.

2. APPROACH

The basic approach is to cut corrected premium Q swept quartz bars at a constant ϕ angle of 23.75°, and vary θ over the range of 33.75° to 34.25°. By careful x-raying techniques, we will define a series of curves which will enable us to define the proper angles of cut to yield crystals with a specified upper turnover temperature.

The "SC" temperature characteristics are of a cubic nature. They vary from the AT, in that the inflection point is near 100°C as opposed to 25°C. Thus, the 'SC' crystals normally function on the left hand side of the cubic curve inflection point, while the 'AT' crystals function on the right side of the curve.

To obtain improvement in the "g" sensitivity, we are evaluating the mounting points, the location of the bonds, the bonding materials and the mounting structure.

The crystal designs, i.e., physical dimensions and overtone numbers are being modeled after similar AT cut crystals. Design sheets will be made available initially and as changes are made.

Finally, measurements will be made to determine the pressure sensitivity and precise temperature data will be taken to determine the retrace characteristics of the 'SC' cut crystals.

3. PROGRAM PROGRESS

The major accomplishments of the second six-month period are as follows:

A. Alleviated a major problem with the aluminum clad nickel ribbon and started development work on gold clad nickel ribbon as a replacement.

B. Obtained correlation of preferred mounting points on SC cut crystals.

C. Developed a computing calculator program that directly converts the x-ray readings to the actual angle.

D. Prepared and presented a paper, "Further Developments on 'SC' Cut Crystals" at the 1980 Frequency Control Symposium.

E. Delivered one (1) each, 5 MHz/fifth overtone and 10.054 MHz/third overtone crystals.

F. Made initial measurements on pressure sensitivity on a 5 MHz, fifth overtone crystal.

G. Reprocessed four (4) 10,054 MHz/third overtone crystals and compared vibration data between two different mounting techniques.

H. Processed and tested nine (9) 10.230400 MHz/third overtone crystals.

I. Completed design on 20.000000 MHz crystals, and fabricated blanks to make 20.0, 23.1^{+} and 34.3^{+} MHz/fifth overtone crystals.

J. Fabricated and tested five (5), 5 MHz, fifth overtone crystals using gold nickel ribbon.

K. Completed "Hot Tuner" for final frequency adjustment.

4. TEST RESULTS AND EVALUATIONS

Results obtained during the second six-month reporting period are as follows:

A. A major processing/assembly problem occurred with our thermocompression bonding technique. The aluminum clad nickel ribbon that was supplied was sufficiently hard, i.e., not properly annealed, to cause the crystals to fall off the ribbon. The phenomenon is easily explainable. The ribbon expanded during the preheat and bonding cycles. During the cool down cycle, severe tensional forces occurred and the ribbon eventually pulled edge metallization and quartz from the crystal mounting flat.

We attempted to anneal the ribbon ourselves, as well as having Dr. J. Vig at ERADCOM do the same. The results were unacceptable as the aluminum delaminated from the nickel.

We were successful, however, in annealing the ribbon after it was attached to the header. The annealing was done at 500°C in a helium atmosphere. The furnace was a Lindberg tube furnace Model 54241 with a two-inch inside diameter ceramic tube from Coors Porcelain Inc.

A new ribbon for TC bonding is being developed. It consists of a stripe of gold coined to a nickel ribbon. The advantage is that we will eliminate one intermetallic contact. A supply of various sample lots of nickel with the gold bonding stripe has been received from Technical Materials Incorporated, and is adequate for our experimental studies. FEI must anneal the ribbon, since the samples received are approximately 1/4 hard. The initial data shows that the bonds are, at a minimum, equivalent in strength. Diagrams of both types of ribbon are contained in "Further Developments on 'SC' Cut Crystals" by B. Goldfrank and A. Warner, Figures 9, 10 and 11, attached to this report, in Appendix I.

Methods of precisely cutting the ribbon to the appropriate dimensions, ± 0.001", have been worked out. Although we have made completed units, none have had bonds which were exactly centered or uniform in thickness. Extremely close control of all processing and fixturing parameters is needed in order to discover the exact effect of the mounting point size and location on the acceleration coefficient of frequency.

B. Independently, Professor Peter Lee of Princeton University calculated the same psi (Ψ) angle as we had determined experimentally. A copy of his data is attached. The fact that the Ψ angle must be optimized for minimum frequency shift with acceleration and since we are trying to improve 'g' sensitivity this correlation is very encouraging.

Professor Lee first defined the coefficient of acceleration sensitivity as

$$K_a = \frac{\Delta f}{f_o} \cdot \frac{1}{F} \cdot \frac{d}{f_o/n}$$

F = force on plate = mass of plate x acceleration

f_o = frequency of resonator

n = overtone number

d = diameter of resonator

This is similar to the coefficient of force sensitivity K_f. Then for each support position Ψ, K_a is computed as a function of acceleration direction. From this, one can obtain $|K_a|$ max, the absolute value of K_a maximum.

The process was repeated for a range of Ψ values, and he was able to obtain values of $|K_a|$ max as a function of Ψ. See Figure B-1.

C. Our system of x-ray measurement of the quartz blank orientation consists of tilting the blank to "undo" the Ø angle and permit the use of the 01.1 plane as in the measurement of an AT blank. The crystal blank is then further rotated about its thickness so that its measured θ" angle is even closer to that of the reference plane, 38° 12.7', than the AT cut.
A similar technique is used to measure the Ø angle, independent of the value of θ.

The blanks are cut from a highly corrected quartz bar, using the same angle as in the x-ray measurement. In effect, we have uncoupled the two angles, Ø and θ, and the angle setting on the saw table for θ is the same as the angle read on the x-ray goniometer, thus permitting an operator to easily make small corrections in θ.

The measured angle Ø' is related to Ø by the known angle of the 01.1 plane. The measured angle θ" is related to θ by the value of Ø. The x-ray goniometer which we use measures Ø' by reference to a standard and reads in degrees, minutes, and seconds. θ" is similarly read on a micrometer dial that reads in inches, 0.0001" corresponding to 2 seconds of arc.

A program has been written for the hand-held Sharp EL5100 Calculator, which has 80 steps of programming which may be held indefinitely, plus 10 memories. It is only necessary to enter the scale readings from the x-ray goniometer and push one button for the specified angles to appear. Conversion from degrees, minutes, seconds to decimal degrees, comparison with reference crystal readings, inter-relationships of the various angles, etc., are all carried out by the single key stroke.

The actual programs are as follows:

1. $f(AB) = \tan^{-1} (\tan((A-B) X D) +36.3) X \cos C = \theta$
2. $f(Ef) = \sin^{-1} (\sin(E \rightarrow deg - F \rightarrow deg - 18.45) \div .7857) = \emptyset$
3. $\theta" = 36.3 + (A-B) X D$, for saw table setting

Where:

A = X-ray dial reading for θ, unknown crystal

B = X-ray dial reading for θ, reference crystal

C = Ø angle in decimal degrees

D = .00555

E = X-ray dial reading for Ø, unknown crystal

F = X-ray dial reading for Ø, reference crystal

D. From late April to late May, a paper entitled "Further Developments in SC Cut Crystals" was prepared. It was presented at the 34th Annual Frequency Control Symposium in Philadelphia. A copy of the paper is included in Appendix I.

E. One (1) each of a 5 MHz, fifth overtone crystal and a 10.054 MHz, third overtone crystal were delivered for evaluation. Data on these crystals is attached in Table E-1. The 5 MHz crystal is a premium Q swept quartz crystal unit. It is bi-convex with a 0.025 inch bevel on both sides. The unit was TC bonded using aluminum-nickel ribbon. It was sealed at 4×10^{-8} torr. The 10.054 MHz crystal is plano-convex in design. The edges are broken to facilitate handling and reduce the possibility of chipping. It is mounted in a diamond shaped notch and epoxied to the three support structures. It was sealed at 8×10^{-8} torr. Data on 'g' sensitivity is contained in Graphs E-2 and E-3.

F. Initial pressure sensitivity studies were conducted, but the data was inconclusive and the set-up of the apparatus was marginal. The set-up was modified and the test repeated on crystal, Serial Number 1379, which is a 5 MHz, fifth overtone crystal.

The results of frequency change in pp10^7 versus pressure in millimeters of mercury, were plotted, as shown on Graph F-1.

Presented as a comparison is Stockbridge's data.[1] See Figure F-2. The insert shows a 0.1 Hz change from vacuum to 1.0 mm. There was, as shown, an unexplainable blip at 60 microns that disappeared approximately one minute later. We are going to attempt to duplicate this phenomenon, and determine if it is equipment or crystal oriented.

G. Four (4) 10.054 MHz, third overtone crystals were processed twice, to evaluate two different mounting structures. Vibration data was taken at the completion of each production cycle and the crystal blank identity was maintained throughout the processing.

The initial processing was done using our standard diamond notch mount. The reprocessed blanks were assembled using the newly developed 'J' mount. The advantages of the 'J' mount are the reduced contact area and reduction in amount of epoxy used to attach

[1]Vacuum Microbalance Techniques, Vol. 5, 1966, C. D. Stockbridge, Bell Labs, Murray Hill, N.J.

the crystal to the support structure. The electrical test data is contained in Table G-1, the temperature data on Graphs G-2 through G-5 and the vibration data in Table G-6 and Graphs G-7 to G-17.

H. Nine (9) 10.230400 MHz, third overtone crystals were processed and tested. The electrical test data appears in Table H-1. The crystals were base plate at 7 x 10^{-8} torr and adjusted to final frequency at 85°C at 5 x 10^{-7} torr.

Four (4) crystals were subjected to 'g' sensitivity testing and the results are shown in Graphs H-2 through H-5. The reprocessing cycle used on 10.054 MHz crystals will be employed on these crystals to compare a different mounting structure with the original structure. (See Paragraph G). It is possible, in reviewing the data, that the 'g' sensitivity may be quartz blank dependent. The sample, however, is small and further study is planned.

I. The designs were completed on several fifth overtone, 20+ MHz crystals. These are contained in Appendix II. A parallel mounting experiment is being conducted on the 20.000000 MHz, fifth overtone crystals. Results will be published in the next six month report.

J. Five (5) 5 MHz, fifth overtone crystals were fabricated and tested. These crystals were fabricated using the gold-nickel ribbon described in Paragraph A. A quantitative analysis of the bond appearance is contained in Figures J-1 through J-5. The amount of squash out is dependent on the unit force applied. Squash out of 5% was due to the fact that the bonding tool was slightly cocked in the holder. The optimum deformation should approximate 50% of the gold ribbon height or 2.5 mils. More work must be done to substantiate the optimum amount of deformation. On some bonds, the squash out was so severe, that although the crystal was firmly attached, very little gold was visible at the interface between the crystal and the ribbon.

A summary of the 'g' sensitivity results is contained in Table J-6 and the actual plots in Graphs J-7 through J-11. In addition, 'g' sensitivity data on thirty-two crystals is contained in Appendix III, Table III-1 and Graphs 1 through 32. These crystals were processed at FEI over the last year and represent crystals fabricated for this program as well as other programs.

Crystal 4205 was bonded using a 0.010" x 0.015" tip at five pounds, while the other four crystals (4207, 4208, 4142 and 4144) were bonded using a 0.020" x 0.050" tip at nine pounds.

K. Frequency Electronics has fabricated, at its own expense, a three position hot tuner. This machine allows us to adjust SC cut crystals to within 0.1 PPM.

One of our initial problems was a 60° to 80° phase shift between an external test box and each position in the tuner. This was reduced to 20° by shorting all the cables.

The three positions of the tuner are mounted on a fourteen inch base plate and covered by a twelve inch spherical dome. A picture of one of the heads is shown in Figure K-1. The heater block, and Pi network are removable for easy maintenance and/or changeover to a different header configuration. The filament is shielded (not shown) front and back to eliminate any possible shorting of the internal electronics. The crystal temperature can be continuous monitored and is accurate to within $\pm$ 1°C. This is more than adequate for any SC cut crystal, since there is normally a 4°C to 6°C range where the crystal frequency does not change more than 1.5 Hz.

The pi networks all have one common ground as do the inputs and outputs for measuring the crystal frequency. The tuner heads are connected to an eight pin feed through, with three inputs, three outputs and two grounds. All other electrical connections are through a separate twenty pin feed through.

The entire tuner is under a laminar flow hood. The vacuum cycle consists of three minutes on a graphite pump, fifteen to twenty minutes on a vac-sorb pump and sufficient time on the ion pump to reach 5×10^{-7} torr. A schematic of the system is shown in Figure K-2.

5. PROPOSED OBJECTIVES FOR NEXT SIX-MONTH PERIOD

A. Continue processing of crystal assemblies.

B. Complete analysis of gold-nickel ribbon as a viable replacement for the aluminum clad nickel ribbon.

C. Continue and complete pressure sensitivity measurements.

D. Prepare crystal assemblies to evaluate further the possible quartz dependence on 'g' sensitivity.

E. Finalize 10 MHz, fifth overtone design.

F. Complete entire drawing package.

G. Compare acceleration sensitivity of crystals cut at $\phi = 23.75°$ versus those cut at $\phi = 21.90°$.

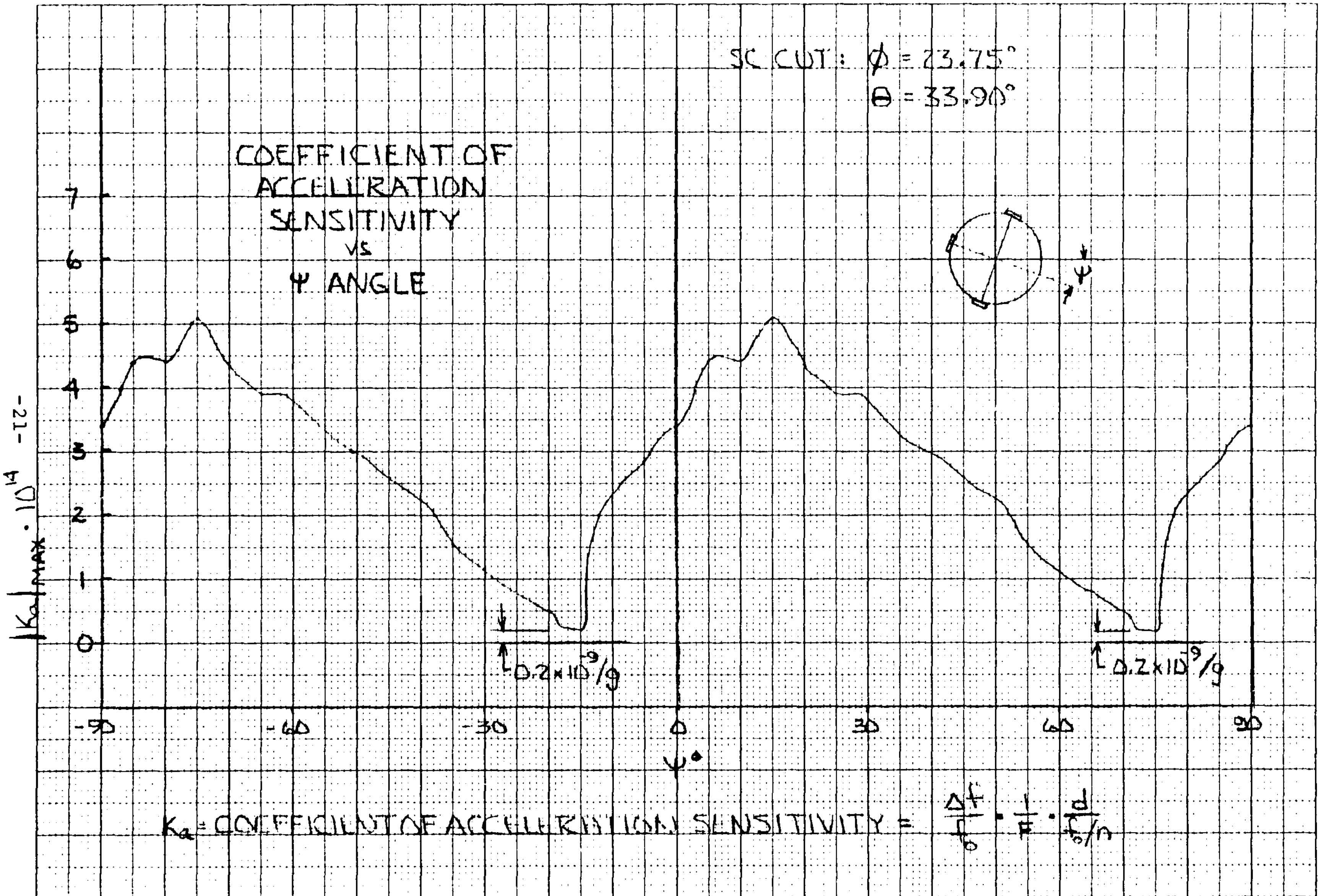

SC CUT: $\phi = 23.75°$
$\theta = 33.90°$
COEFFICIENT OF ACCELERATION SENSITIVITY vs Ψ ANGLE
$|K_a|_{MAX} \cdot 10^{14}$
0.2×10⁻⁹/g
0.2×10⁻⁹/g
-90
-60
-30
0
30
60
90
Ψ°
K_a = COEFFICIENT OF ACCELERATION SENSITIVITY = $\frac{\Delta f}{f_0} \cdot \frac{1}{F} \cdot \frac{d}{f_0/n}$

FIGURE B-1

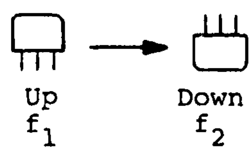
TABLE E-1

CRYSTAL TYPE/SERIAL NUMBER

PARAMETER	5 MHz/5 3909	10 MHz/3 3801
1. F_s (Hz)	4999917.9	10054170.6
2. C_L for F_p (pF)	10	32
3. F_p (Hz)	4999925.6	10054190.0
4. Δf_{3-1} (Hz)	7.8	21.4
5. C_o (pF)	1.65	3.6
6. C_1 (pF)	3.63×10^{-5}	1.52×10^{-4}
7. $R_{26°C}$ (Ω)	320	70
8. $Q_{26°C}$	2.74×10^6	1.49×10^6
9. Turnover (°C)	75	72
10. F_s @ T.O. (Hz)	5000014	10054326
11. R @ T.O. (Ω)	310	70
12. Q @ T.O.	2.82×10^6	1.49×10^6
13. Acceleration		
a) Radial, Worst Case[1]	3.8×10^{10}/g	4.2×10^{10}/g
b) Thickness (Up/Down)[2]	3.6×10^{10}/g	8.3×10^{10}/g

[1]Crystal position as shown at bottom of graph on page 23.

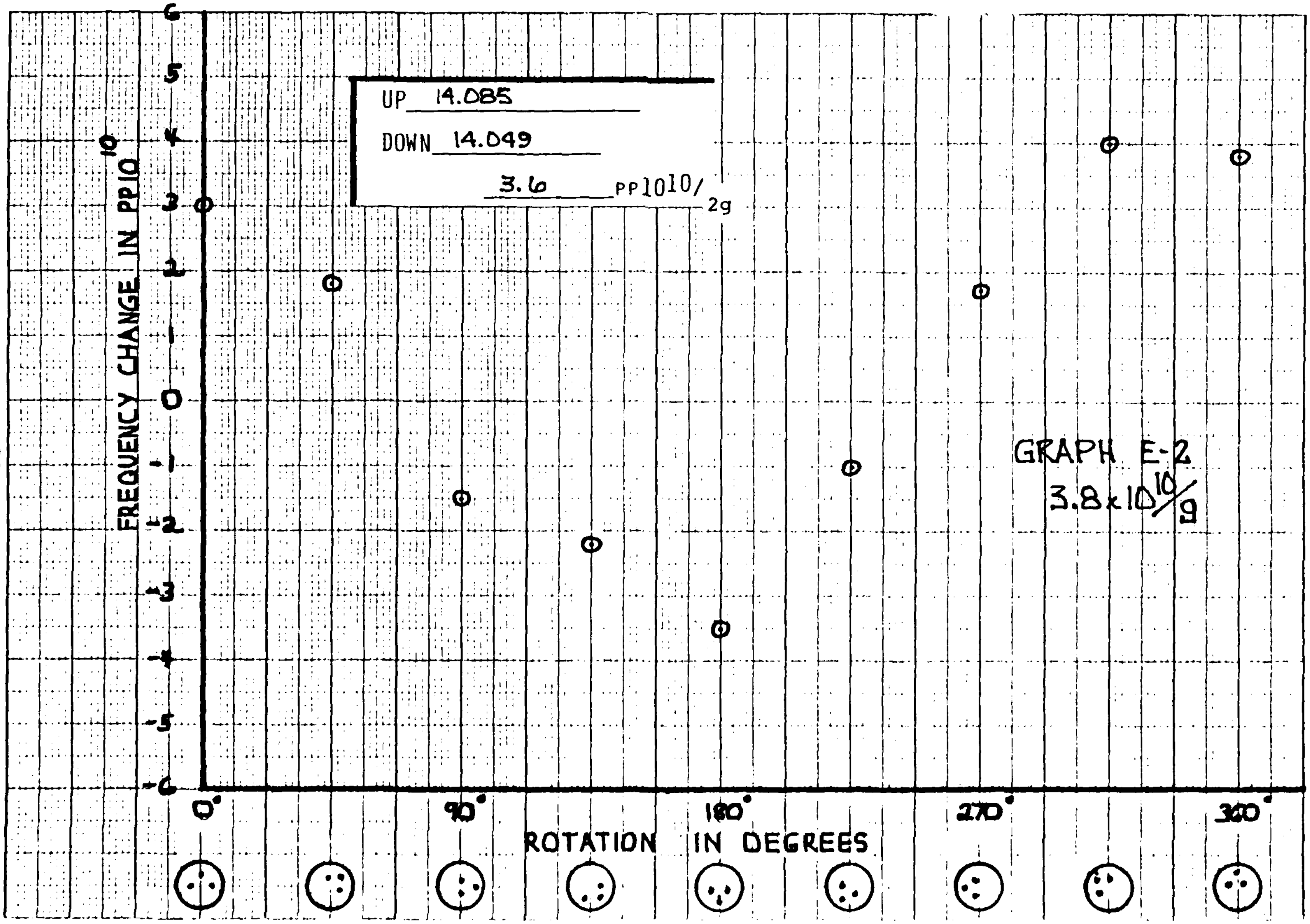
[2]Crystal position:

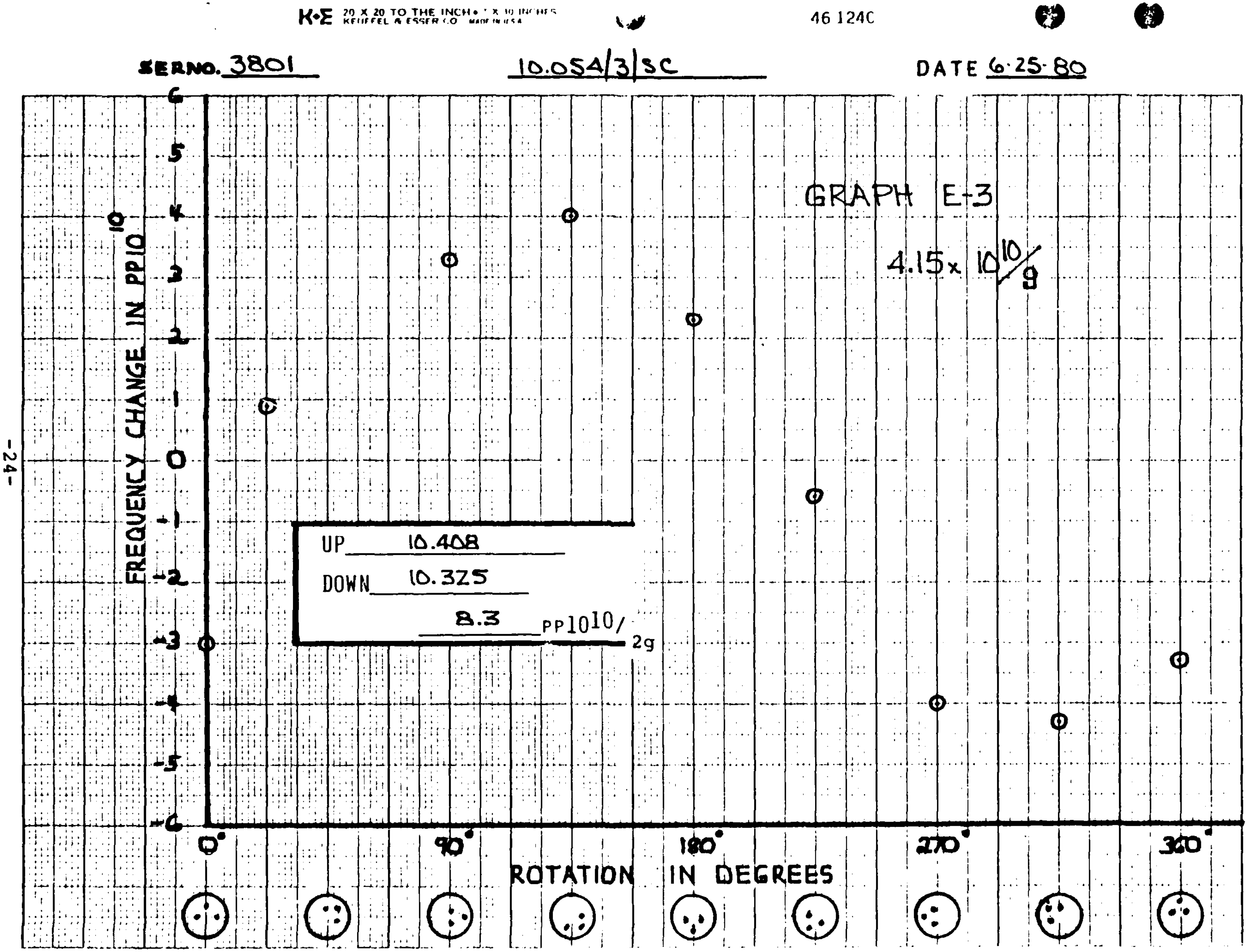


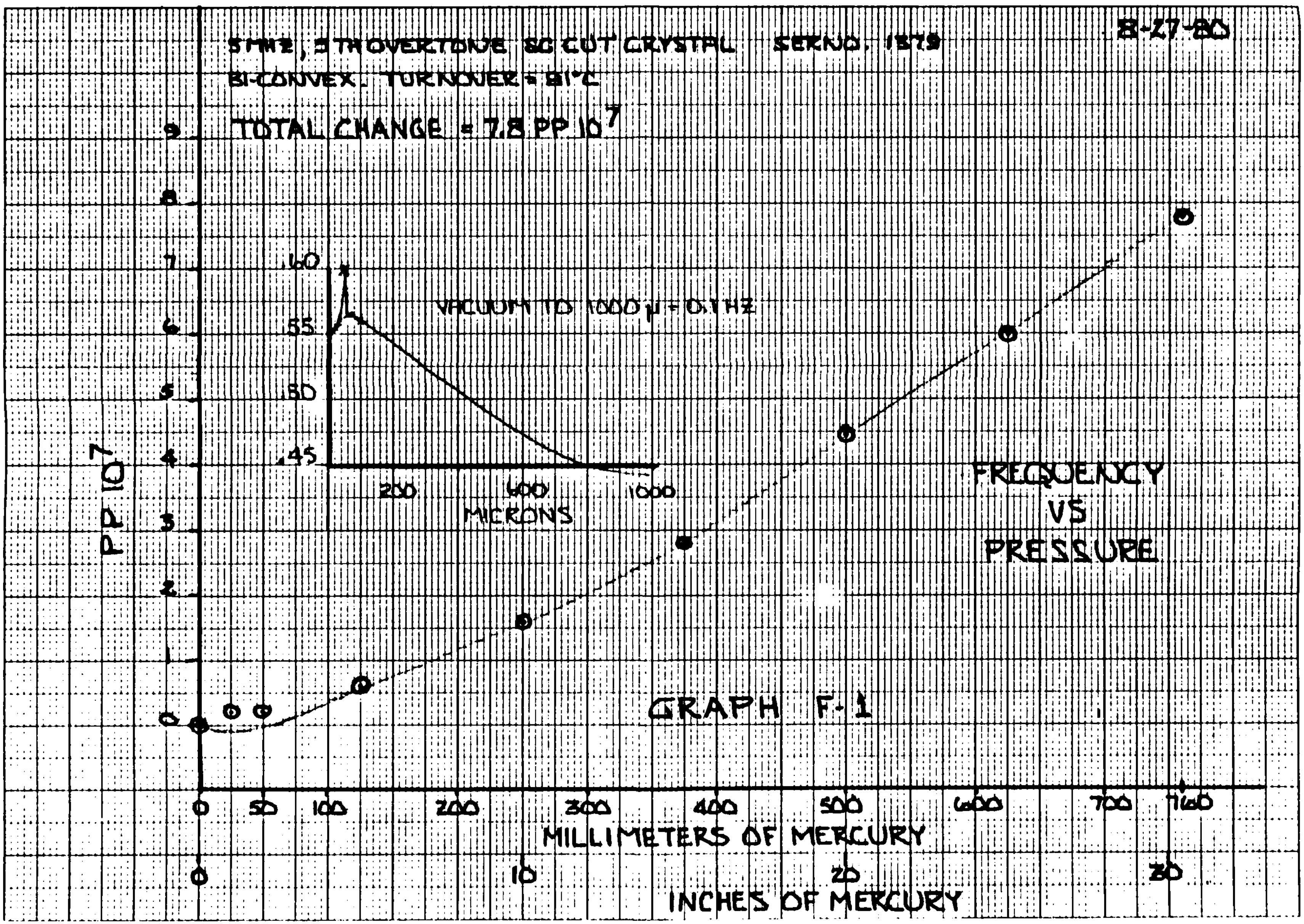
$$\text{Acceleration Effect} = \frac{|f_1 - f_2|}{2g}$$

K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3909 5.0/5/SC DATE 6-10-80




K•E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 124C
SER NO. 3801
10.054/3/SC
DATE 6-25-80
GRAPH E-3
4.15x 10^10/g
UP 10.408
DOWN 10.325
8.3 PP10^10/2g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES


5MHZ, 5TH OVERTONE SC CUT CRYSTAL SER NO. 1579
BI-CONVEX. TURNOVER = 81°C
TOTAL CHANGE = 7.8 PP 10^7
8-27-80
PP 10^7
VACUUM TO 1000 μ = 0.1 HZ
MICRONS
FREQUENCY VS PRESSURE
GRAPH F-1
MILLIMETERS OF MERCURY
INCHES OF MERCURY

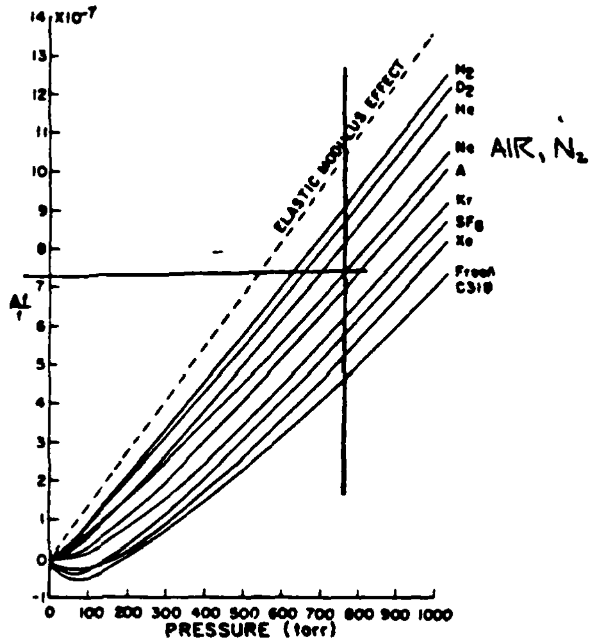


Fig. 5. Experimental frequency change observed versus pressure in different gases with a 5-Mc fifth overtone AT-cut quartz crystal. If there were no viscous loading all the curves would lie close to the dotted line.

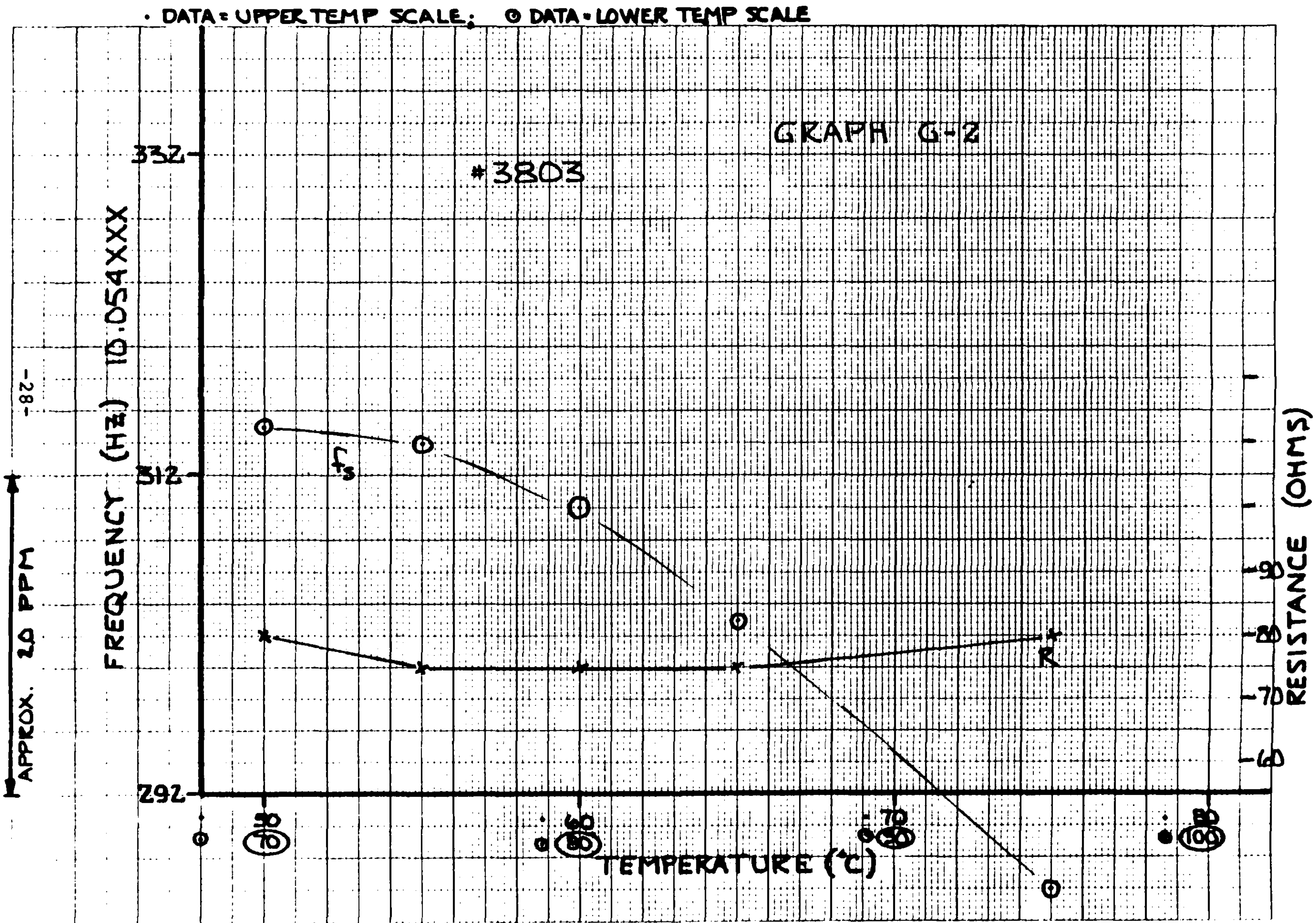
Data from Stockbridge

FIGURE F-2

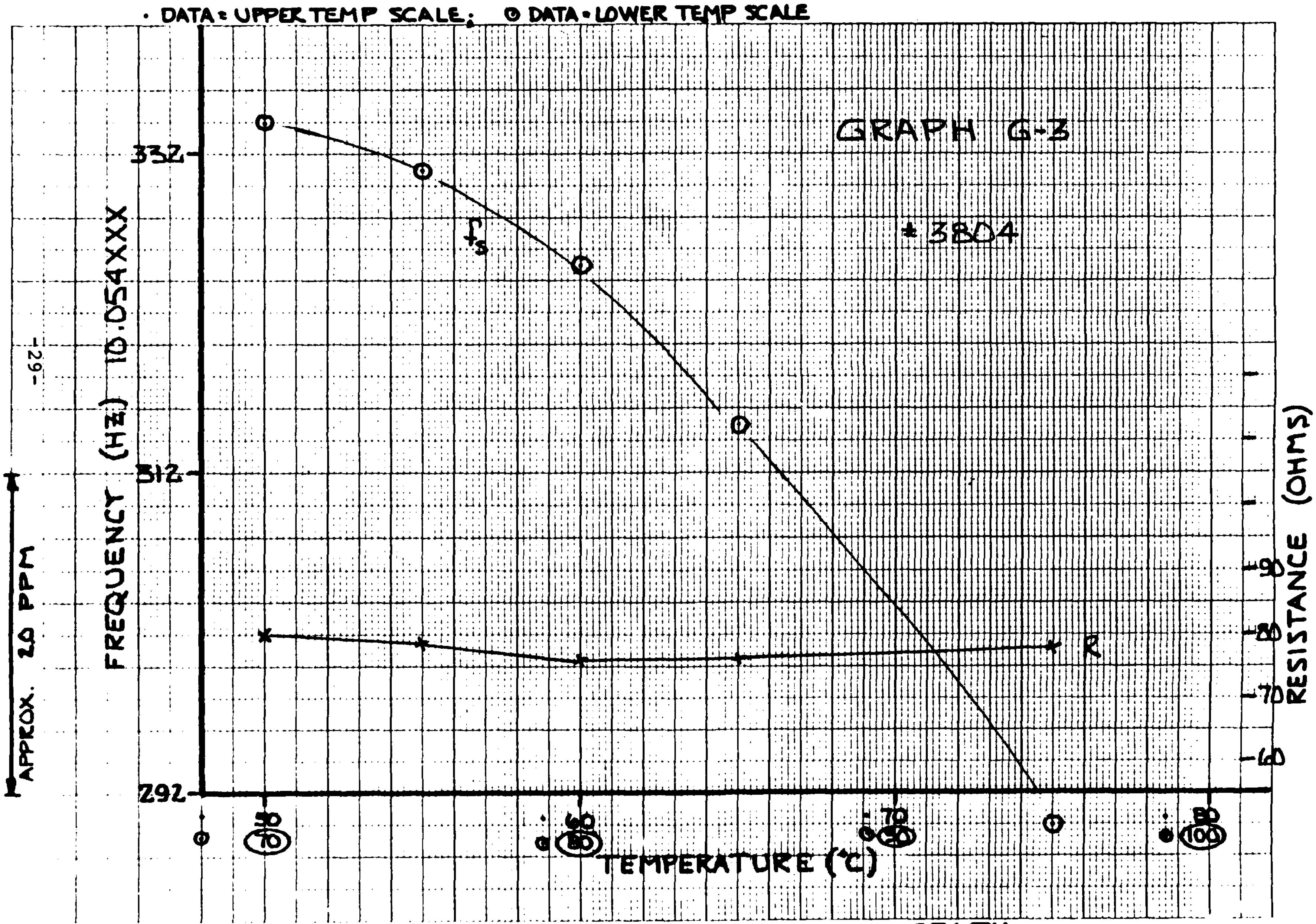
TABLE G-1

ELECTRICAL TEST DATA

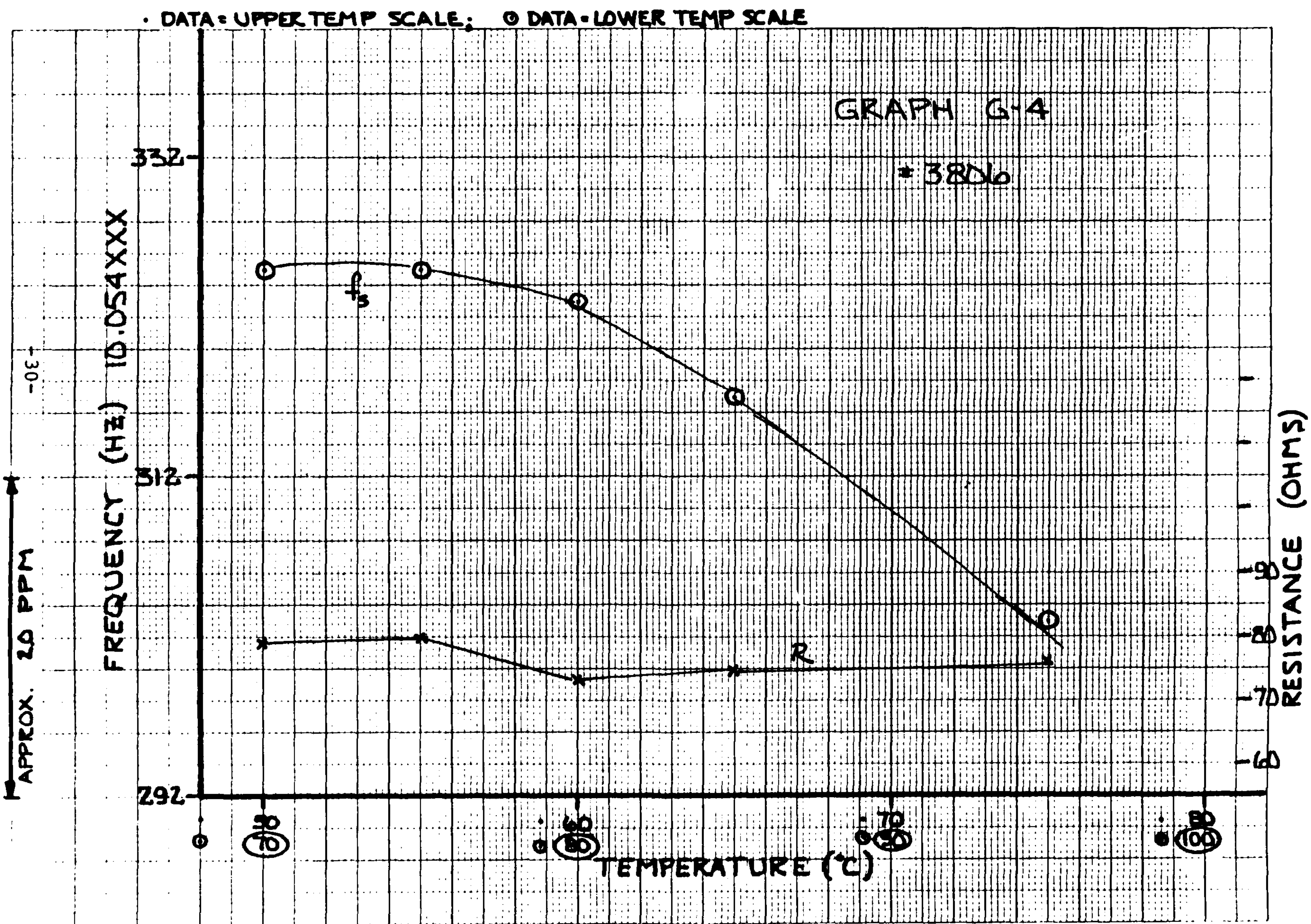
SERNO.	f_s @ 25°C	R	f_p @ 25°C w/32 pF	Δf	C_o	$C_1 \times 10^{16}$	$Q \times 10^{-6}$	T.O.(°C)
3803	10.054200	80	10.054220	20	3.5	1.41	1.40	70
3804	10.054186	80	10.054206	20	3.5	1.41	1.40	64
3806	10.054176	80	10.054196	20	3.5	1.41	1.40	72
3807	10.054170	80	10.054190	20	3.5	1.41	1.40	72



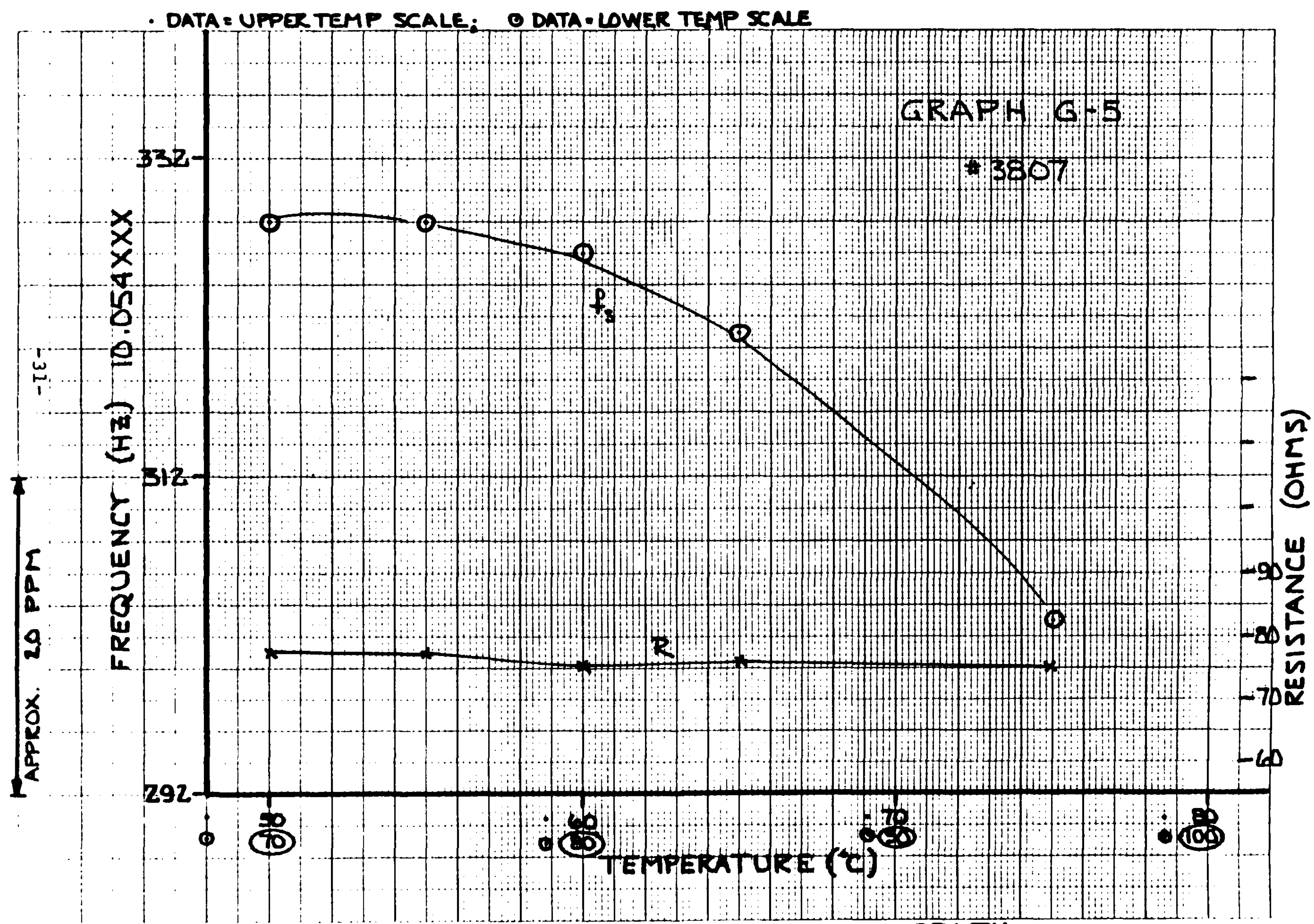
SC CUT CRYSTAL TURNOVER GRAPH



SC CUT CRYSTAL TURNOVER GRAPH



SC CUT CRYSTAL TURNOVER GRAPH



SC CUT CRYSTAL TURNOVER GRAPH

TABLE G-6

SUMMARY OF DATA PRESENTED IN GRAPHS G-7 THROUGH G-17

ACCELERATION

S/N	RADIAL WORST CASE ($PP10^{10}/g$)	THICKNESS (UP/DOWN) ($PP10^{10}/g$)	COMMENTS
3803	7.0	2.7	Diamond Mount
3804	5.3	3.0	Diamond Mount
3806	8.0	4.8	Diamond Mount
3807	2.7	2.5	Diamond Mount
3803	6.5	4.4	'J' Mount
3804	7.1	4.3	'J' Mount
3806	5.7	4.8	'J' Mount
3807	5.5	2.0	'J' Mount
3803	6.8	4.6	'J' Mount Retest
3804	6.7	4.2	'J' Mount Retest
3807	6.0	2.6	'J' Mount Retest

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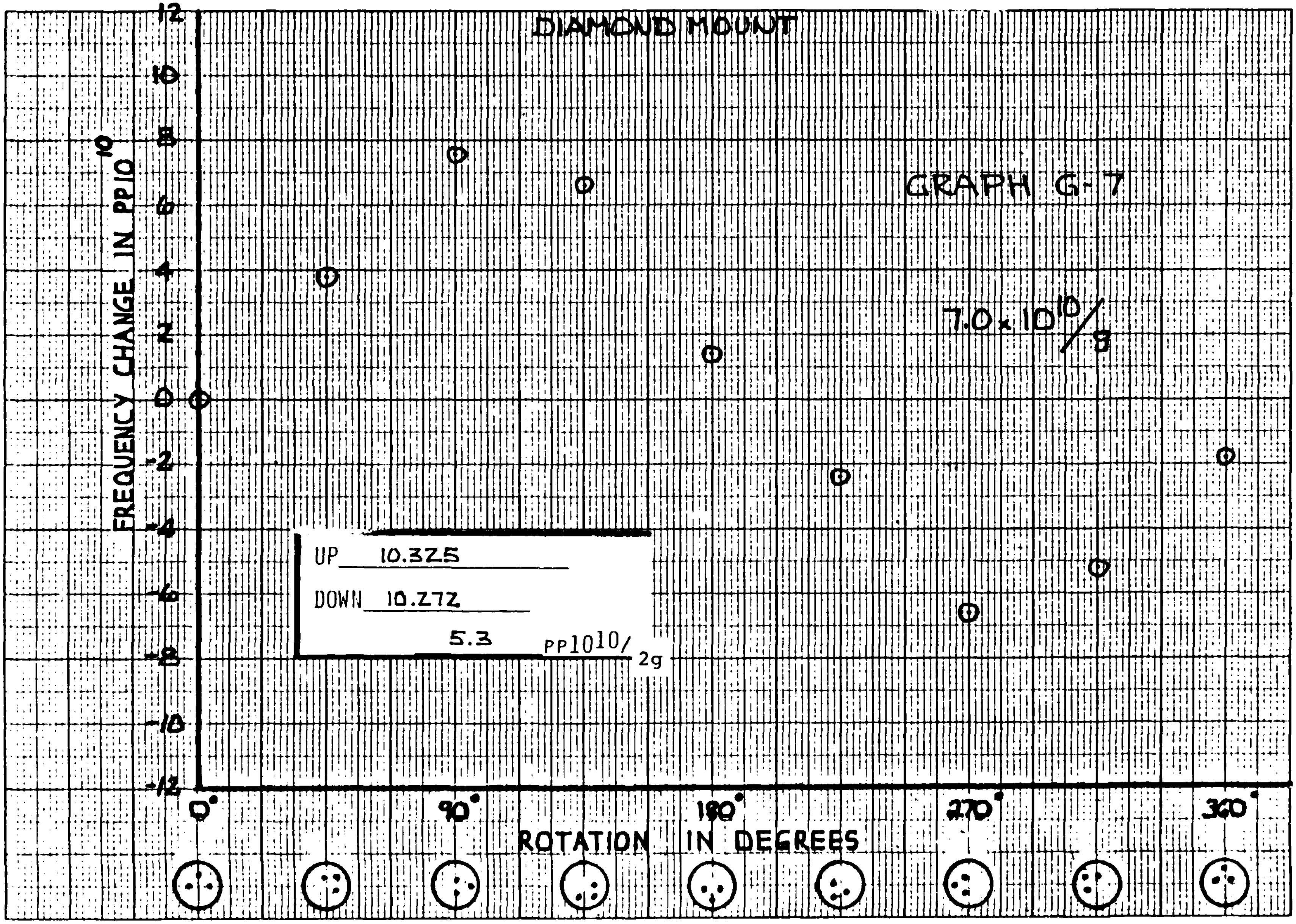
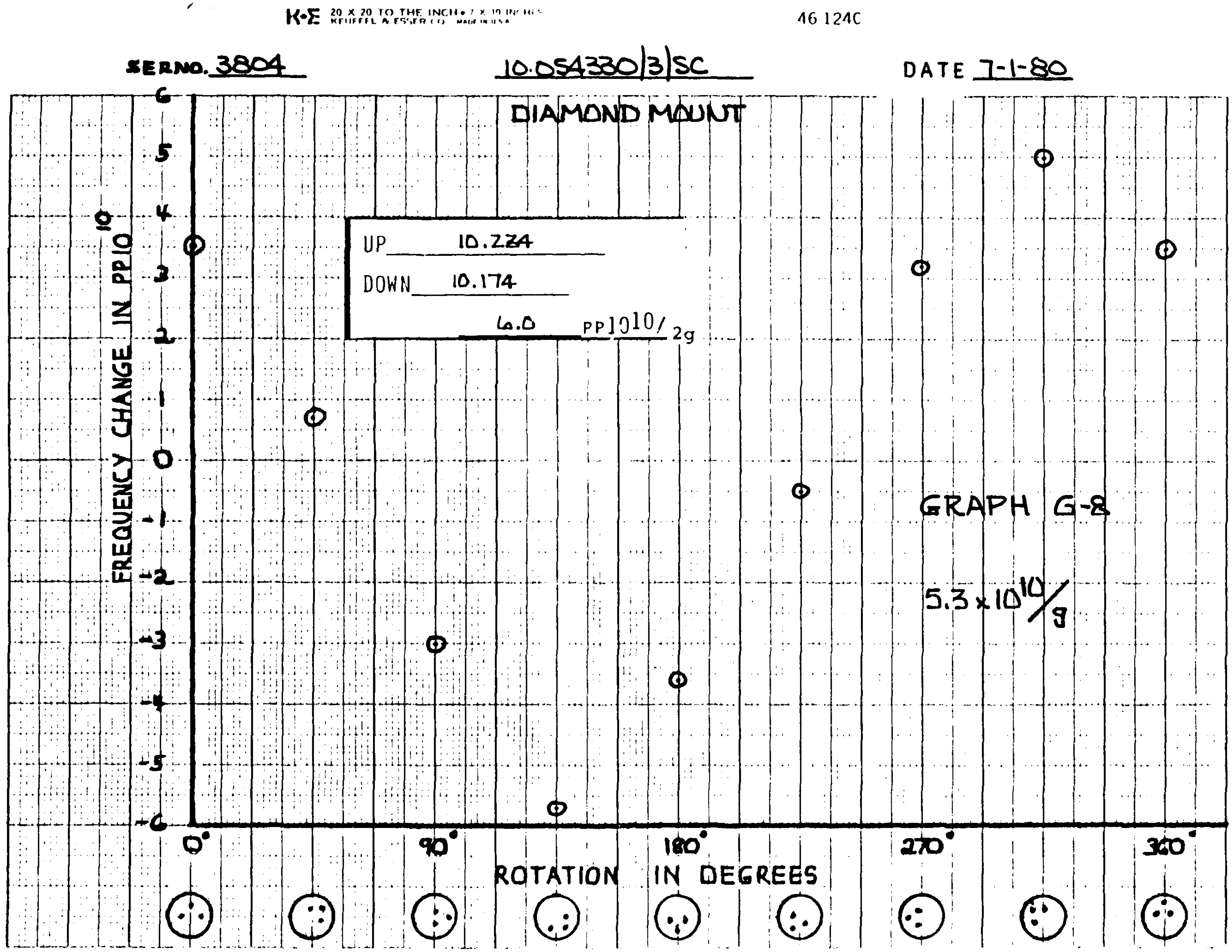
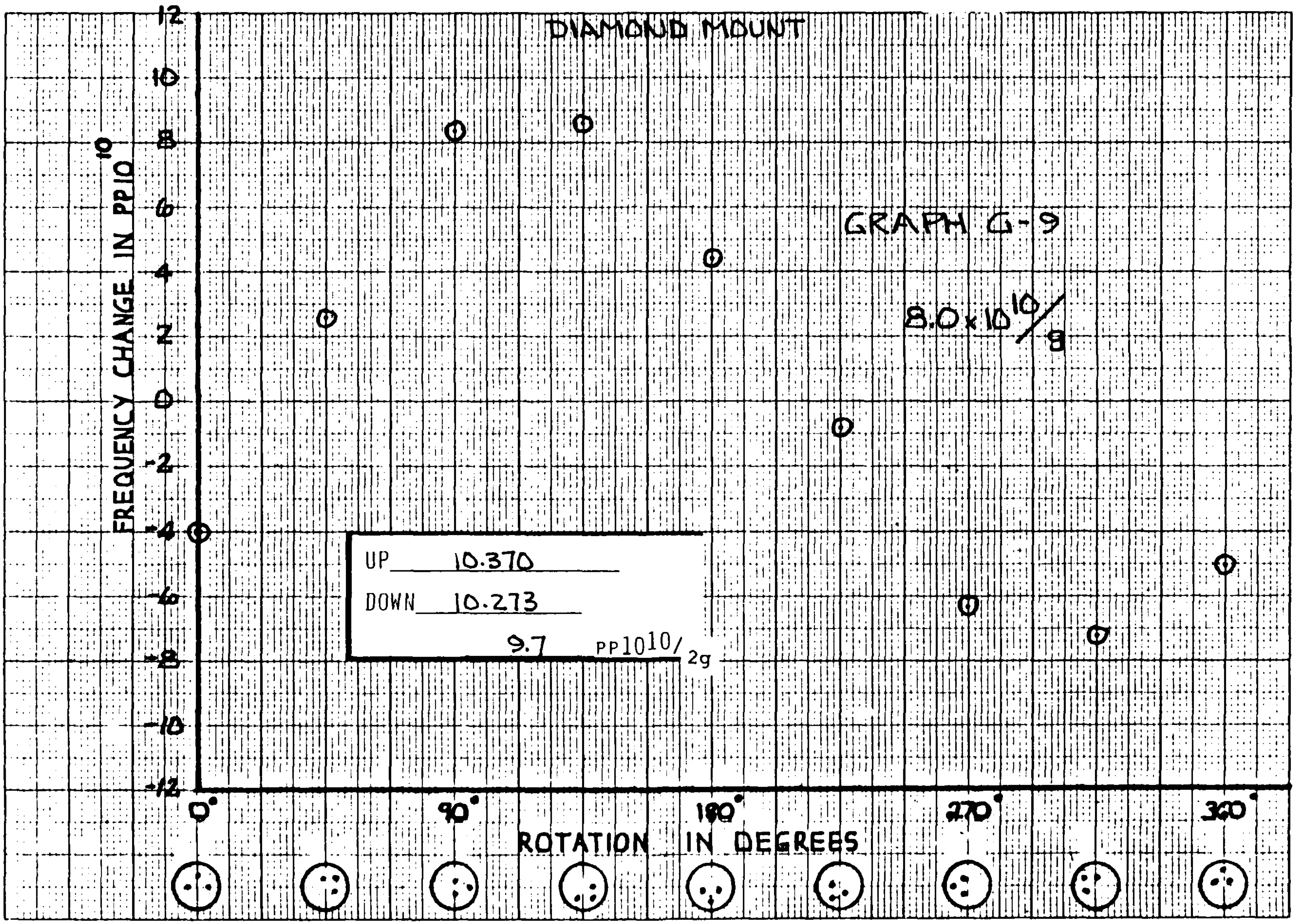
SER NO. 3803 10.054330/3/SC DATE 6-29-80

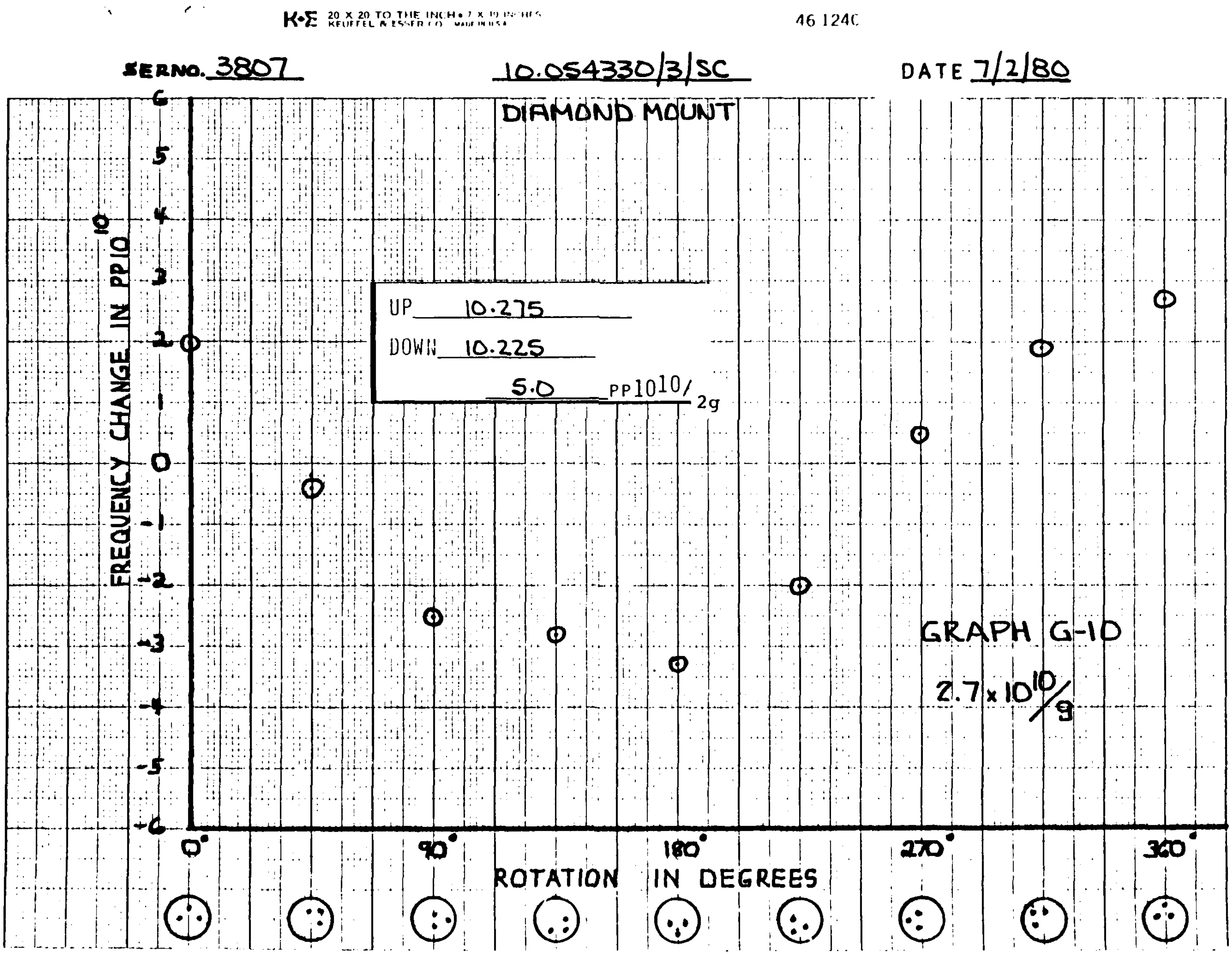



K·E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SER NO. 3804
10.054330/3/SC
DATE 7-1-80
DIAMOND MOUNT
UP 10.224
DOWN 10.174
6.0 PP10¹⁰/2g
GRAPH G-8
5.3 x 10¹⁰/g
FREQUENCY CHANGE IN PP10¹⁰
ROTATION IN DEGREES
0°
90°
180°
270°
360°
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6

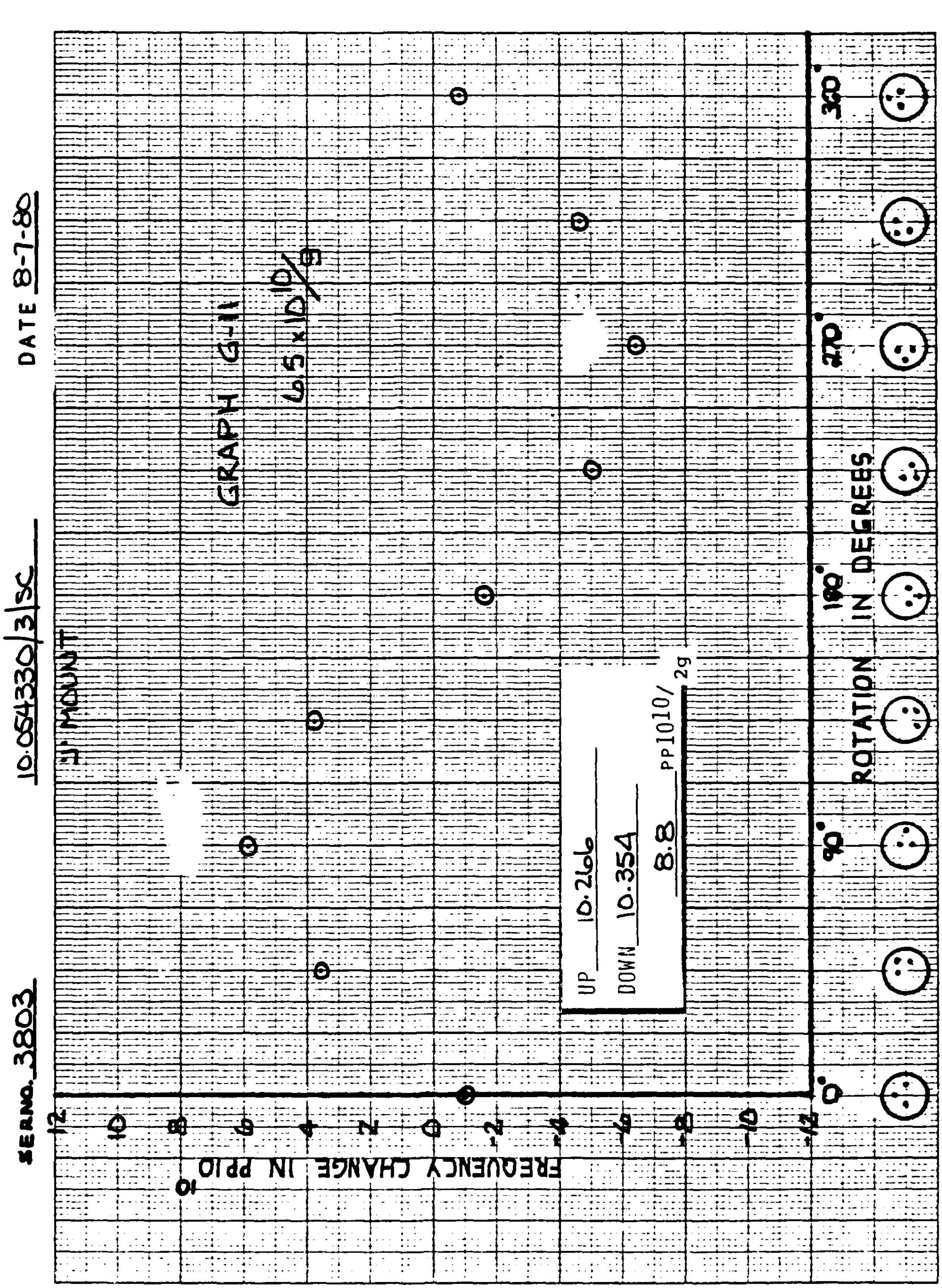
K&E KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3806 10.054330/5/SC DATE 6-29-80



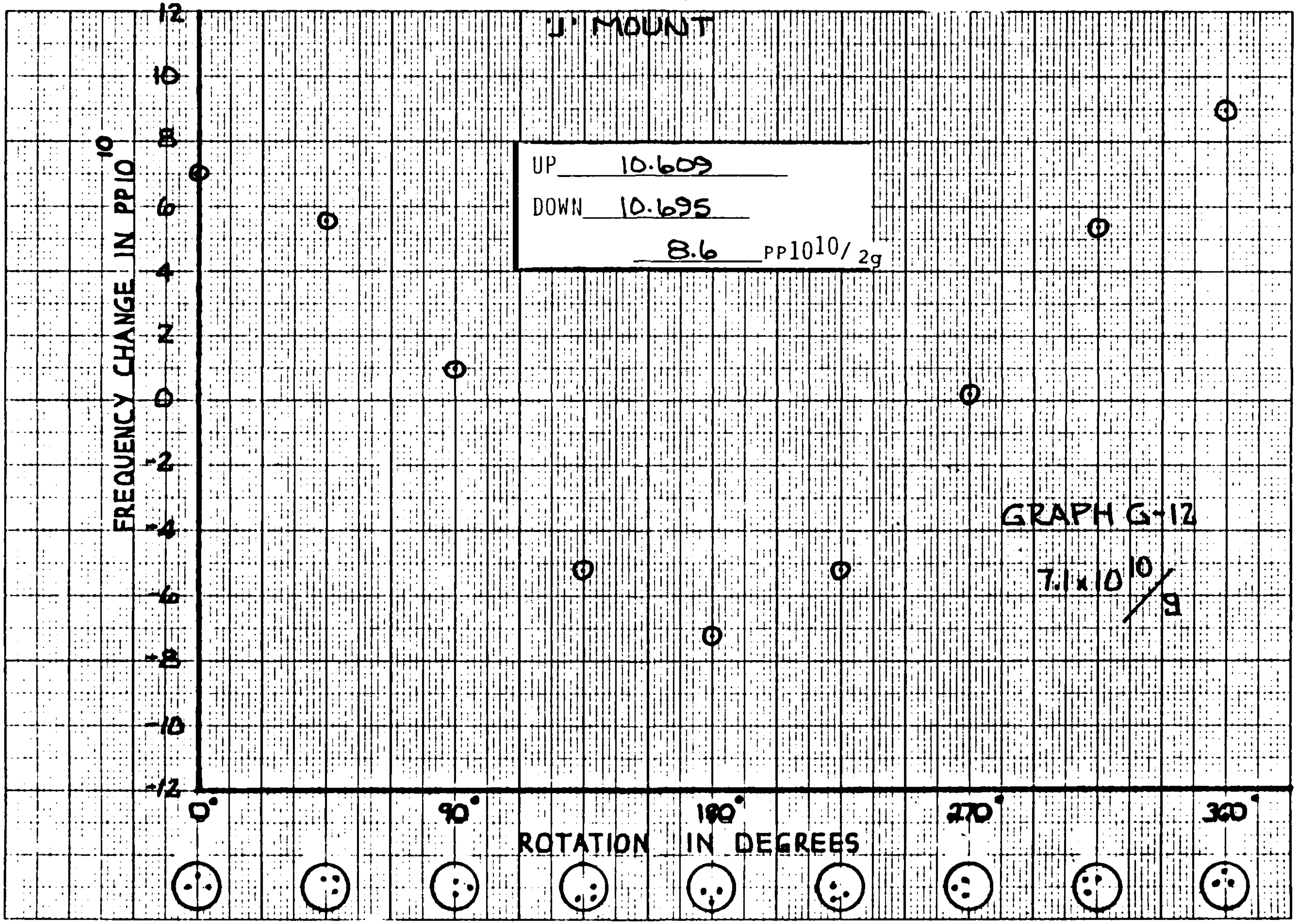


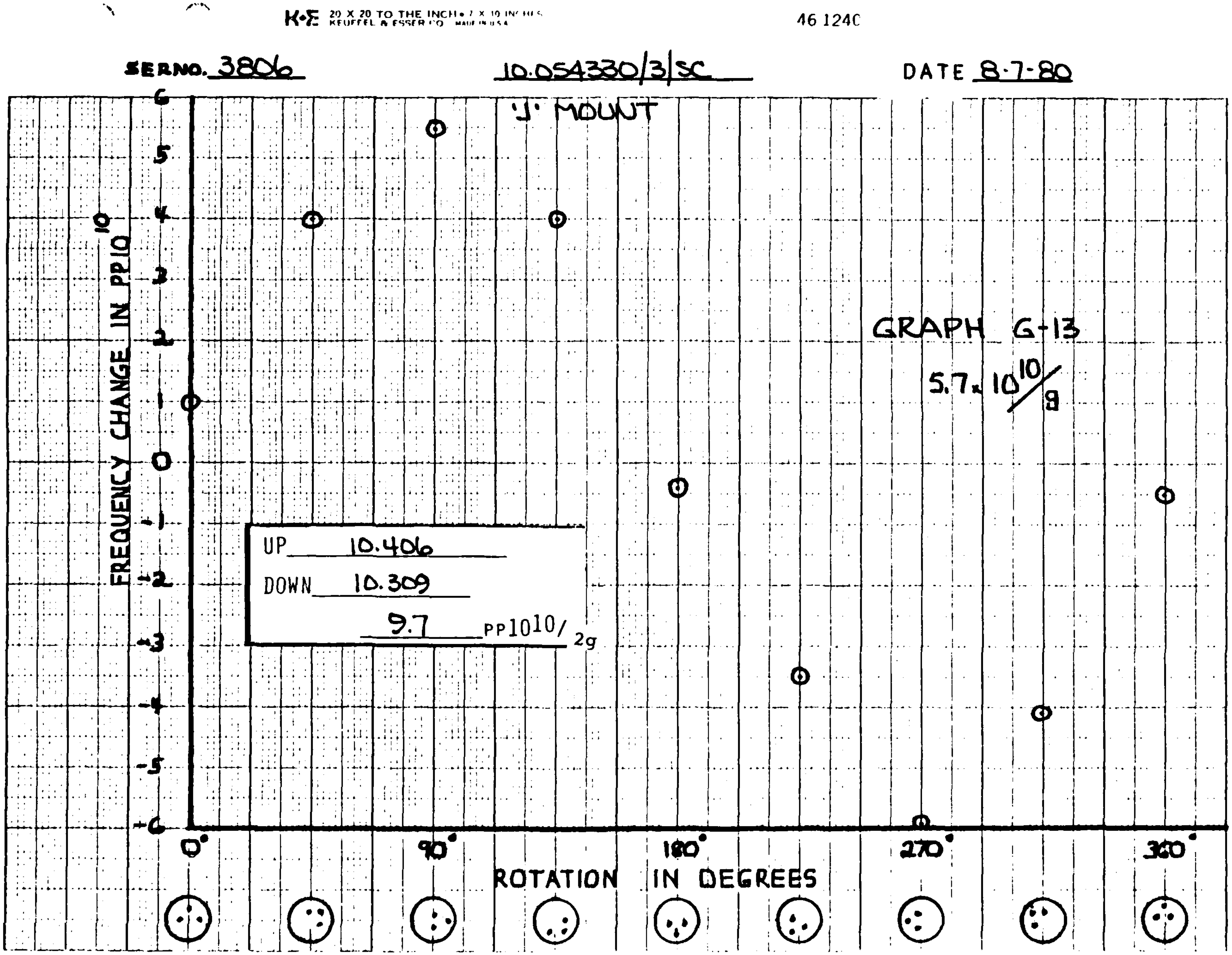
K+E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SERNO. 3807
10.054330/3/SC
DATE 7/2/80
DIAMOND MOUNT
UP 10.275
DOWN 10.225
5.0 PP10 10/2g
FREQUENCY CHANGE IN PP10 10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES
GRAPH G-10
2.7 x 10 10/g


SER NO. 3803
10.054330/3/SC
DATE 8-7-80
J MOUNT
GRAPH G-11
6.5 x 10^10/g
UP 10.266
DOWN 10.354
8.8 PP10^10/2g
FREQUENCY CHANGE IN PP10^10
ROTATION IN DEGREES
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0°
90°
180°
270°
360°
46 1240
KEUFFEL & ESSER CO. MADE IN U.S.A.

K+E KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

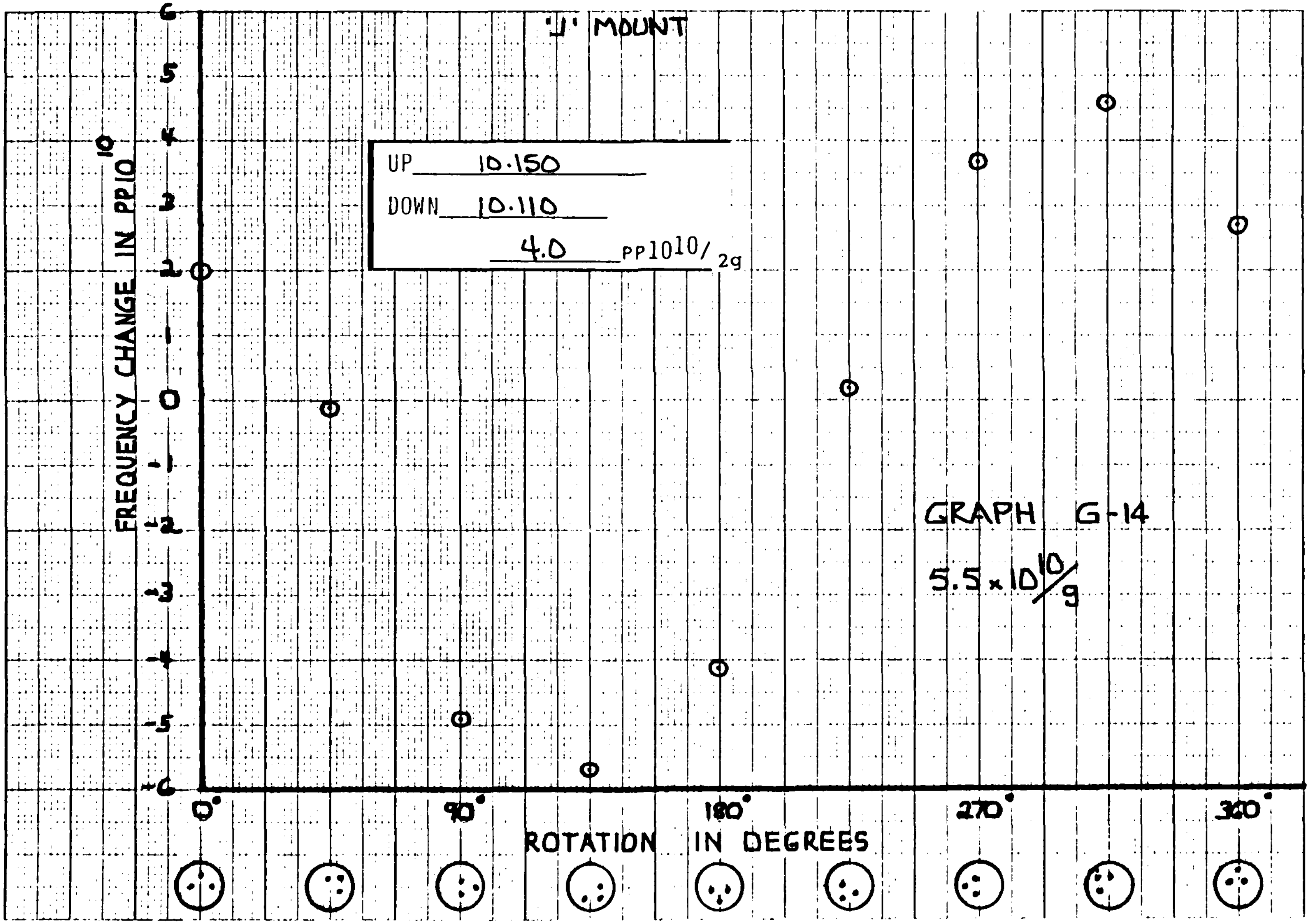
SER NO. 3804 10.054330/3/SC DATE 8-7-80

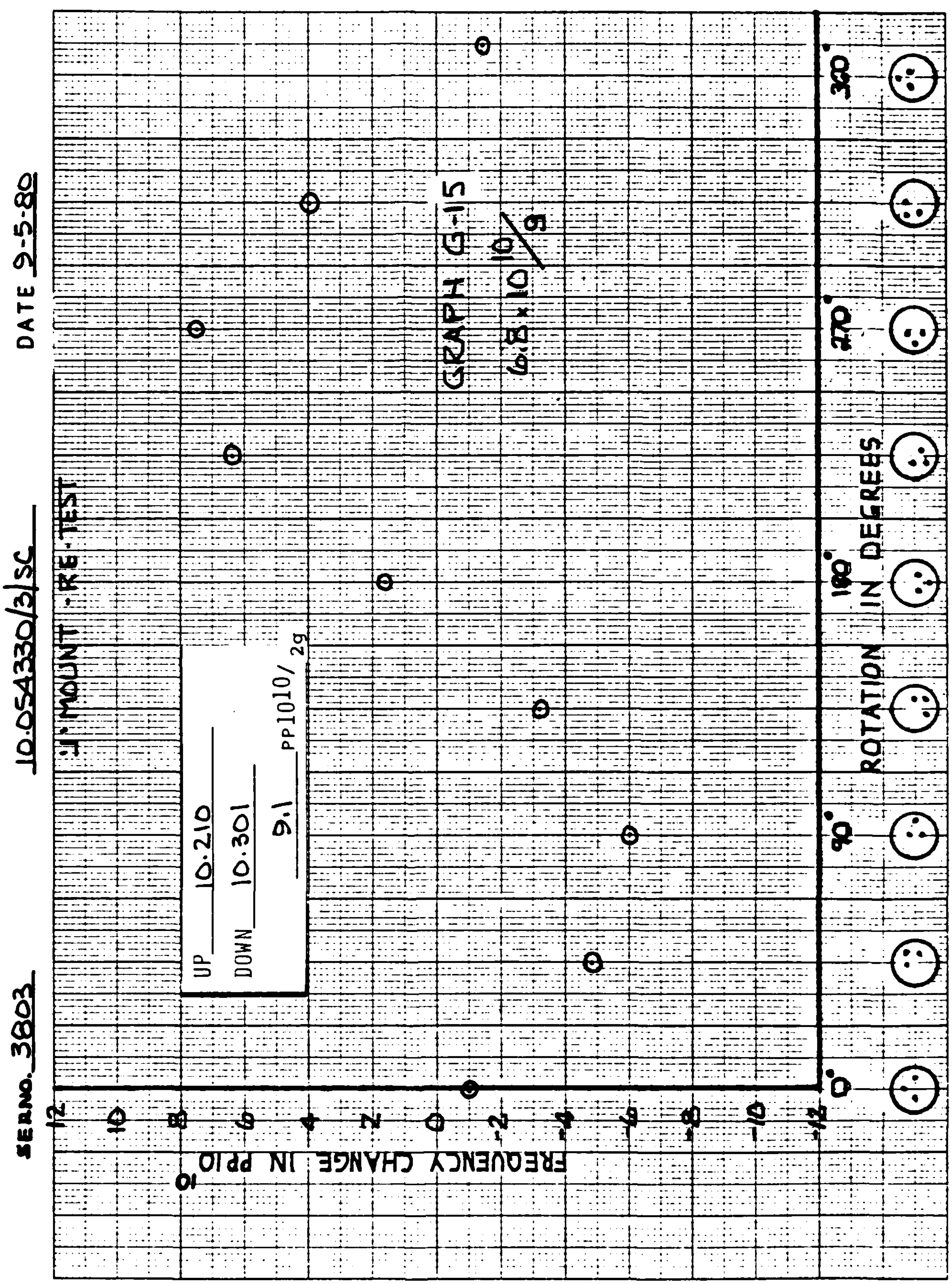



K+E 20 X 20 TO THE INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SER NO. 3806
10.054330/3/SC
DATE 8-7-80
'J' MOUNT
GRAPH G-13
5.7x10^10/g
UP 10.406
DOWN 10.309
9.7 PP10^10/2g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES

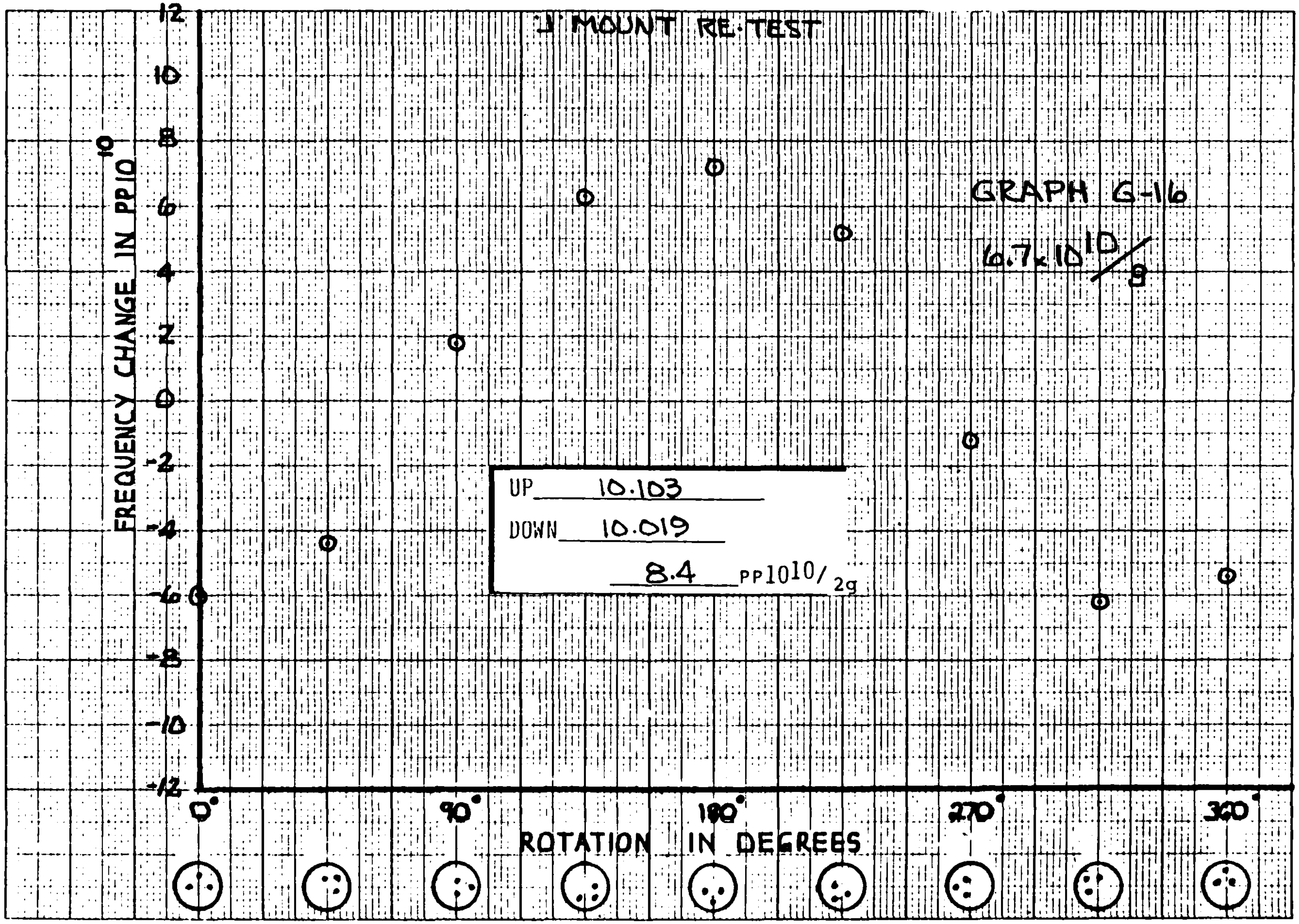
K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

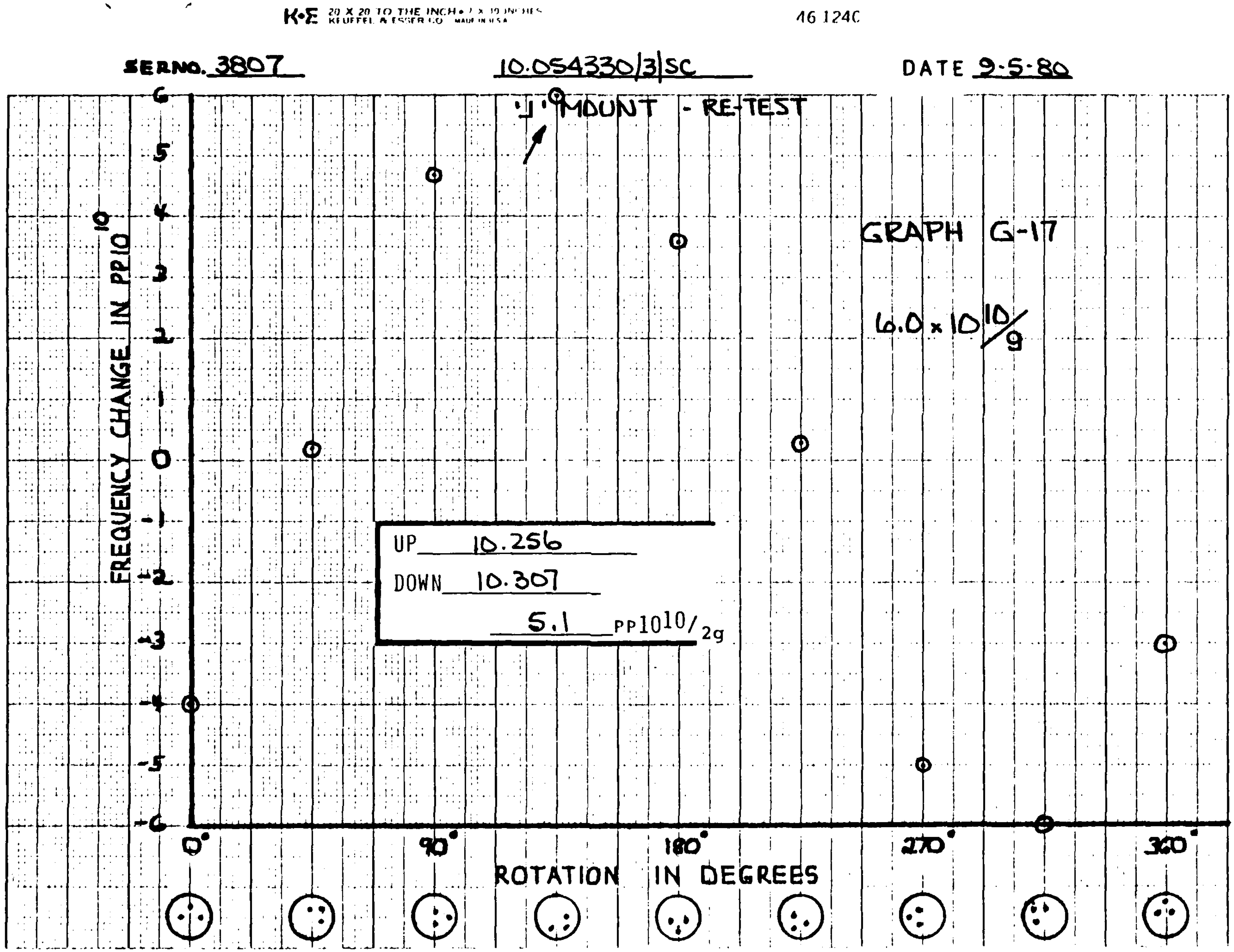
SER NO. 3807 10.054330/3/SC DATE 8-7-80




SER NO. 3803
10.054330/3/SC
'J' MOUNT · RE-TEST
DATE 9-5-80
UP 10.210
DOWN 10.301
9.1 PP1010/2g
GRAPH G-15
6.8 x 10^10/g
FREQUENCY CHANGE IN PP10^10
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0°
90°
180°
270°
360°
ROTATION IN DEGREES

SER NO. 3804 10.054330|3|SC DATE 9-5-80



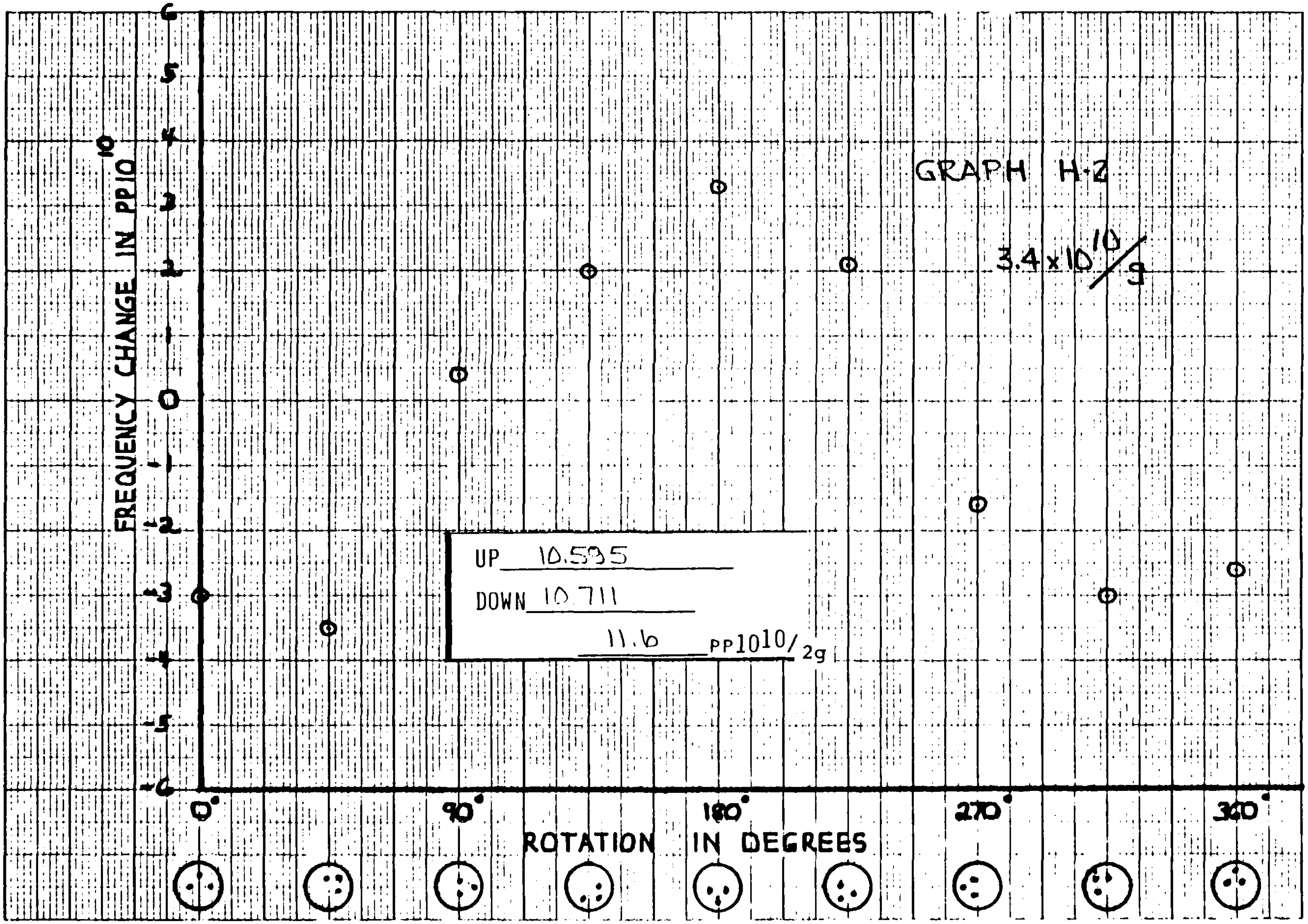


K•E 20 X 20 TO THE INCH
KEUFFEL & ESSER CO.
46 1240
SER NO. 3807
10.054330/3/SC
DATE 9-5-80
'J' MOUNT - RE-TEST
GRAPH G-17
6.0 x 10 10/g
UP 10.256
DOWN 10.307
5.1 PP10 10/2g
FREQUENCY CHANGE IN PP10 10
ROTATION IN DEGREES
0°
90°
180°
270°
360°

TABLE H-1

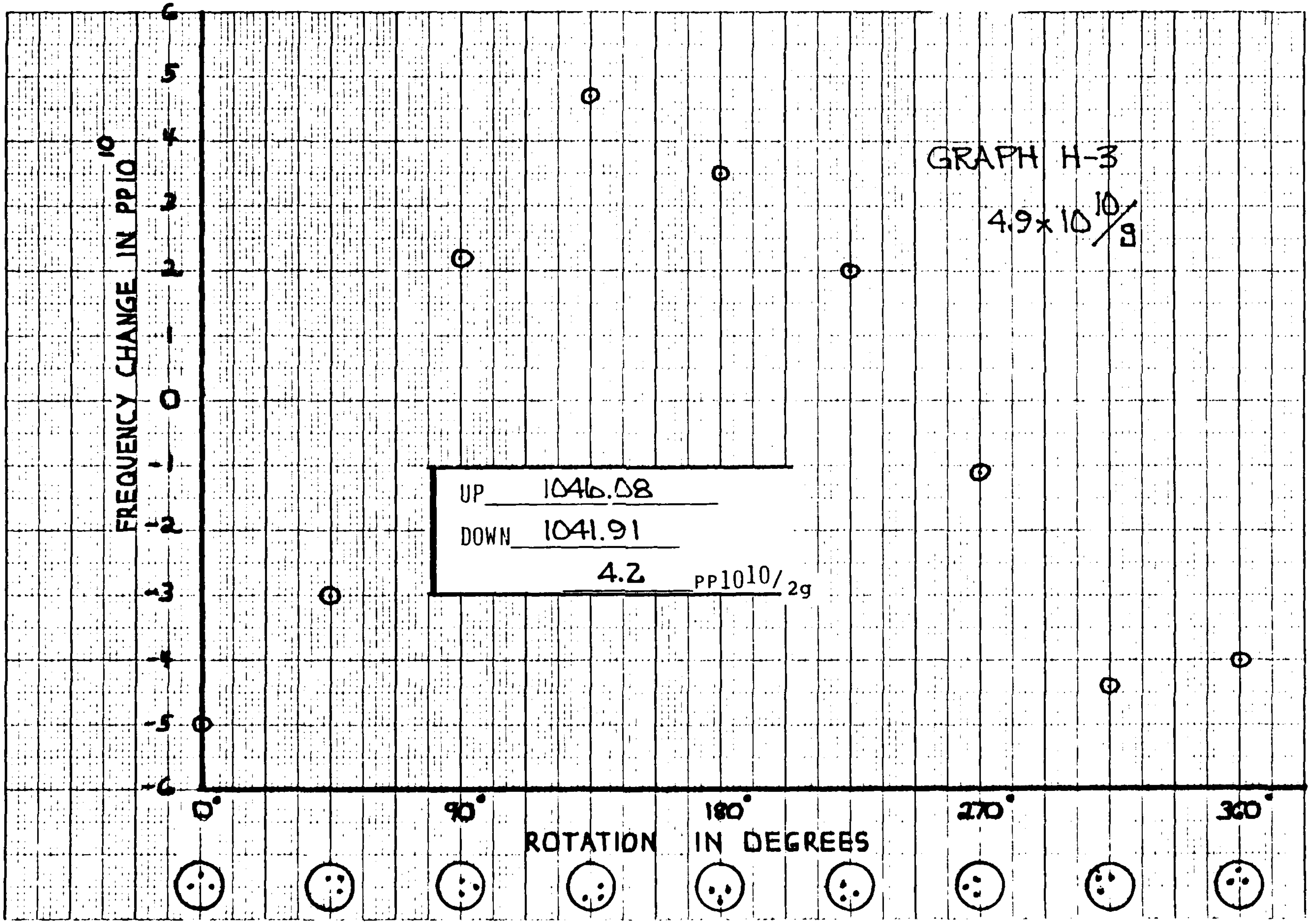
CRYSTAL ASSEMBLY FINAL DATA SHEET											
P/N ______		SPEC: ______	NOM. FREQ: 10.230400 MHz				PROJ: 7554		FSO: 0140B		
S/N	f_s @ 25 °C	R_s Ω	f_p 32 pF; 25 °C	Δf (Hz)	C_o (pF)	C_1 x10^{-16} F	Q x10^{+}	T.O. TEMP.	SPURS dB	SPURS Ω	f_p T.O.
4181	10.230266	80	10.230286	20	4.5	1.43	1.36	68		10.230	438
4182	10.230306	80	10.230326	20	4.5	1.43	1.36	63		10.230	443
4183	10.230276	75	10.230298	22	4.5	1.57	1.32	66		10.230	430
4184	10.230342	75	10.230364	22	4.5	1.57	1.32	73		10.230	529
4185	10.230346	75	10.230366	20	4.5	1.43	1.45	63		10.230	461
4136	10.230264	80	10.230284	20	4.5	1.43	1.36	72		10.230	432
4187	10.230386	75	10.230406	20	4.5	1.43	1.45	~50		10.230	479
418[illegible]	10.230290	75	10.230312	22	4.5	1.57	1.32	68		10.230	440
4189	10.230296	75	10.230316	20	4.5	1.43	1.45	65		10.230	418
			4184 TUNED IN	ERROR	+100	HZ					
			ALL CRYSTALS	TUNED	@85°C						
			AT 85°C ALL	CRYSTALS	EXCEPT	4184	ARE	10.230	400 ±	10HZ	

SER NO. 4182 10.230400|3|SC DATE 9-5-80



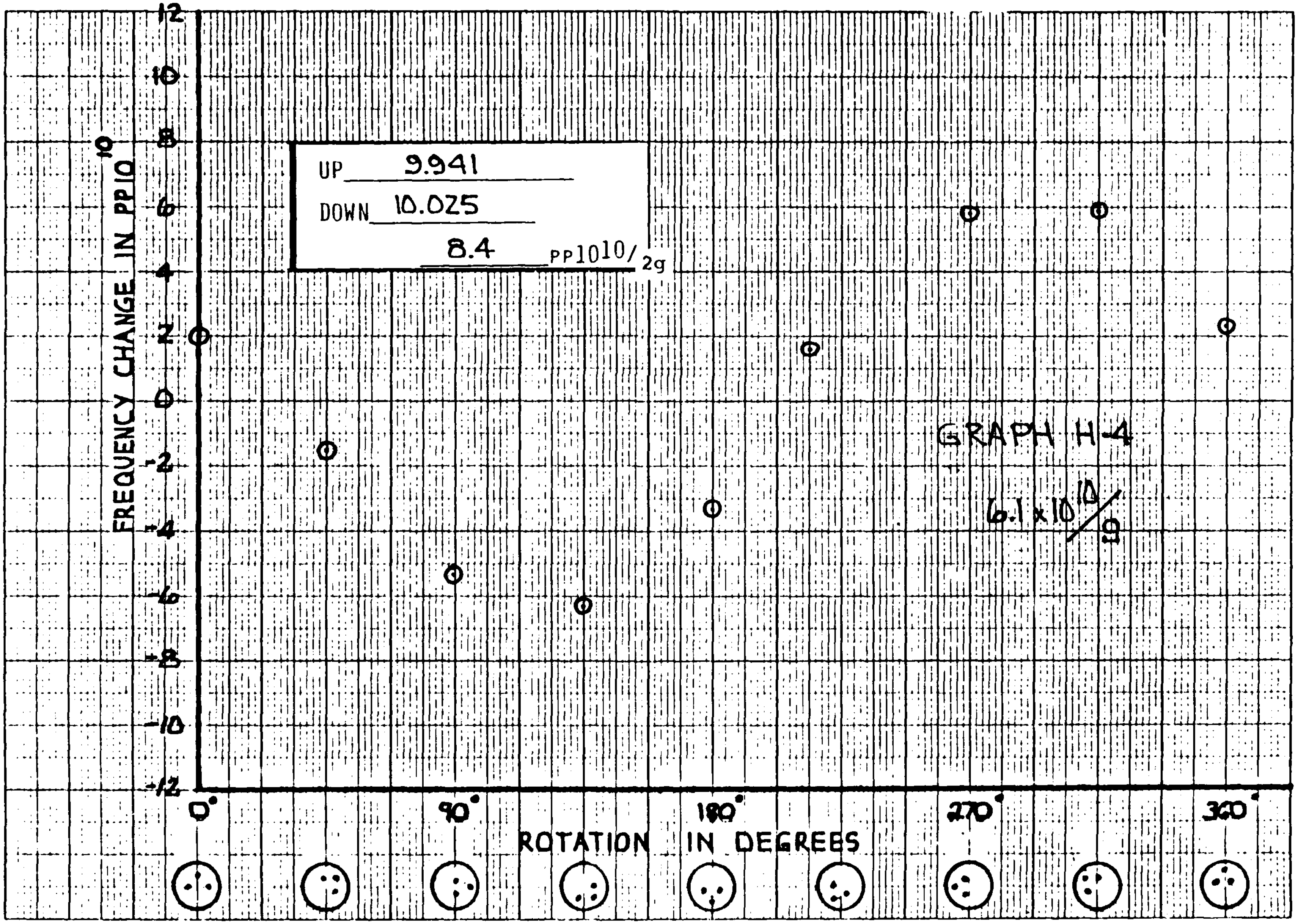
K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 124C

SER NO. 4184 10.230400|3|SC DATE 9-5-80



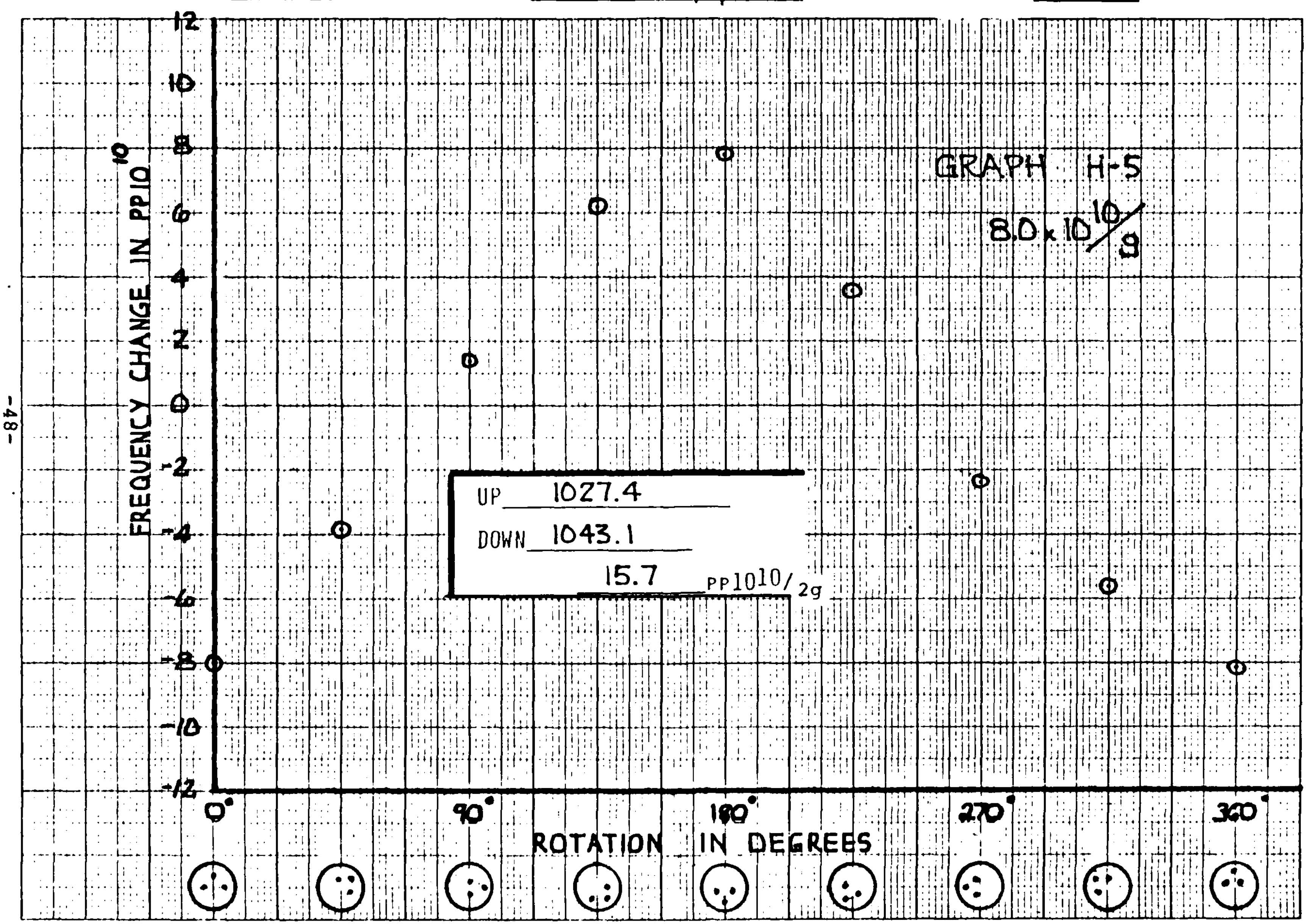
K•E 10 X 10 TO THE INCH KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 4185 10.230400/3/SC DATE 9/5/80



K+E KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 4187 10.230400/3/SC DATE 9-5-80



FIGURES J1 - J5

		BOND LOCATION		
SERNO.	FIG	LEFT	CENTER	RIGHT
4205	J-1	1 5	5 2	2 5
4207	J-2	0 1	2 3	0 0
4208	J-3	0 0	1 0	1 0
4142	J-4	2 1	2 3	1 2
4144	J-5	2 2	1 1	0 0

CENTER BOND MADE ON -X FLAT.

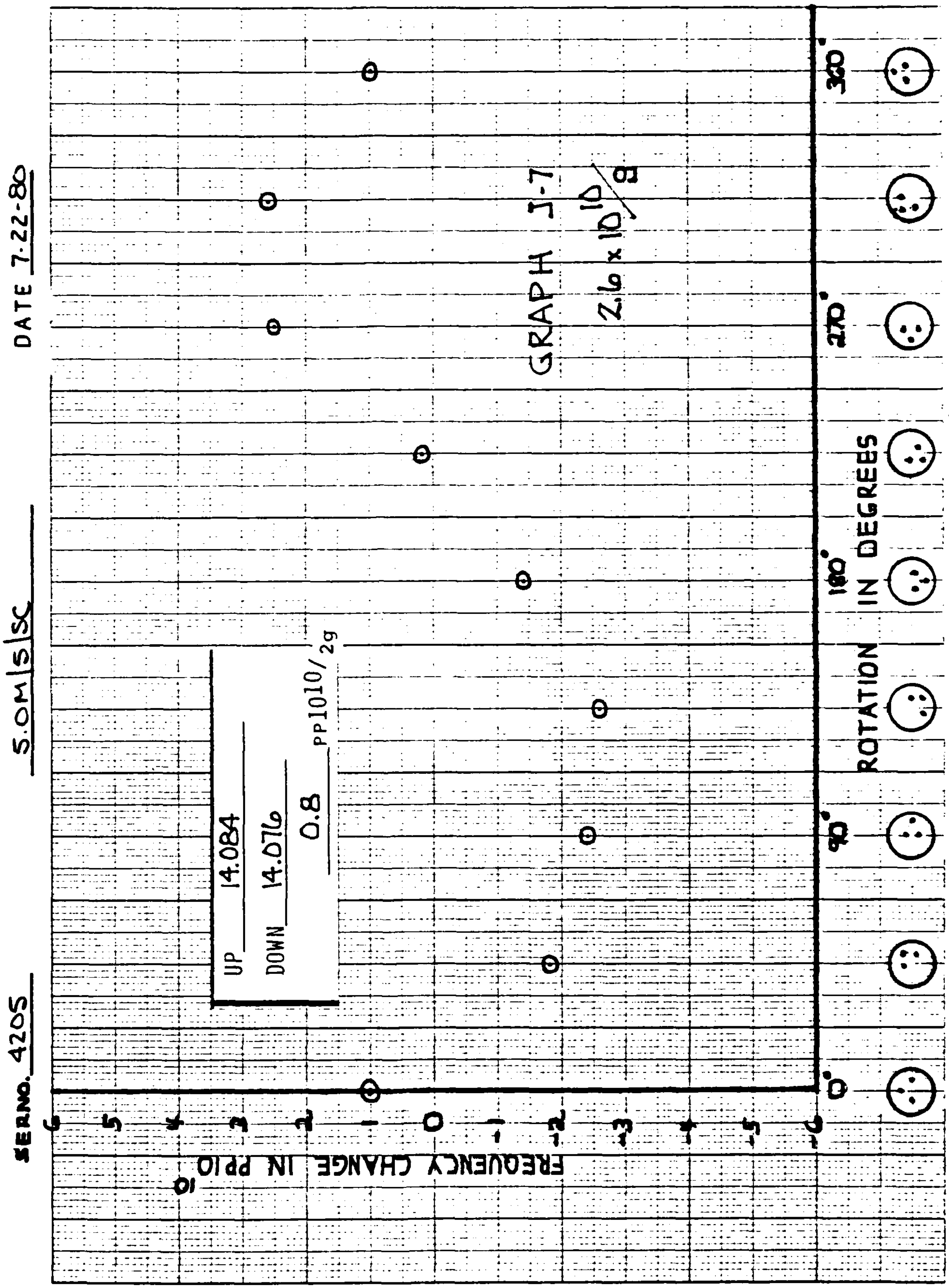
THE RATINGS AT EITHER SIDE OF EACH FIGURE DETERMINE THE RELATIVE AMOUNT OF "SQUASH OUT" OF THE GOLD RIBBON DURING BONDING.

RATING	% SQUASH OUT
0	100%
1	80%
2	60%
3	40%
4	20%
5	5%

TABLE J-6

SUMMARY OF 'g' SENSITIVITY DATA ON 5.000000 MHz, FIFTH OVERTONE SC CUT CRYSTALS

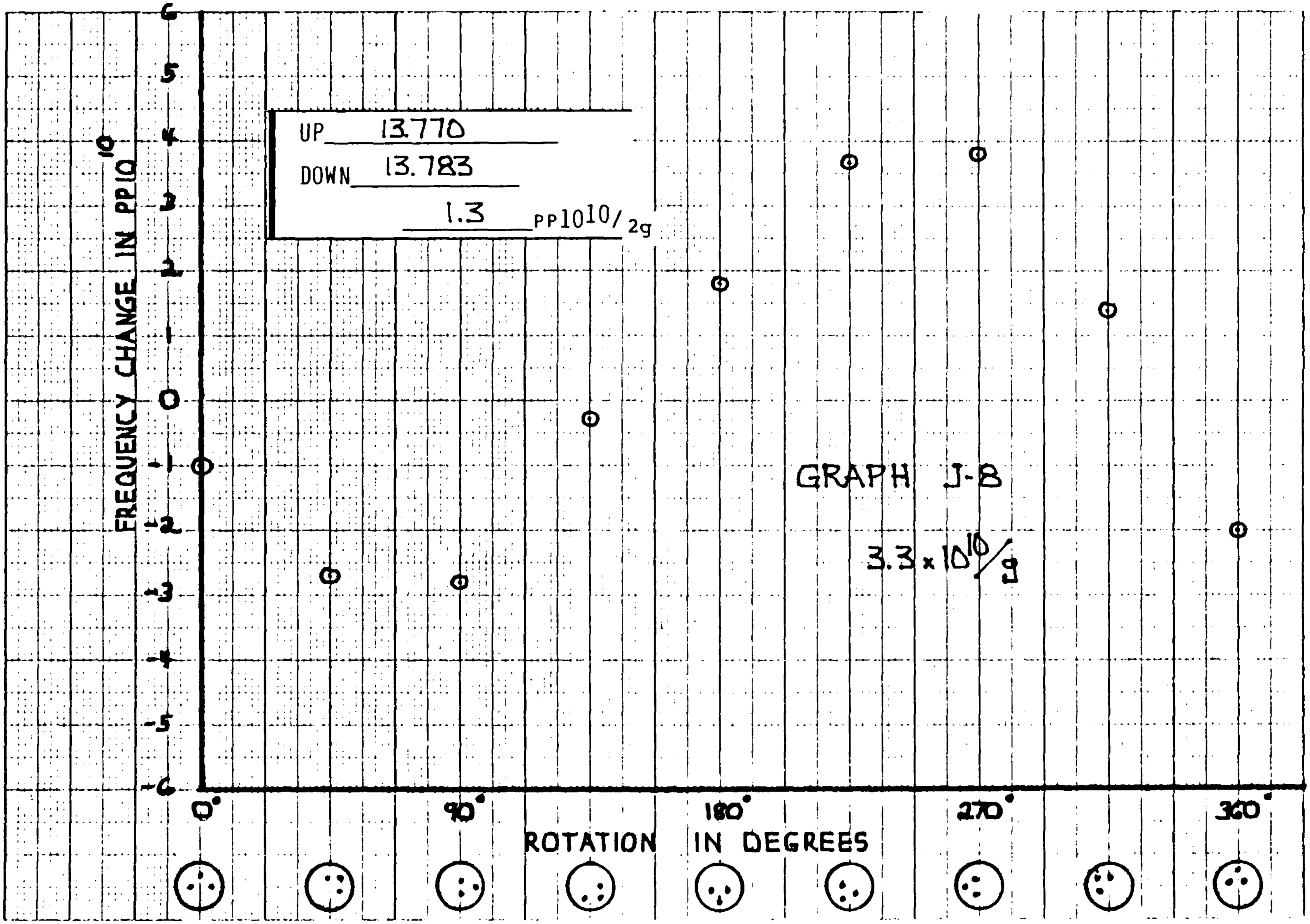
	ACCELERATION	
SERNO	RADIAL WORST CASE ($PP10^{10}/g$)	THICKNESS (UP/DOWN) ($PP10^{10}/g$)
4205	2.6	0.4
4207	3.3	0.7
4208	2.7	0.8
4142	5.1	1.9
4144	4.5	1.5


SER.NO. 4205
5.0M|5|SC
DATE 7-22-80
GRAPH J-7
2.6 x 10^10/g
UP 14.084
DOWN 14.076
0.8 PP10^10/2g
FREQUENCY CHANGE IN PP10^10
ROTATION IN DEGREES
0°
90°
180°
270°
360°
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6

K•E 20 X 20 TO THE INCH

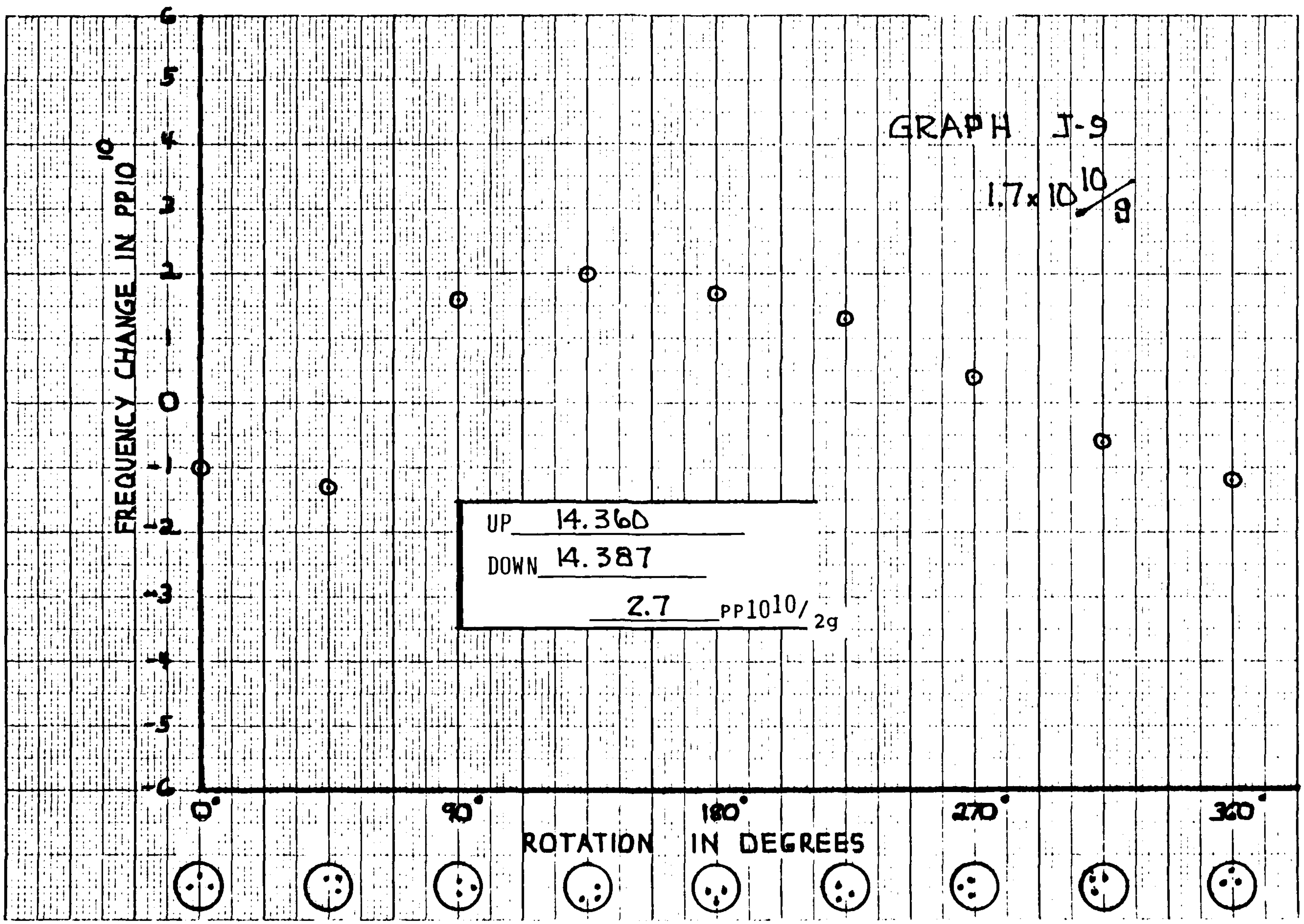
46 1240

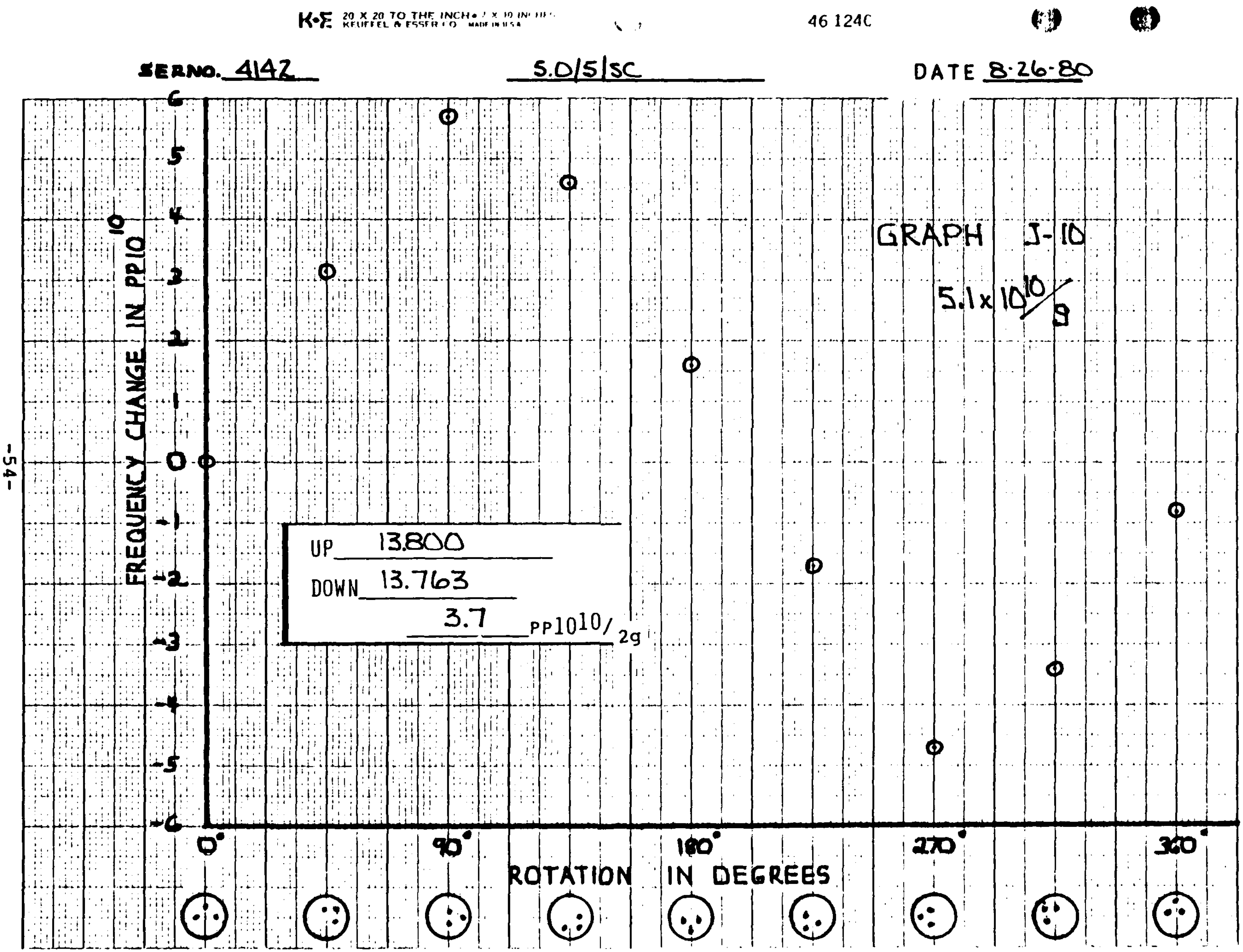
SERNO. 4207 5.0/5/SC DATE 8-26-80



K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 4208 5.0/5/SC DATE 8-26-80





K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 124C
SER NO. 4142
5.0/5/SC
DATE 8-26-80
GRAPH J-10
5.1x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
UP 13.800
DOWN 13.763
3.7 PP10^10/2g
0°
90°
180°
270°
360°
ROTATION IN DEGREES

SER NO. 4144 5.0/5/SC DATE 8-26-80

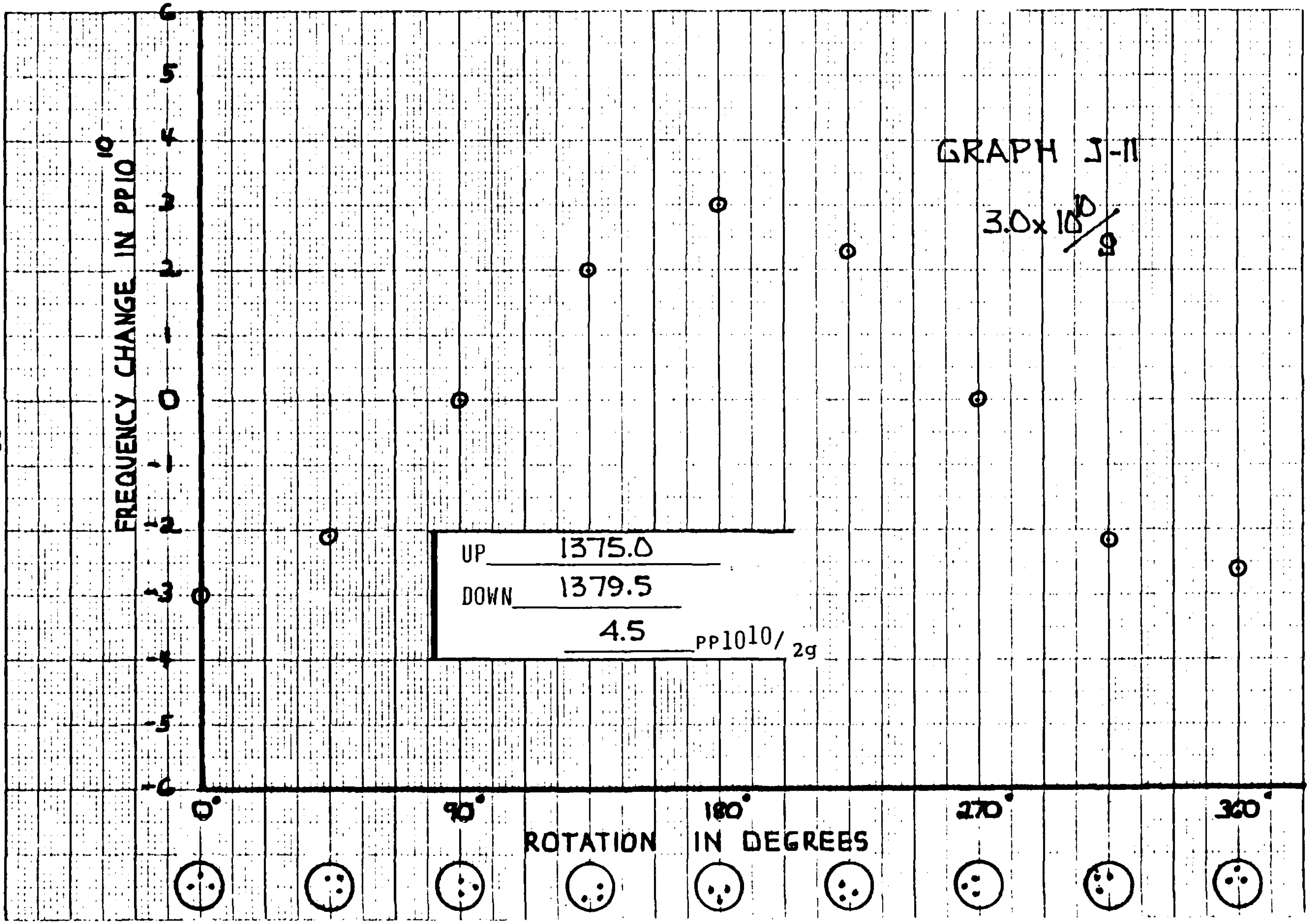
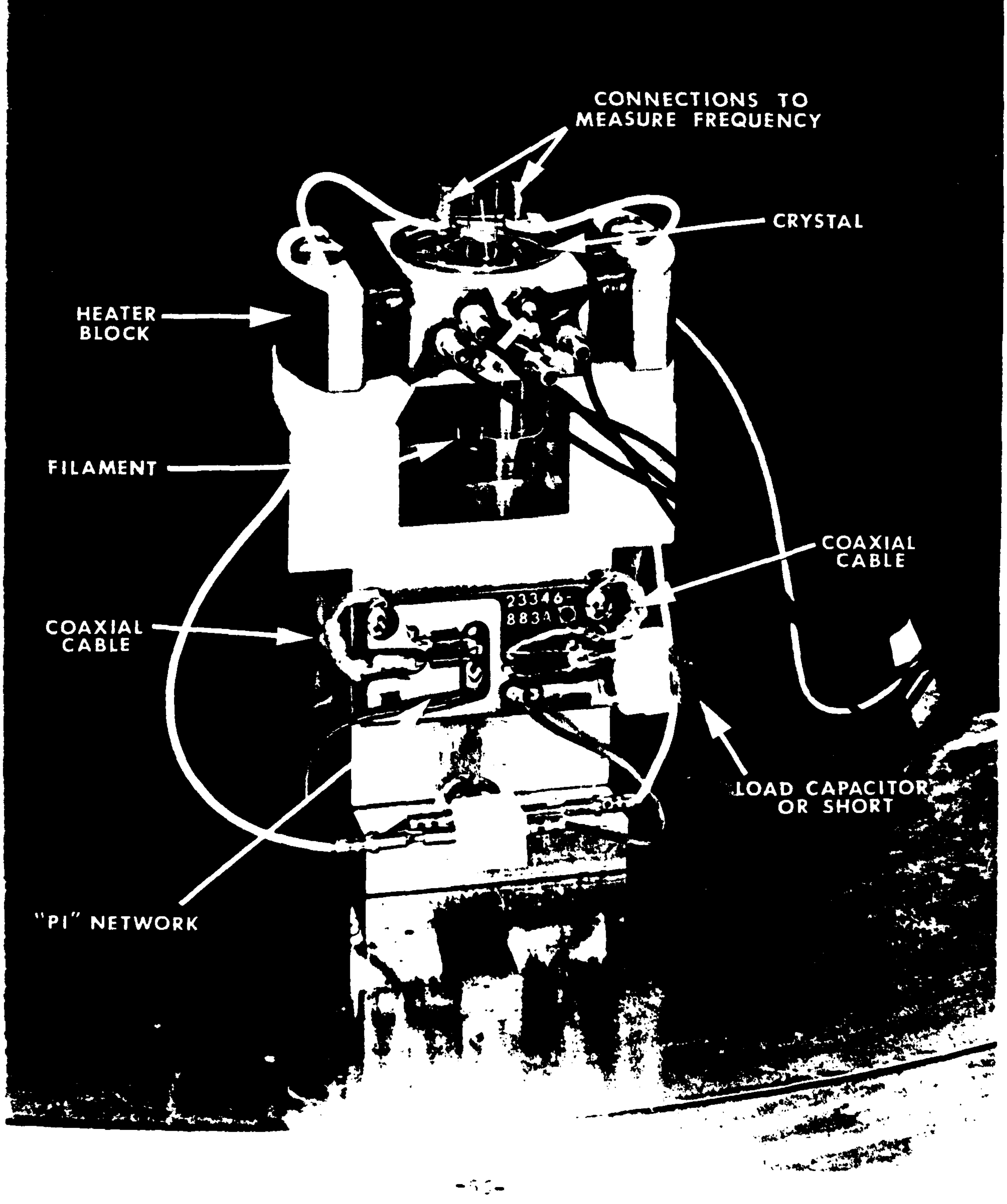


FIGURE K-1

HOT TUNER HEAD



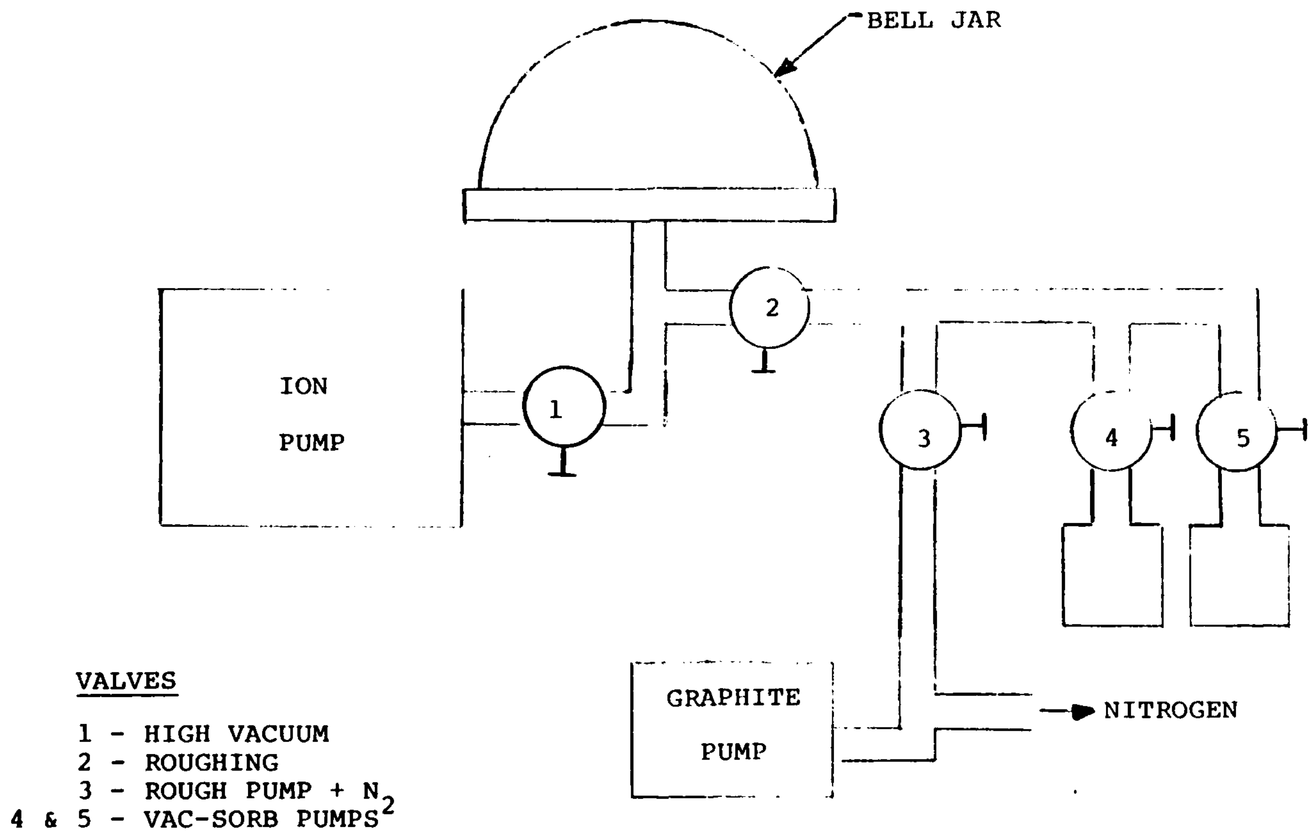


FIGURE K-2

HOT TUNER LAYOUT

APPENDIX I

"FURTHER DEVELOPMENTS ON SC CUT CRYSTALS"

B. Goldfrank
A. Warner

FURTHER DEVELOPMENTS ON 'SC' CUT CRYSTALS

Bruce Goldfrank and Art Warner

Frequency Electronics, Inc.
New Hyde Park, New York 11040

Introduction

'SC' cut crystals have found their way into many new designs. The applications, though many and varied, center around the requirements of good 'g' sensitivity, resistance to radiation, fast warmup and good temperature characteristics. The temperature and strain effects on the 'SC' cut crystal are such that a large improvement over AT cut crystals is possible. In particular, data will be given on the improvement in radiation resistance of the 'SC' over the 'AT'.

In order to produce a successful SC crystal unit, i.e., one that exploits this design to the fullest, significant changes in design philosophy, design parameters, measuring techniques, testing methods, and production tools must be made. Three of the more important changes involve angle control prior to final lapping, angle measurements, and frequency adjustment. Where low 'g' sensitivity is important, the crystal plates must be thermo-compression bonded using small, uniform, very precisely located mounting spots.

Orientation

That the orientation of the plate must be closely controlled can be understood when we consider the typical AT frequency versus temperature curve. The center of the curve which is the inflection point, is at room temperature, and as the specified operating temperature goes higher, angle control becomes easier. For the SC, the inflection point is near 100°C and as the operating temperature approaches that point the angle control becomes difficult. 70°C to 80°C zero temperature coefficient (ZTC) for the SC cut is like 40°C to 50°C for the AT cut. At 80°C, one minute of arc error can shift the ZTC by 20°C. The benefit is, of course, that once angle control is achieved the temperature curve is much flatter.

Figure 1 shows a quartz bar and the stages of orientation, following the IEEE standard nomenclature, Y X w l $t\phi\theta\psi$. Visualize a starting plate which is a Y cut, rotate it about the Z axis by the angle ϕ and then rotate it about its new length, X', by the angle theta. The usual illustrations show the plate rectangular in shape. The final doubly oriented plate is usually shown the same size and shape as the starting plate. However, one can see that if we arrange to saw the

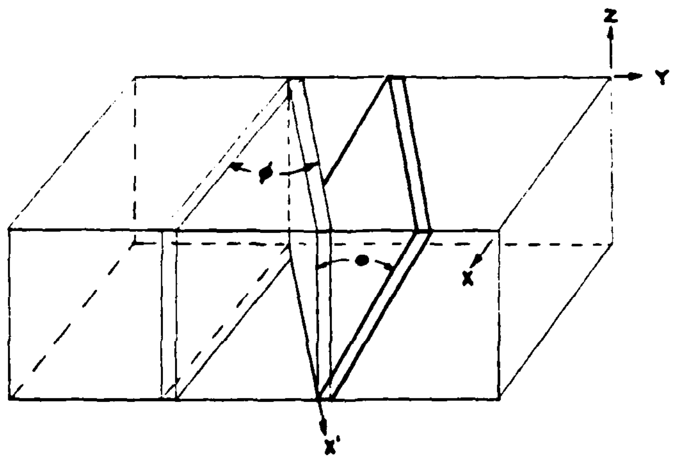


Figure 1. Stages of Orientation for a YXwlt$\phi\theta\psi$ Blank

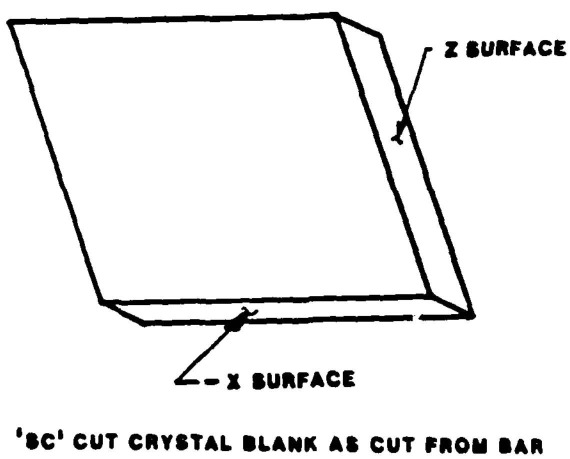


Figure 2. Quartz Blank As Cut From a Y Bar

Proc. 34th Ann. Freq. Control Symp., USAERADCOM, Ft. Monmouth, NJ 07703, May 1980.

doubly oriented plate from the bar, the shape will not be rectangular but will be as shown in Figure 2. If this were an AT, usual practice would be to simply mount it in the X-ray with the X axis vertical and compare the crystal face with the nearby 01.1 crystal plane at 38° 12.7'. However, with the SC we must first "undo" the ϕ angle, that is tilt the plate until the 01.1 plane is in a vertical position. The tilt itself is not particularly critical, but now the mounting flat, or if you will, the rotation of the plate about its thickness, becomes extremely critical, since this rotation will now tilt the reference plane.

Our answer to this problem is to highly correct the -X and one Z surface of the quartz bar itself before cutting. This is straight forward since, of course, there are X-ray planes parallel to these surfaces. These highly corrected surfaces are then used not only to orient the bar in the saw, but also to orient the blank in the X-ray goniometer.

Now, which edge surface should we use for the X-ray reference flat? The X' axis lies in the Z surface, some 14° away from using the -X surface as a reference flat and the X' would be the normal choice.

In either case, the equation to convert from the angle measured by the X-ray, to the specified θ angle is fairly simple, but it turns out there is an advantage to using the -X surface 14° away from the X' to locate the axis about which the X-ray angle is to be measured.

Figure 3 shows the relationship between the specified θ angle for various ϕ angles. The outer curve shows the equation developed by Ballato and Iafrate, and the other two curves show the corresponding angles θ' and θ'' measured by the tilt-back method for both X' axis and the -X surface. We can see that the angle measured using the -X surface, the upper curve, is much closer to the 38° 13' reference plane, even closer than that of the AT. Also we can see the slope is about 1 in 6 or 6' error in measuring ϕ results in 1' error in measuring θ. You may also have noticed that for the SC cut at $\phi = 23°$, that the 14° shift in reference flat location corresponds to a 5 or 6 degree shift in indicated angle, or almost 2 to 1. Two minutes error in reference flat equals one minute error in angle measurement. To keep this error to an absolute minimum, we use, as indicated earlier, the actual corrected surface generated on the quartz bar before it is cut. In addition we use a special jig that avoids any error due to chipping at the edges. Figure 4 shows the tilt back vacuum jig used with the X-ray. The reference surface makes contact along a line away from the crystal edge. Figure 5 shows this reference contact a little more clearly. Repeatability using this method is about 10 seconds of arc. The ϕ angle is measured by a 90° turn of the quartz blank. No tilt is needed in this case, because the X-ray plane in this position is within 1-1/2 degrees of vertical, again closer than the AT for this measurement.

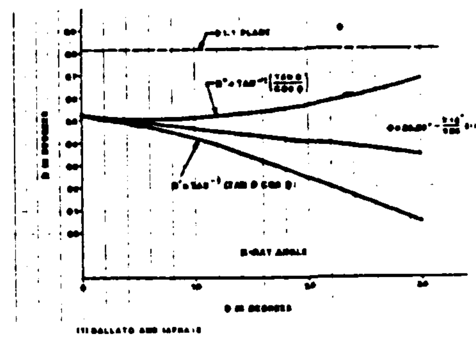


Figure 3. Relationship Between Specified θ and ϕ Angles and Those Measured By The Tilt-Back X-ray Method

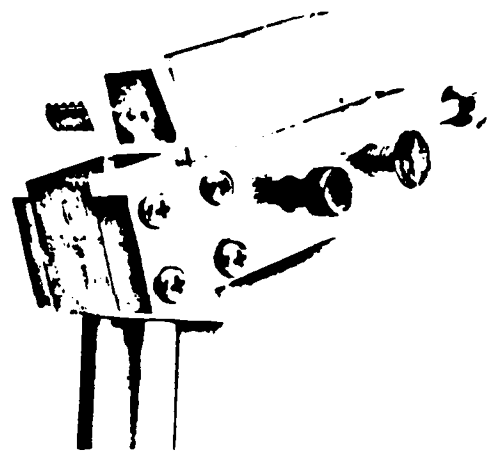


Figure 4. Tilt-Back Vacuum Jig Used With The Double-Crystal X-ray Goniometer

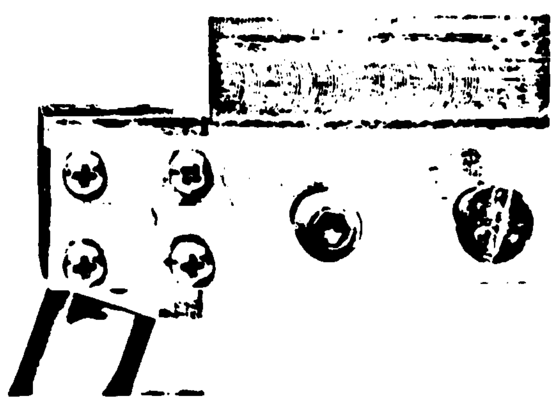


Figure 5. Tilt-Back Jig Showing -X Surface Contact

Figure 6 shows the precision saw. The setting is accomplished by a tilt and a rotation. Figure 7 is another view. One advantage of the tilt and rotation, rather than a double tilt is that the tilt and the rotation angles are exactly those measured by the X-ray. So necessary corrections to the saw table are directly applied from the X-ray reading. To obtain actual specified θ and ϕ angles, in practice, it is only necessary for the operator to enter the X-ray dial reading into a pre-programmed calculator and push the button.

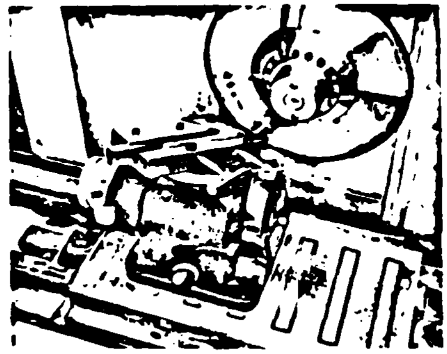


Figure 6. One View of the Precision Saw

Advantages of -X Surface Reference and Tilt Method of Orientation

1. An existing double crystal X-ray goniometer set for AT cut can be used with no change other than the tilt jig.
2. The angle is close enought to 01.1 plane for calibrating of standards by a turnover method.
3. Orientation of the sensitive reference flat is generated right on the quartz bar before cutting.
4. The ϕ angle is determined without a tilt jig and is simply measured by the X-ray.
5. By using a standard reference crystal, accuracies of a few seconds of arc are possible.
6. There is a direct correspondence between saw table angles and the angles measured by the X-ray.
7. Specified angles are obtained easily by using a simple programmed calculator.
8. The 14° psi angle generated automatically turns out to be the correct mounting point for the crystal plate.

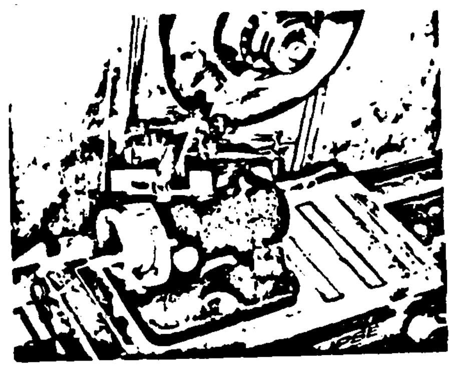


Figure 7. One View of the Precision Saw

Frequency Adjustment

The fact that the inflection point of the SC temperature frequency curve is above the operating temperature makes room temperature frequency adjustment a disaster. The slope is about 10 Hz per degree at 5 MHz. In addition frequency adjustment by circuit means is limited to about 1/4 of that of the AT. Therefore frequency adjustment at or near the temperature at which the crystal is to be operated is imperative. Figure 8 shows a small heater used in the vacuum deposition chamber. Temperature sensing control is by a thermistor bridge, the lead wires from the crystal are of special material and pass thru the temperature controlled block on their way to a network which sets the operating phase conditions. Deposition is by evaporation from a small tungsten filament.

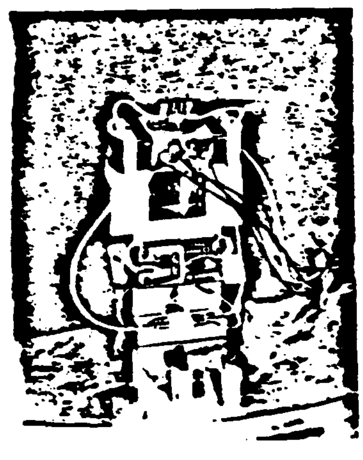


Figure 8. Crystal Unit Heater For Gold Evaporation in Vacuum

Crystal Mounting

Figure 9 shows an experimental approach to thermo-compression (TC) ribbon mounting of the crystal plate. The ribbon is nickel, and it has a gold triangular strip bonded thereon. The TC bond will be gold to gold, and in the shape of a long thin rectangle, about 5 x 50 mils. This method permits a better location of the mounting points with respect to the center of the plate, and also permits TC bonding to very thin plates.

Figure 10 is a photo of one such bond on a 5 MHz 5th overtone plate. Figure 11 is a drawing of a typical thermocompression bond. Recent discussions with and calaculations by Prof. Peter Lee, of Princeton University, have indicated the extreme importance of the mounting points in obtaining a low 'g' sensitivity crystal unit. He indicates a ψ angle near -15° as optimum for a 3 point 90° mount. It is interesting to note that the natural angle generated in cutting the blank, (-14.8°) which Frequency Electronics uses, the experimental angle reported by Kusters, Adams, and others of Hewlett Packard in 1977, and Peter Lee's calculated angle are all essentially the same. I believe the naturally generated angle is the correct one, but further experimentation will be necessary with precisely mounted units, to verify this.

Radiation Effects

An unexpected bonus came to light when some 24 MHz SC units in oscillators intended for use in the Galileo Probe of Jupiter were subjected to radiation of 1.0 megarads. The SC units changed 1 part in 10^{14}/rad versus 2 parts in 10^{12} per rad for AT units. This is about 2 orders of magnitude improvement in radiation susceptibility. This again needs further study.

Conclusion

Figure 12 shows a graph of one 5 MHz doubly contoured SC unit made at Frequency Electronics, Inc. subjected to a 2G acceleration by a simple turn-over test. Plate up to plate down was $1PP10^{11}$. Rotation in the vertical plane shows less than $1PP10^{10}$ per G. Future studies will be aimed at increasing the yield of such units.

Acknowledgment

This work was supported in part by a grant from USAERDCOM, #DAAK20-79-C-0272.

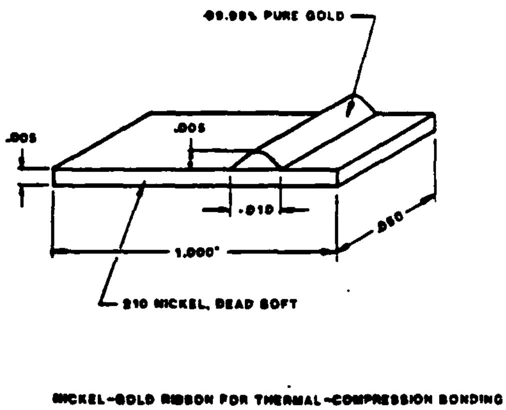


Figure 9. Experimental Gold Bonded Nickel Mounting Ribbon

Figure 10. Experimental Thermo-Compression Bond To A 5 MHz SC Plate

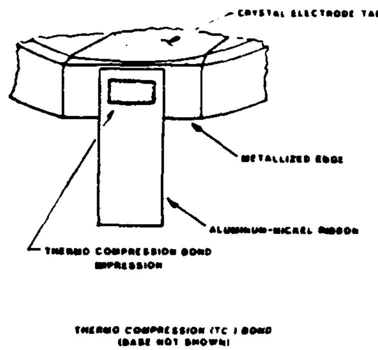


Figure 11. Typical Thermo-Compression Bond

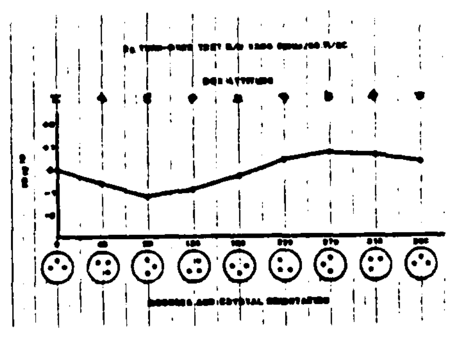


Figure 12. Turn-Over Test of One 5 MHz, 5th Overtone SC Unit Showing a 'g' Sensitivity of Less Than $1PP10^{10}$

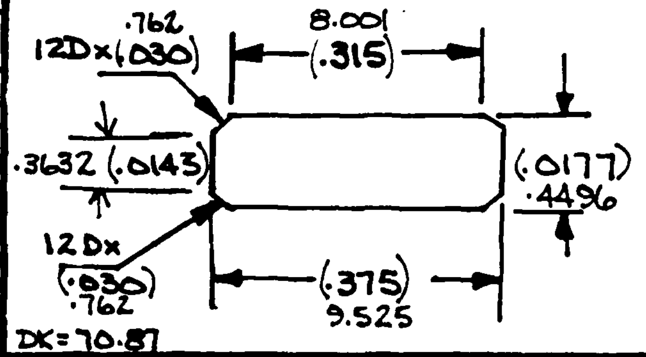
APPENDIX II

CRYSTAL DESIGNS

QUARTZ	FREQUENCY	O.T.	CUT	JOB NO.	FSO NO.
PQSQ	20.000000	5	SC	7554	

NO.	OPERATION		THICKNESS or FREQUENCY
1	P/L (FUND)	#5	3.716MHz ±10KHz
2	P/L (FUND)	#3	3.990MHz ±5KHz
3	ETCH		4.000MHz ±2KHz
4	-		
5	POLISH (5TH)	C/O	20.075MHz ±2KHz
6	BEVEL	#9	.030 x 12 DIOP
7	BEVEL	#9	.030 x 12 DIOP
8			
9	ETCH		20.080MHz ±2KHz
10			
11			
12			

DESIGN	BLANK DIM.	.375 x .030	'Z' ANG.	φ = 23.75° θ = 34.05°



DESIGNED PLATE BACK:	1.0F²
ELECTRODE DIAM:	.265
HEADER	: TO-8
MOUNT	: LOW PROF. DIAM. or "J" MOUNT
BOND METHOD	: EPOXY

MARKING DETAIL

TOP

SERNO'S

XXXX — - SERNO

SEAL CODE
YY = YEAR DIGITS
ZZ = WEEK DIGITS

SIDE

20.000000MHz/5/SC	
YYZZ	7554

QUANTITY REQUIRED :

SPECIAL INSTRUCTIONS

DIMPLED CAN

SPECIFICATIONS	SPEC:
FREQ. CAL. AT	: T.O. w/ 20pF
FREQ. TOL.	: ± 20 Hz
TURNOVER TEMP.	: 65°C to 85°C
OPERATING TEMP.	: N/A
C_0	: 4.7 pF ± 0.5pF
C_1	: 1.4×10^{-16} F ± 0.14×10^{-16} F
'Q'	: 450,000 MIN.
RESISTANCE	: 100 Ω MAX
Δf AT 20 pF	: 74 Hz ± 10 Hz
SPURIOUS MODES	: -3dB ±250KHz
DATA REQUIREMENTS	: TEST PLAN 4
CONDITIONING	: 1 HRS 190 °C
SEAL RANGE	: 5×10^{-8}
H_2 FIRING	: 3½ HRS 270 °C

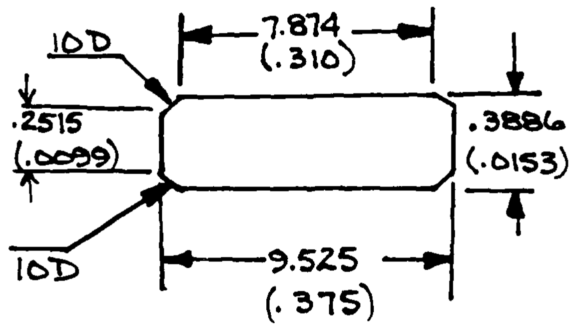
B Goldfrank	7/10/80		
DESIGNED	DATE	APPROVED	DATE

22477-883-06A

			RELEASED: 2-16-79		INIT: BH
QUARTZ	FREQUENCY	O.T.	CUT	JOB NO.	ESC NO.
PQSQ	23.116690	5	SC	7554	

NO.	OPERATION	THICKNESS or FREQUENCY
1	P/L #5	4278 ± 10 KHz
2	P/L #3	4599 → 4608
3	ETCH	4611 KHz ± 1 KHz
4	POLISH C/O	23.219 MHz ± 2 KHz
5	BEVEL	10D to .310
6	RE-BLOCK	
7	BEVEL	10D to .310
8	ETCH	23.225 MHz ± 2 KHz
9		
10		
11		
12		

DESIGN	BLANK DIM.	.375 x .030	'Z' ANG.	φ = 23.75°, θ = 34.05°



DESIGNED PLATE BACK: 1.0F[2]

ELECTRODE DIAM: .265

HEADER : TO-8

MOUNT : Lo. Prof. Diamond

BOND METHOD : EPOXY

MARKING DETAIL

TOP

XXXX — SERNO

SEALCODE
YY = YEAR DIGITS
ZZ = WEEK DIGITS

SERNO'S

SIDE

24.325570 MHZ
7554 YYZZ

QUANTITY REQUIRED :

SPECIAL INSTRUCTIONS

SPECIFICATIONS	SPEC:
FREQ. CAL. AT	: T.O w/ 20pF
FREQ. TOL.	: ± 20 Hz
TURNOVER TEMP.	: 70°C ± 10°C
OPERATING TEMP.	:
C_0	: 3.6pF ± 0.4pF
C_1	: 1.0×10^{-15} F ± 10%
'Q'	: 350K MIN.
RESISTANCE	: 100 Ω MAX.
Δf AT 20 pF	: 74 Hz ± 10 Hz
SPURIOUS MODES	: -3 dB ± 250 KHz
DATA REQUIREMENTS:	TEST PLAN 4
CONDITIONING	: 1 HRS 180 °C
SEAL RANGE	: 5×10^{-8}
H_2 FIRING	: 4 HRS 270 °C

B. Goldfrank	3/24/80		
DESIGNED	DATE	APPROVED	DATE

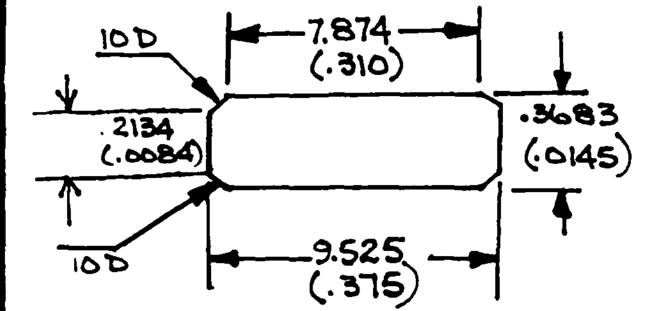
22477-883-06A

RELEASED: 2-16-79	INIT: (BH)

QUARTZ	FREQUENCY	O.T.	CUT	JOB NO.	ESN NO.
PQSQ	24.325570	5	8C	7554	

NO.	OPERATION	THICKNESS or FREQUENCY
1	P/L #5	4525 ±10KHz
2	P/L #3	4837 → 4847
3	ETCH	4851 ± 2 KHz
4	POLISH c/o	24.436MHz ±2KHz
5	BEVEL	10D to .310
6	RE-BLOCK	
7	BEVEL	10D to .310
8	ETCH	24.443 MHz ±2KHz
9		
10		
11		
12		

DESIGN	BLANK DIM.	(.375x.030) 9.53x.762	'Z' ANG.	φ=23.75° θ=34.05



DESIGNED PLATE BACK: 1.0 F²

ELECTRODE DIAM: .265

HEADER : TO-8

MOUNT : Lo PROF. DIAM.

BOND METHOD : EPOXY

MARKING DETAIL

TOP

SERNO'S

XXXX — SERNO

SEAL CODE
YY = YEAR DIGITS
ZZ = WEEK DIGITS

SIDE

24.325570 MHZ
7554 YYZZ

QUANTITY REQUIRED :

SPECIAL INSTRUCTIONS

SPECIFICATIONS	SPEC: Y 1032
FREQ. CAL. AT	: T.O. w/ 20pF
FREQ. TOL.	: ±20 Hz
TURNOVER TEMP.	: 70°C ± 10°C
OPERATING TEMP.	:
C_0	: 3.6pF ± 0.4pF
C_1	: 1.0×10^{-15}F ± 10%
'Q'	: 350 K MIN
RESISTANCE,	: 100 Ω MAX.
Δf AT 20 pF	: 74 Hz ± 10Hz
SPURIOUS MODES	: −3dB ±250KHz
DATA REQUIREMENTS:	TEST PLAN 4
CONDITIONING	: 1 HRS 180 °C
SEAL RANGE	: 5 x 10^{-8}
H_2 FIRING	: 4 HRS 270 °C

J. Goldfrank	3/24/80		
DESIGNED	DATE	APPROVED	DATE

APPENDIX III

'g' SENSITIVITY DATA

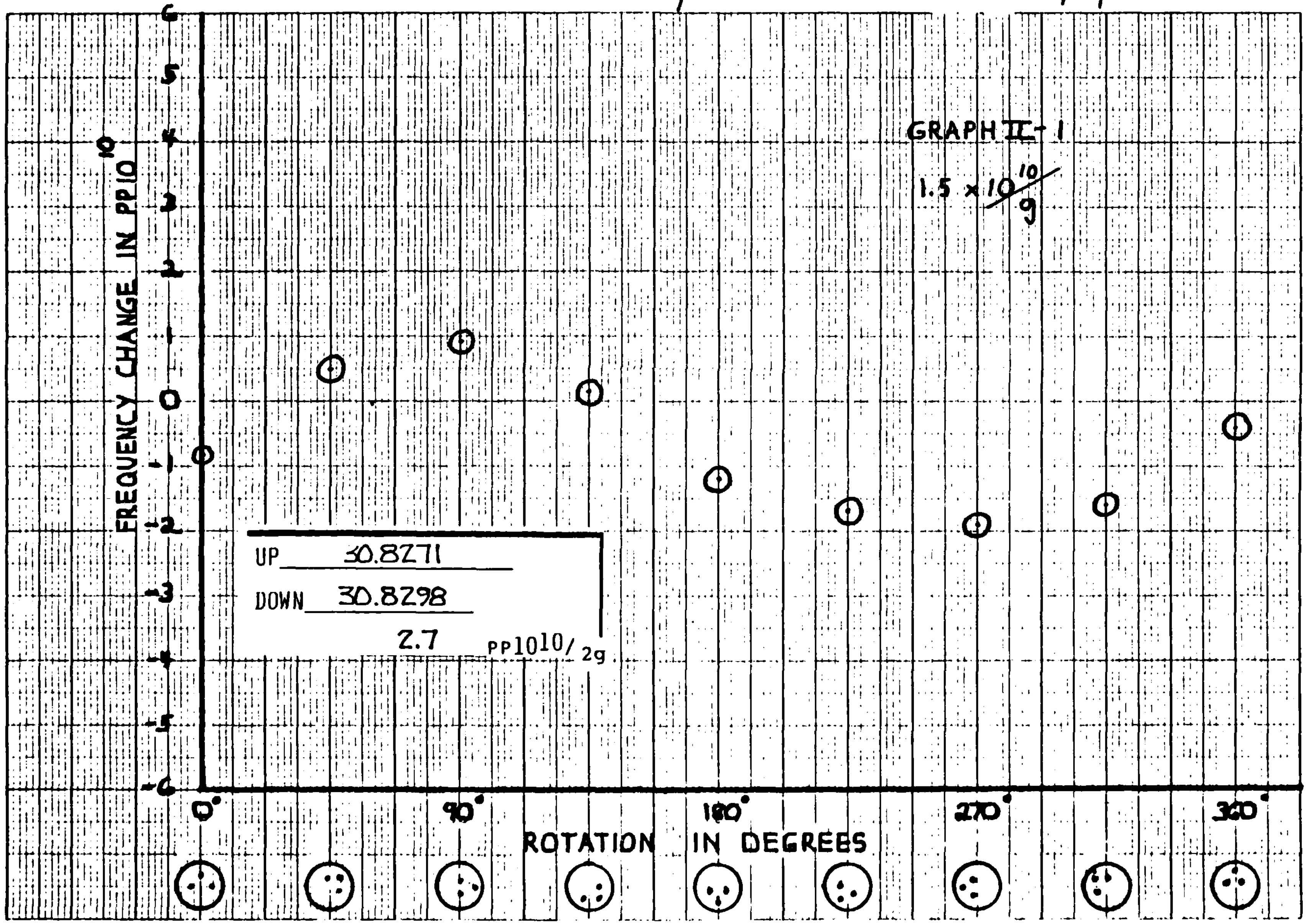
TABLE III-1

SUMMARY OF 'g' SENSITIVITY TESTING IN PP10^{10}/g

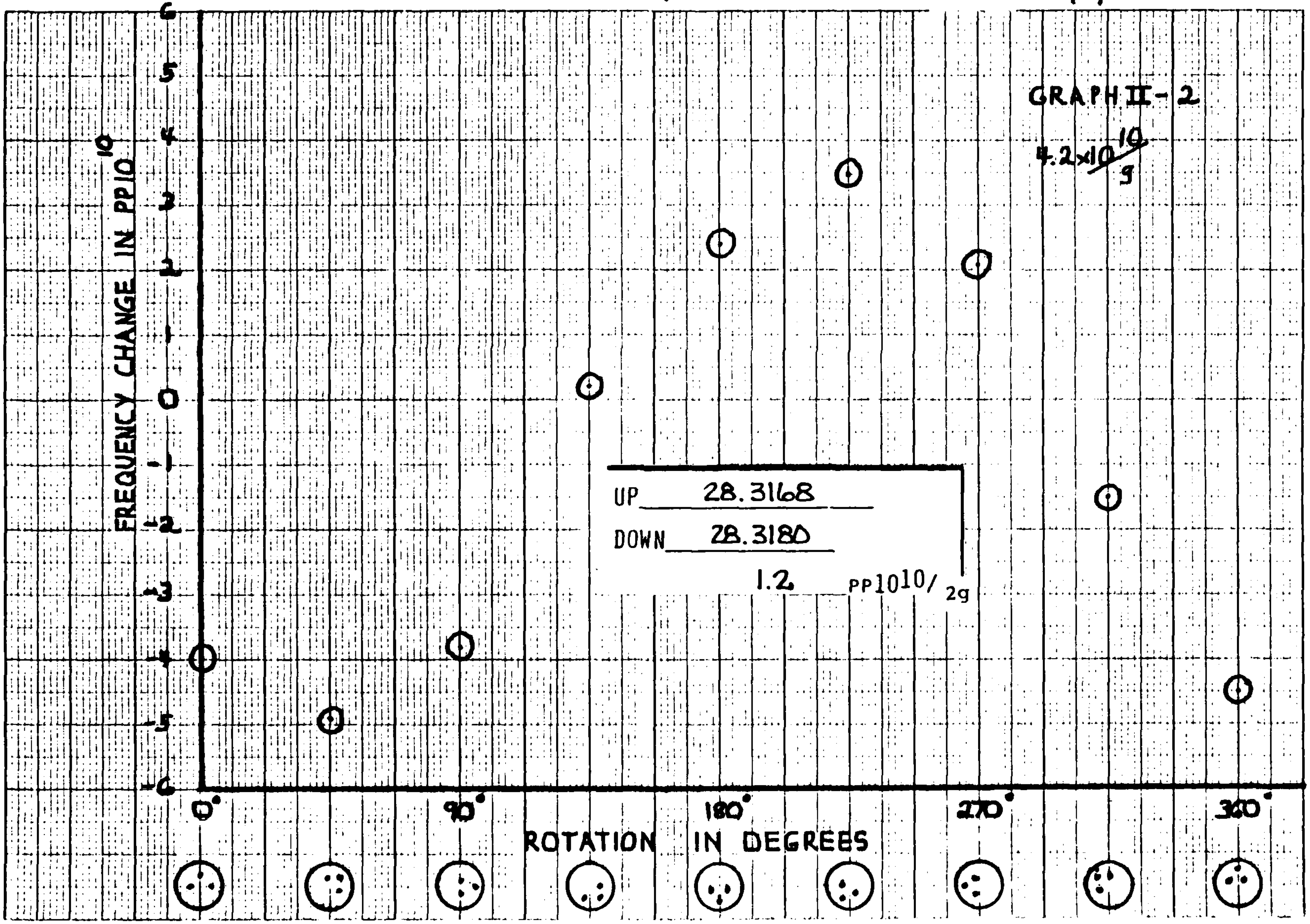
SERNO	RADIAL WORST CASE	THICKNESS (UP/DOWN)	SERNO	RADIAL WORST CASE	THICKNESS (UP/DOWN)
1370	1.5	1.4	3725	3.1	1.2
1371	4.2	0.6	3726	7.8	0.5
1373	6.5	1.0	3728	7.1	1.5
1374	8.5	0.5	3729	3.5	2.2
1375	7.5	1.8	3653	11.7	1.9
1376	1.4	1.7	3655	5.7	0.3
1377	3.5	N/A	3734	2.2	1.3
1378	2.5	N/A	3735	6.9	0.1
1379	3.5	1.0	3736	1.9	0.3
1380	1.0	0.05	3903	2.4	0.6
1382	7.5	0.8	3910	2.0	0.5
1383	5.6	1.4	3920	1.2	1.3
1384	3.0	1.1	3921	2.9	2.3
1385	4.5	0.15	3922	1.2	2.3
1386	1.3	1.6	3923	1.9	0.7
3721	3.3	0.9	4204	4.5	1.4

K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

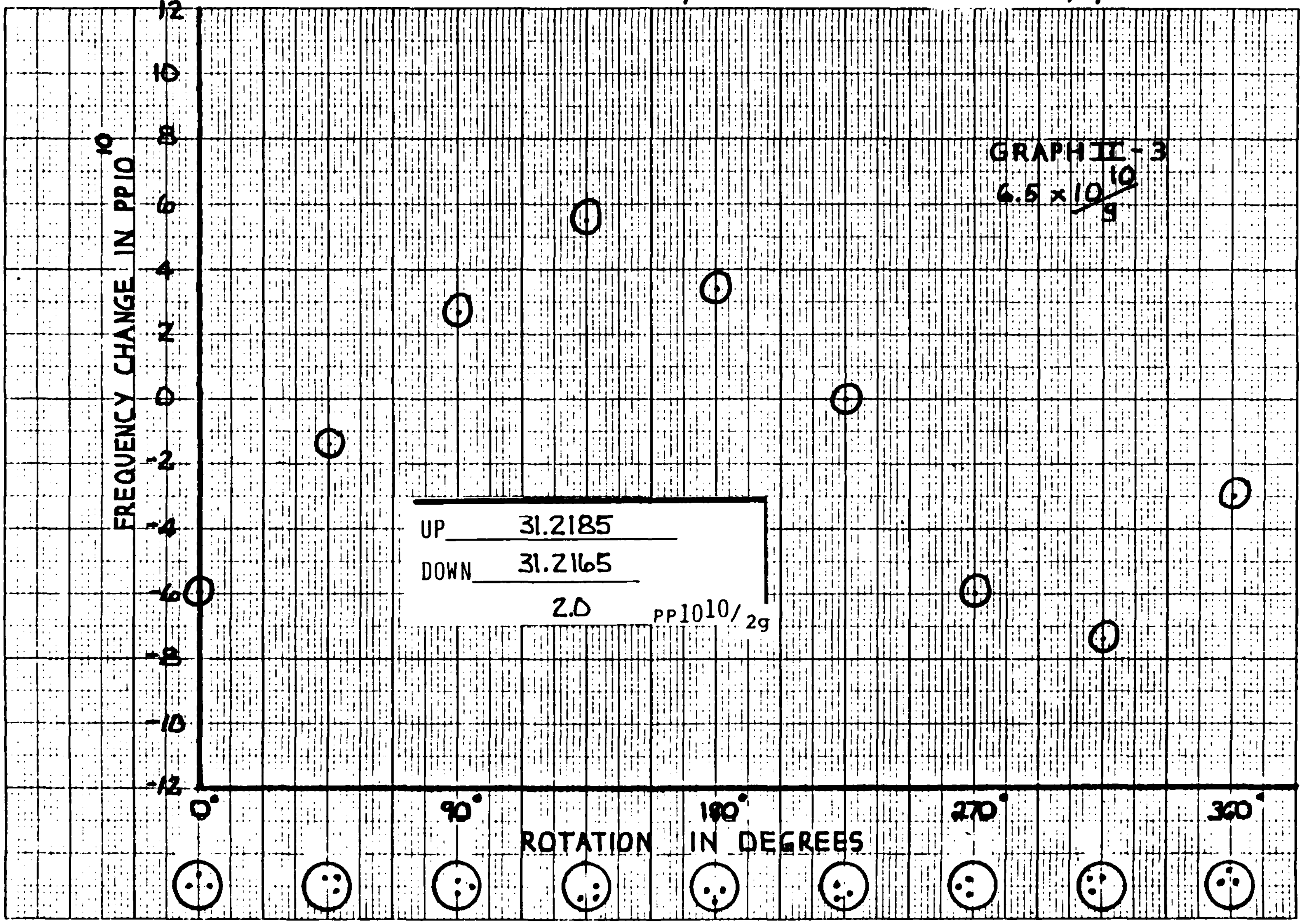
SER NO. 1370 5.0M/5 DATE 9/8/80

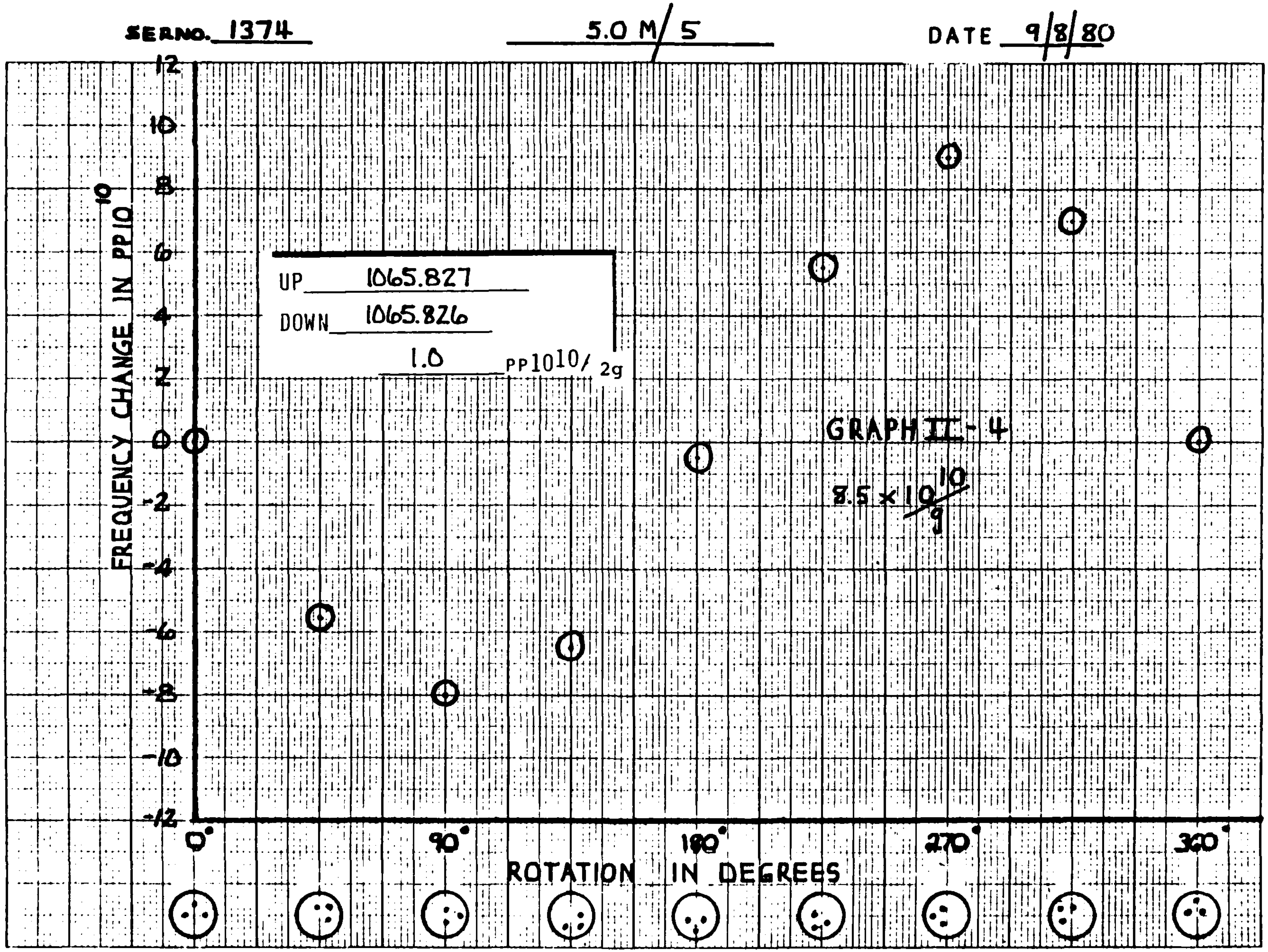


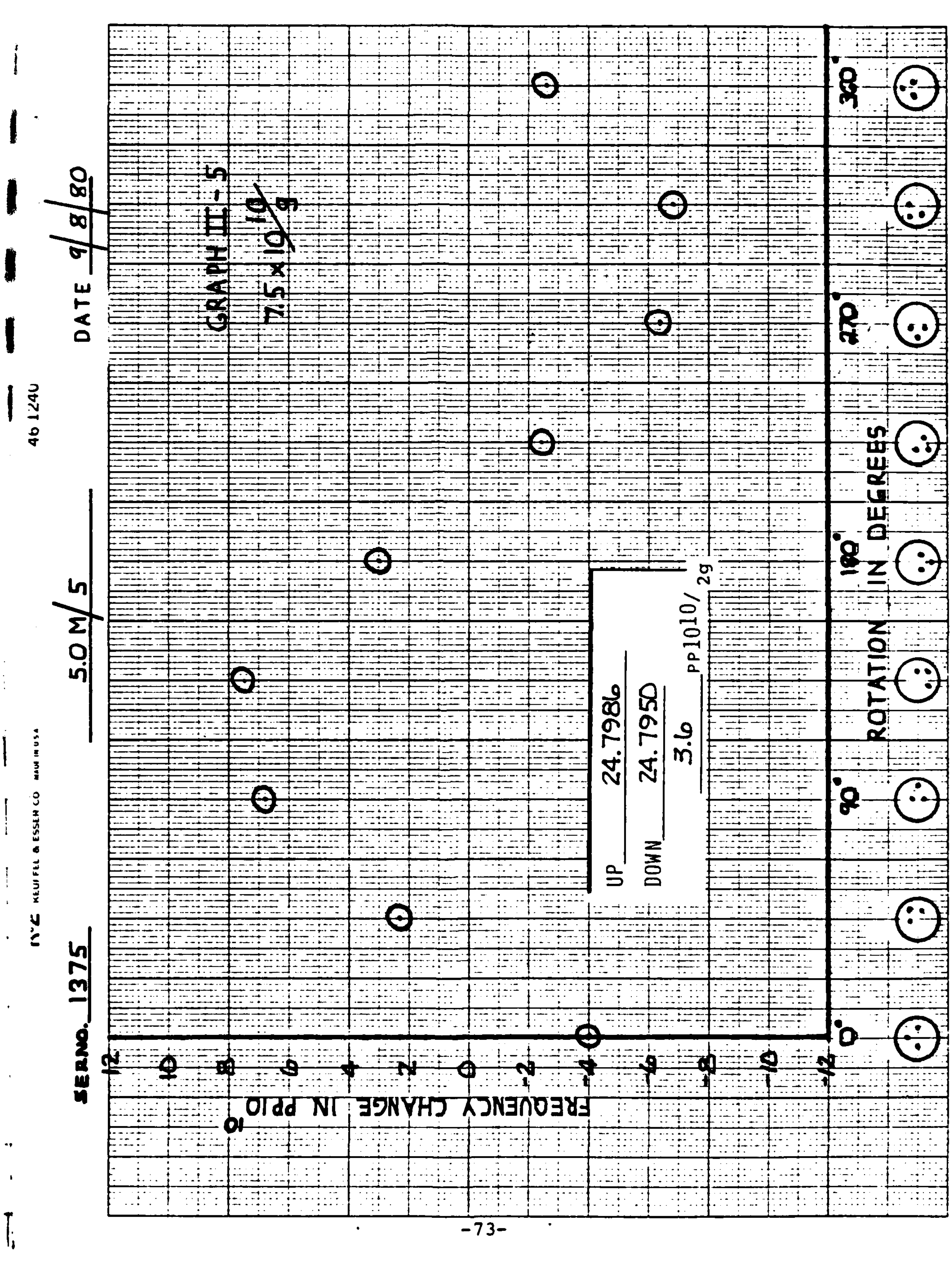
SER NO. 1371 5.0 M/5 DATE 9/8/80

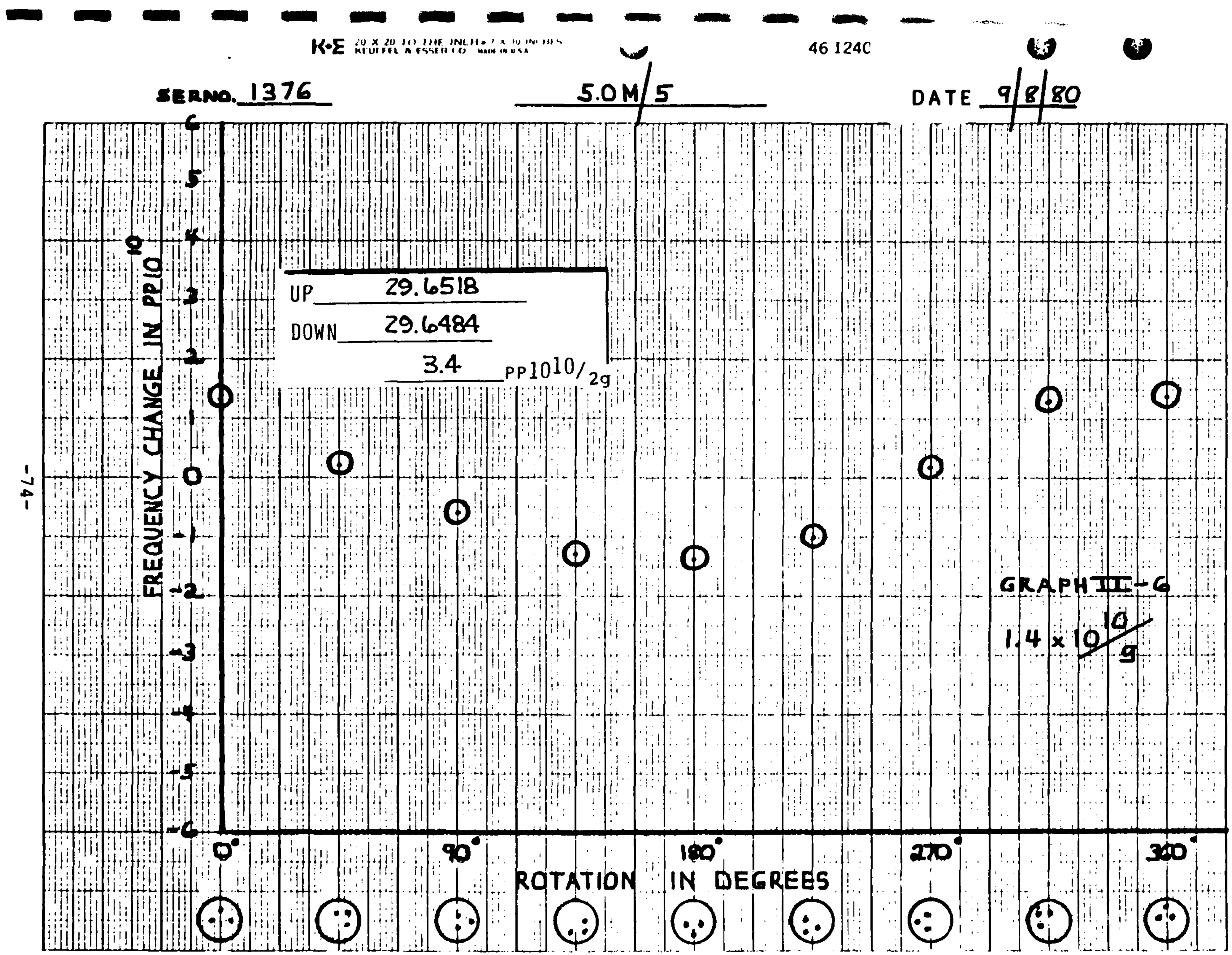


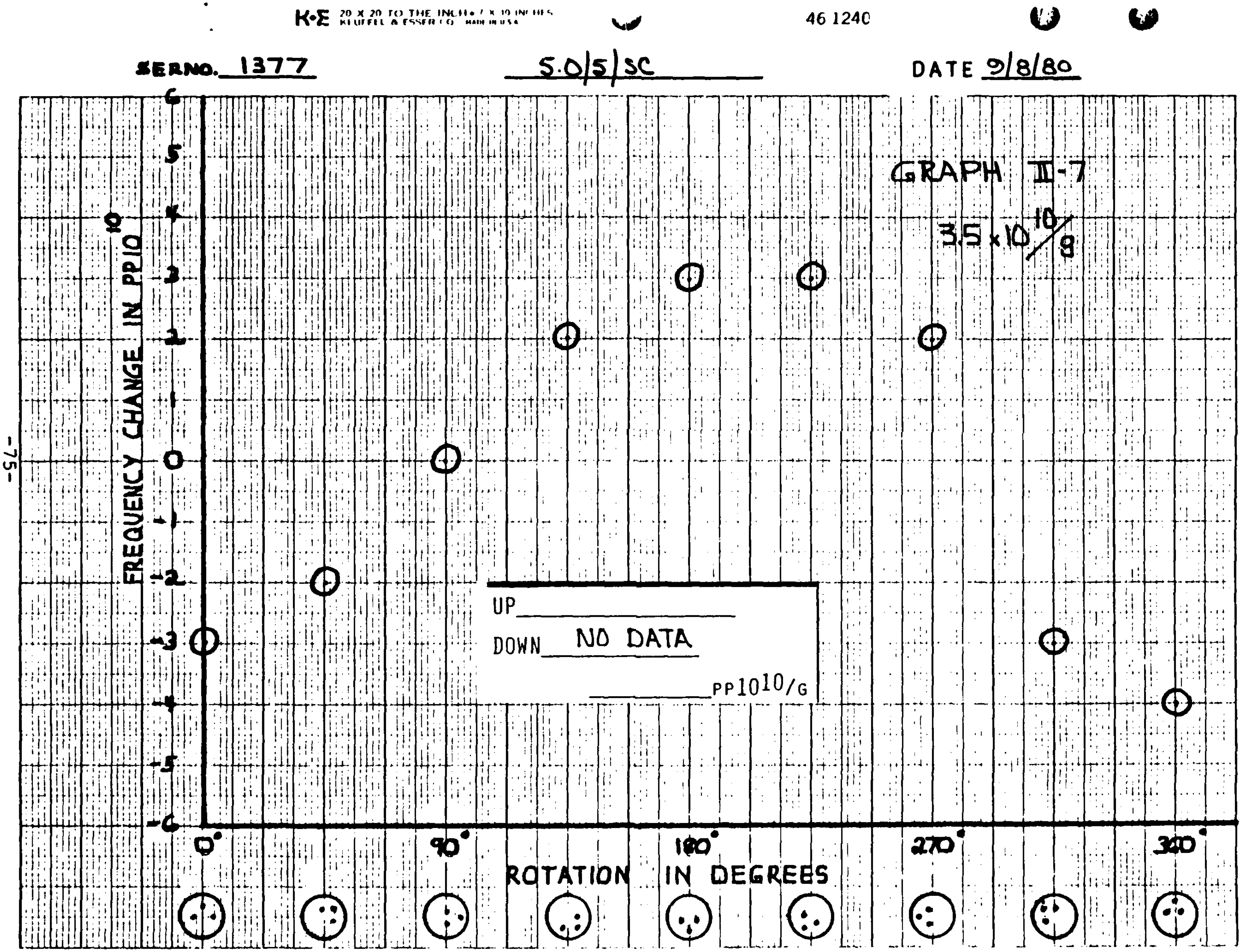
SER NO. 1373 5.0M/5 DATE 9/8/80

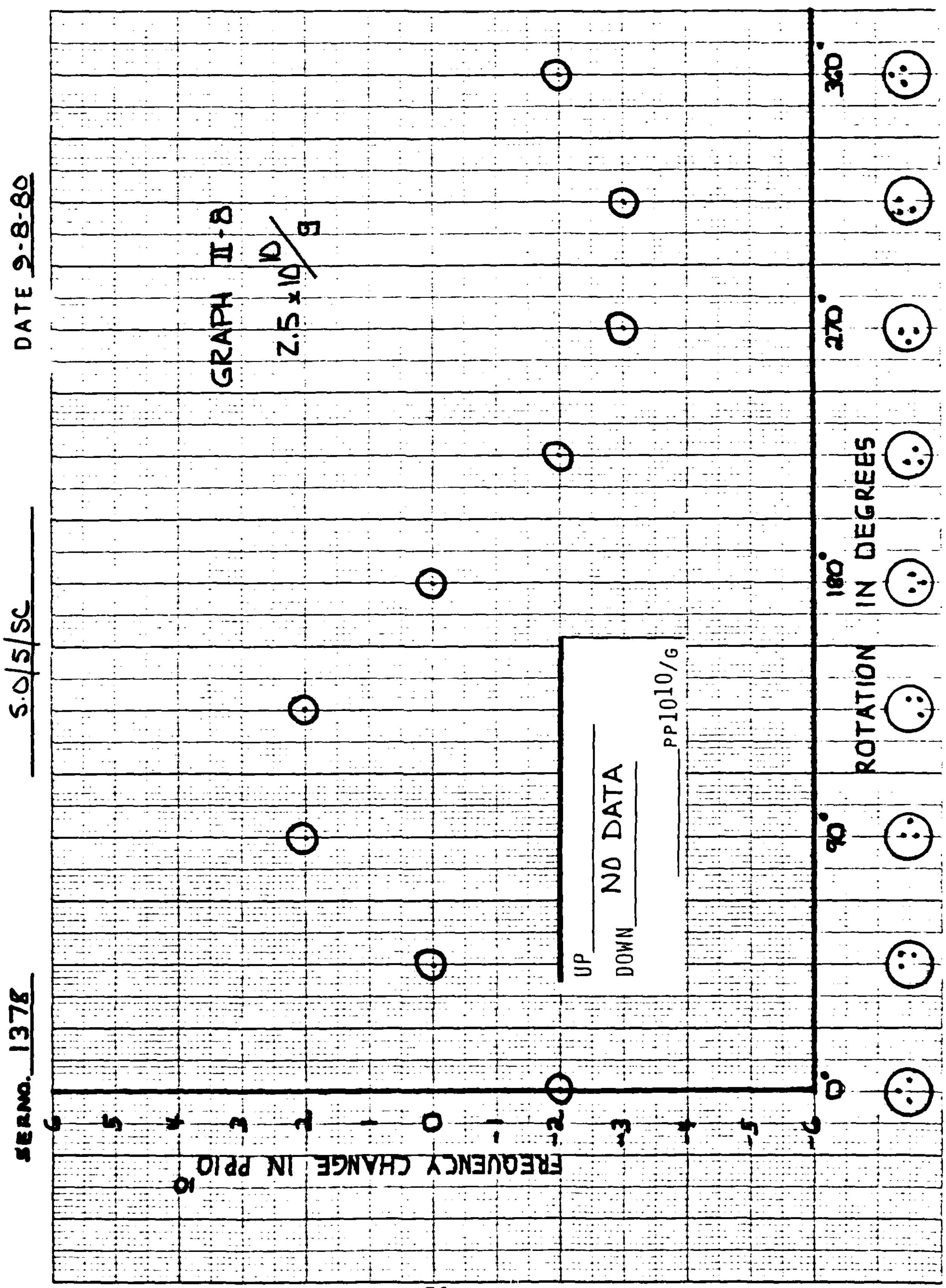



SER NO. 1374
5.0 M/5
DATE 9/8/80
UP 1065.827
DOWN 1065.826
1.0 PP1010/2g
GRAPH II-4
8.5 x 10^10/g
FREQUENCY CHANGE IN PP10^10
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0°
90°
180°
270°
360°
ROTATION IN DEGREES


SER NO. 1375
5.0 M/5
DATE 9/8/80
46 1240
K&E KEUFFEL & ESSER CO. MADE IN U.S.A.
GRAPH II-5
7.5 x 10-10/g
UP 24.7986
DOWN 24.7950
3.6 PP1010/2g
FREQUENCY CHANGE IN PP1010
ROTATION IN DEGREES
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
0°
90°
180°
270°
360°

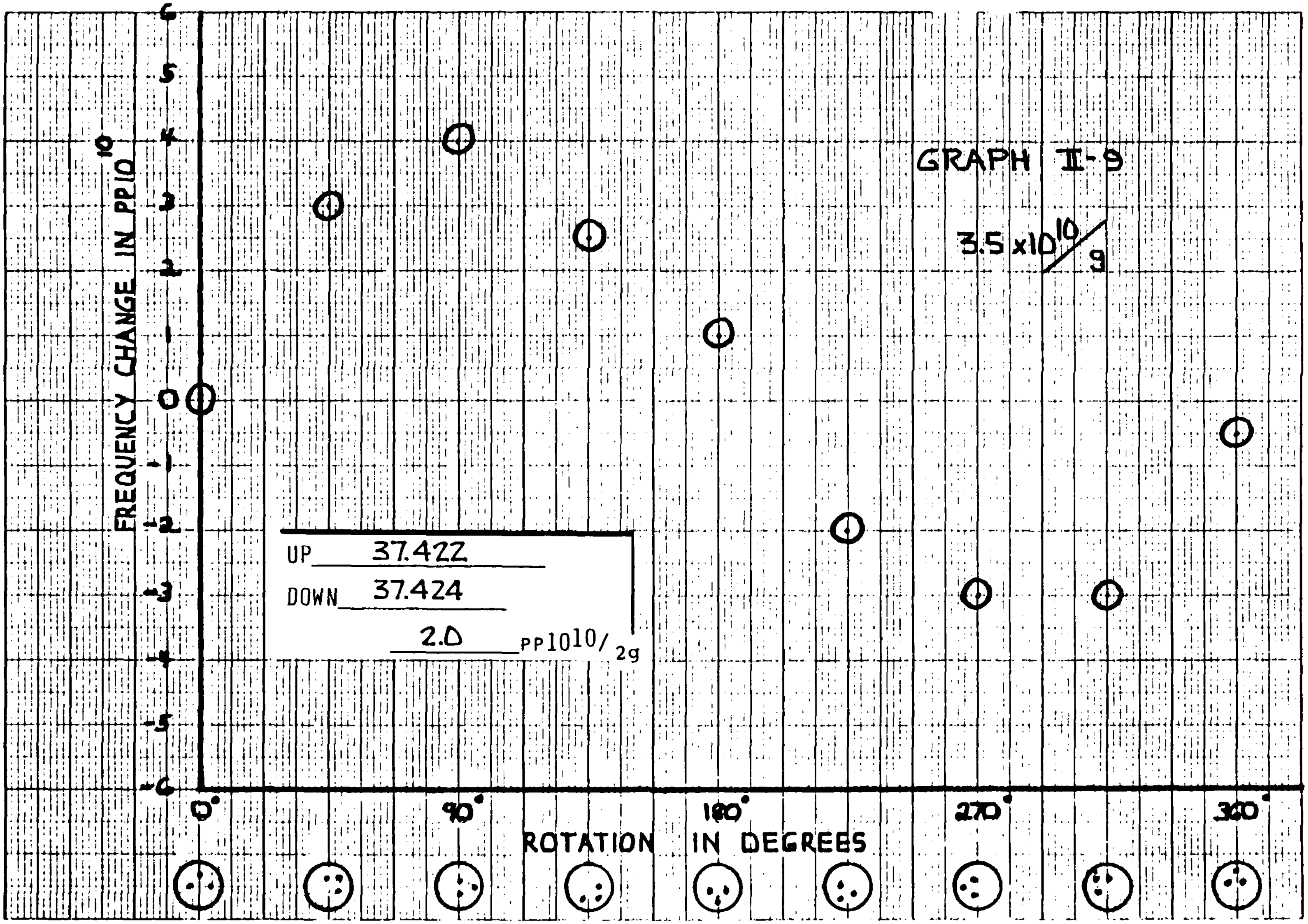

K·E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SER NO. 1376
5.0M/5
DATE 9/8/80
UP 29.6518
DOWN 29.6484
3.4 PP10^10/2g
GRAPH III-6
1.4 x 10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES

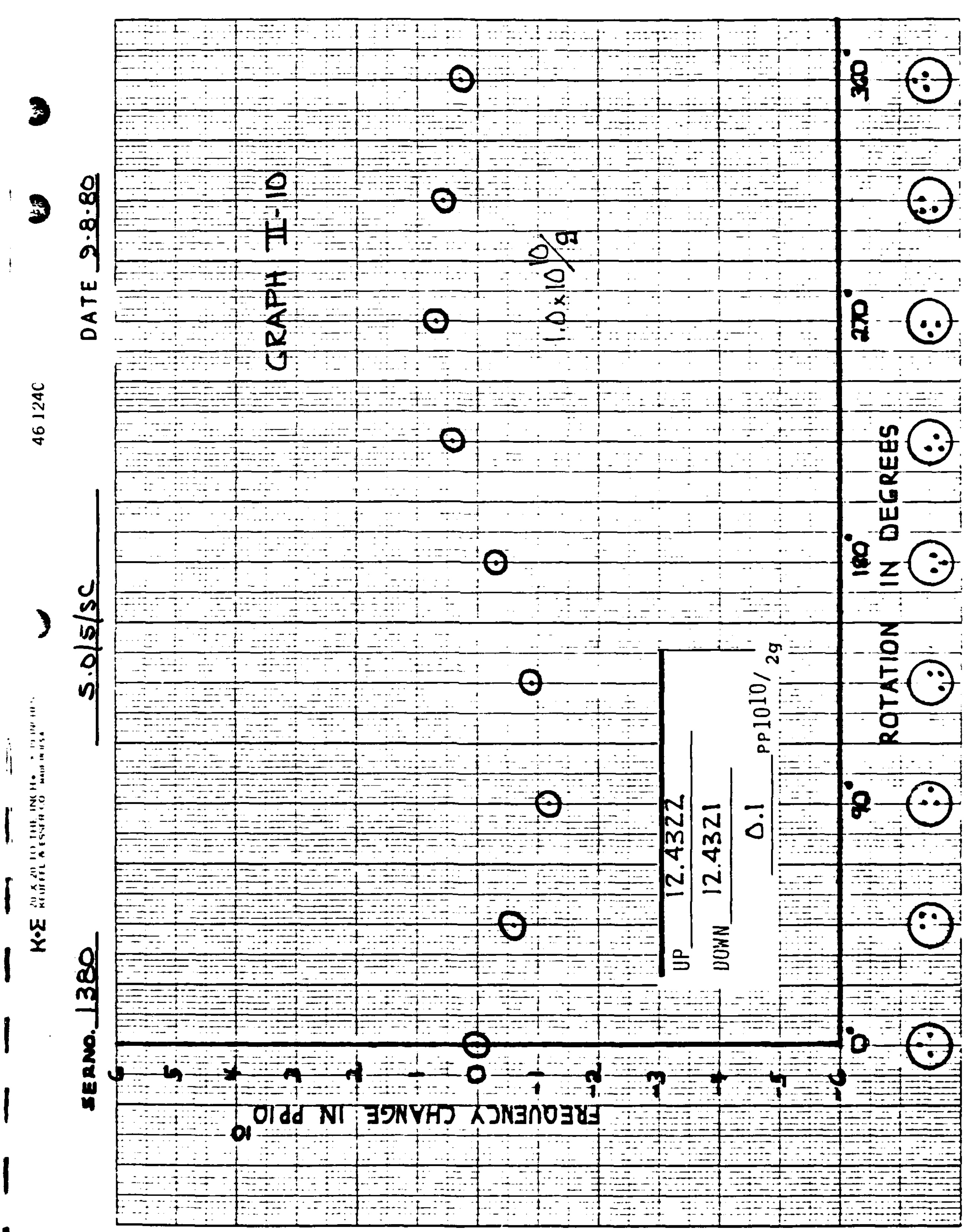

K·E 20 X 20 TO THE INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SER NO. 1377
5.0/5/SC
DATE 9/8/80
GRAPH II-7
3.5 x 10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
UP
DOWN NO DATA
PP10^10/G
0°
90°
180°
270°
360°
ROTATION IN DEGREES


SER NO. 1378
5.0/5/5C
DATE 9-8-80
GRAPH II-8
2.5 x 10 10/g
FREQUENCY CHANGE IN PP10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
UP
DOWN NO DATA
PP1010/G
0°
90°
180°
270°
360°
ROTATION IN DEGREES

K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN USA 46 1240

SER NO. 1379 S.D/5/SC DATE 9-8-80

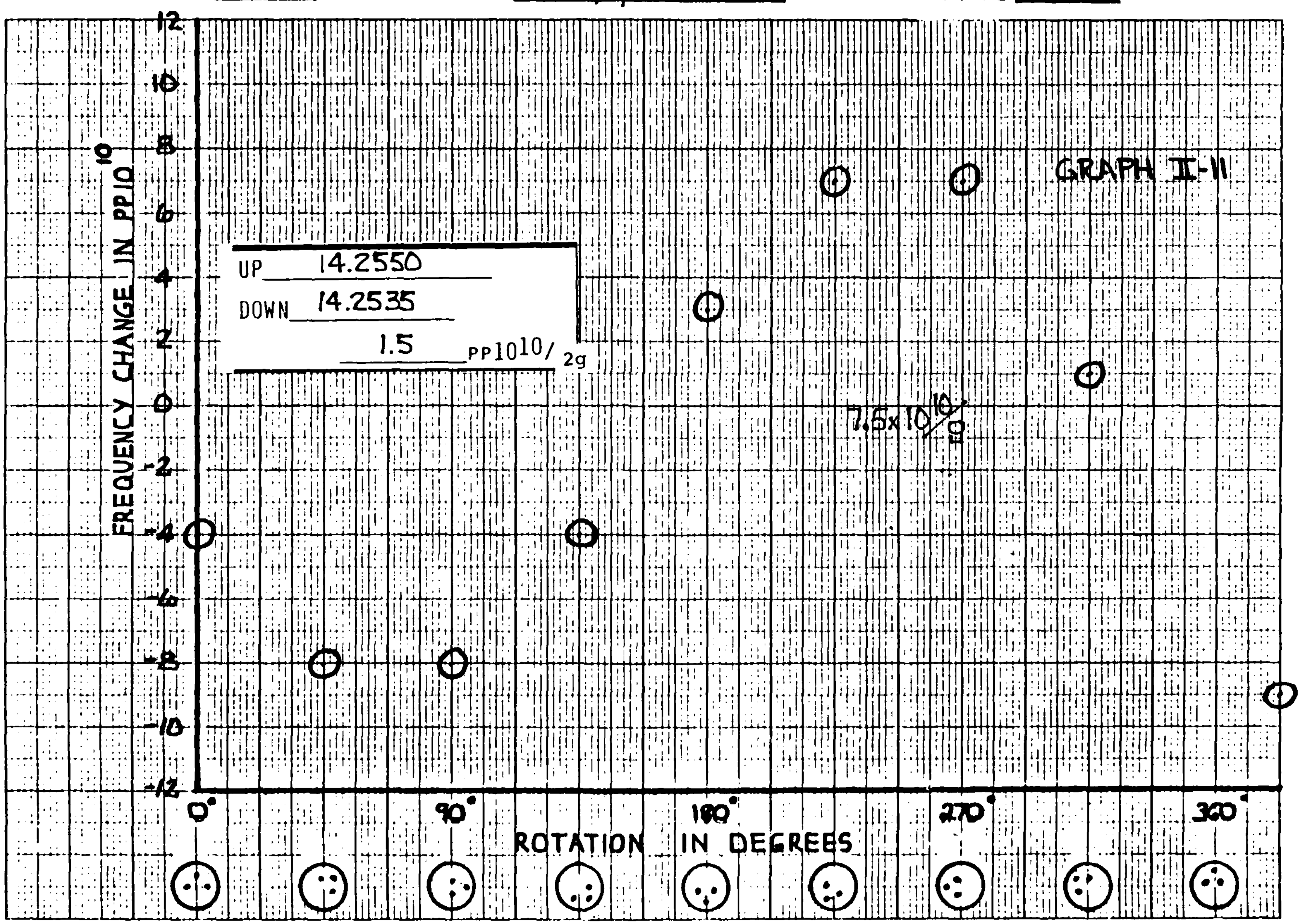


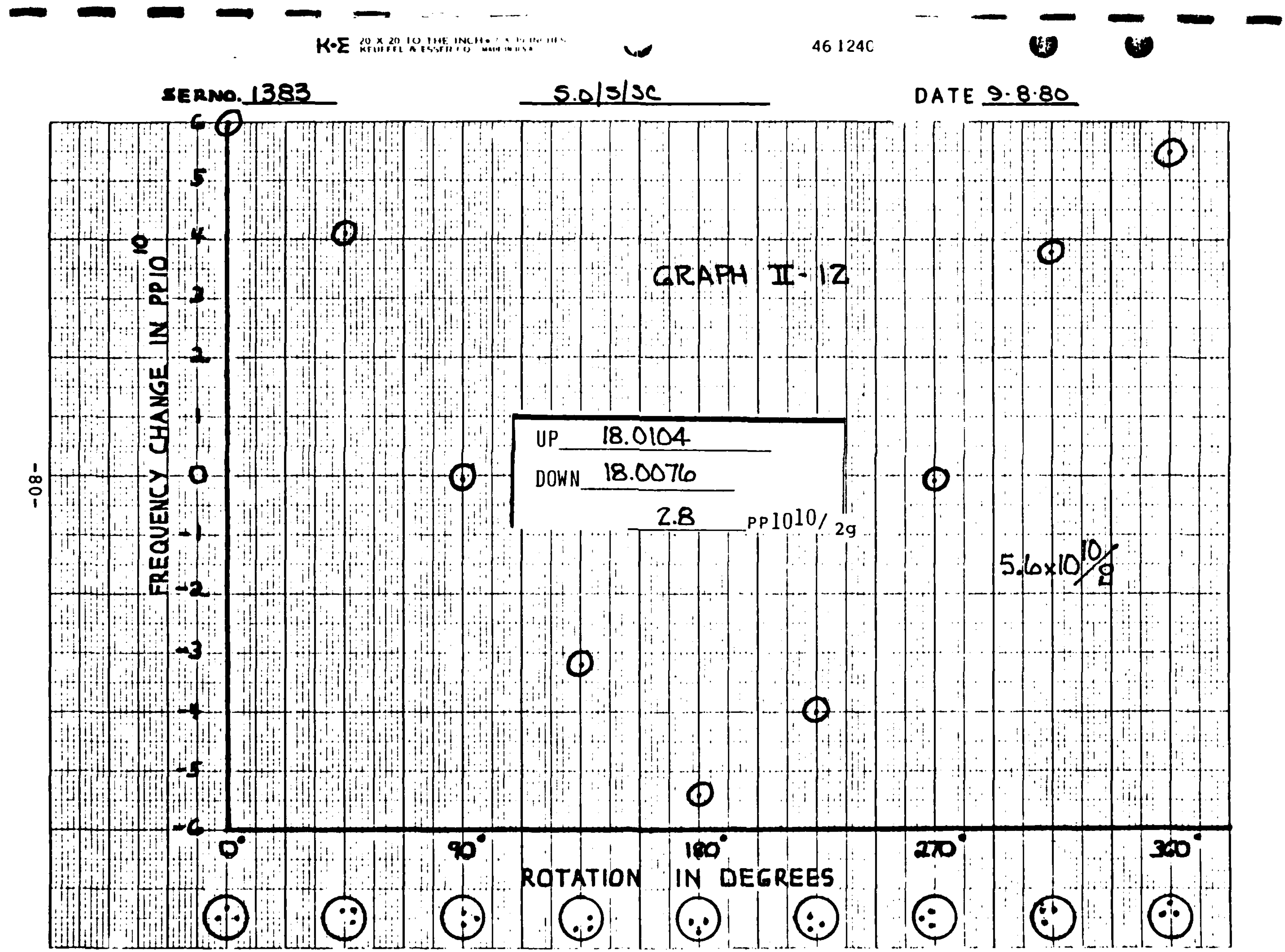


SER NO. 1380
K·E
S.O/S/SC
46 1240
DATE 9·8·80
GRAPH II-1D
1.0x10^10/g
UP 12.4322
DOWN 12.4321
Δ.1 PP10^10/2g
FREQUENCY CHANGE IN PP10^10
6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6
0° 90° 180° 270° 360°
ROTATION IN DEGREES

K+E KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

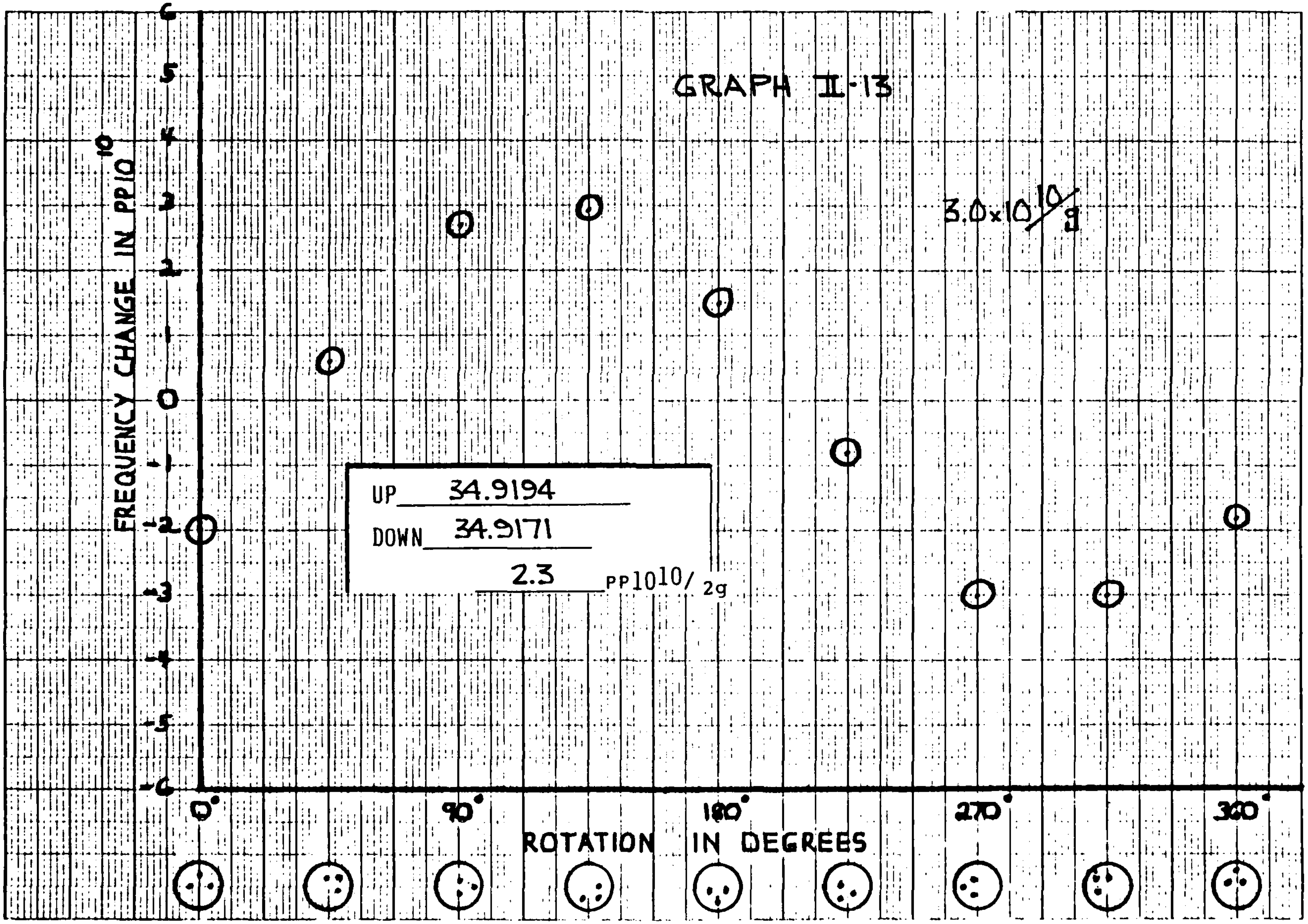
SER NO. 1382 5.0/5/3C DATE 9-8-80

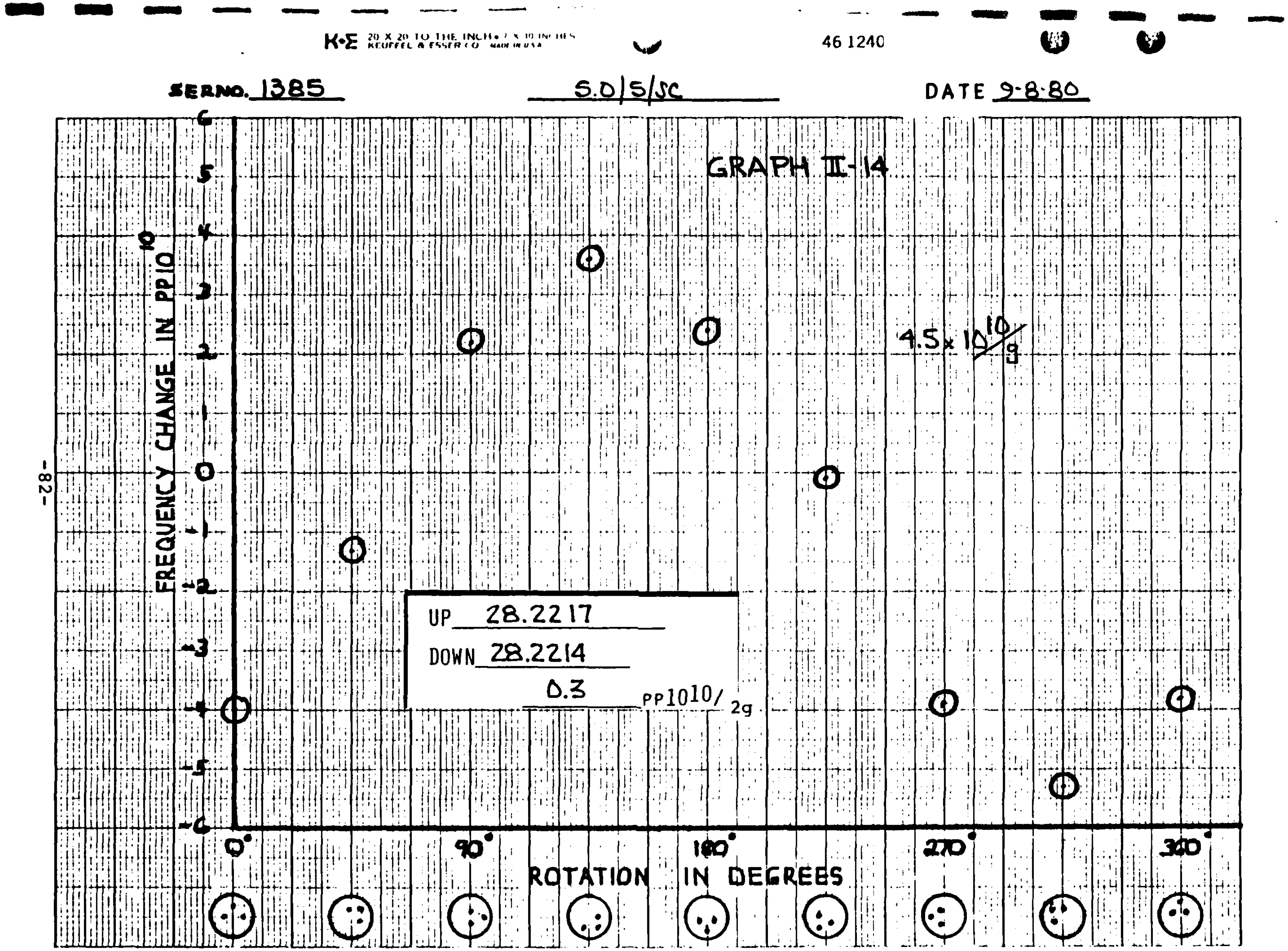


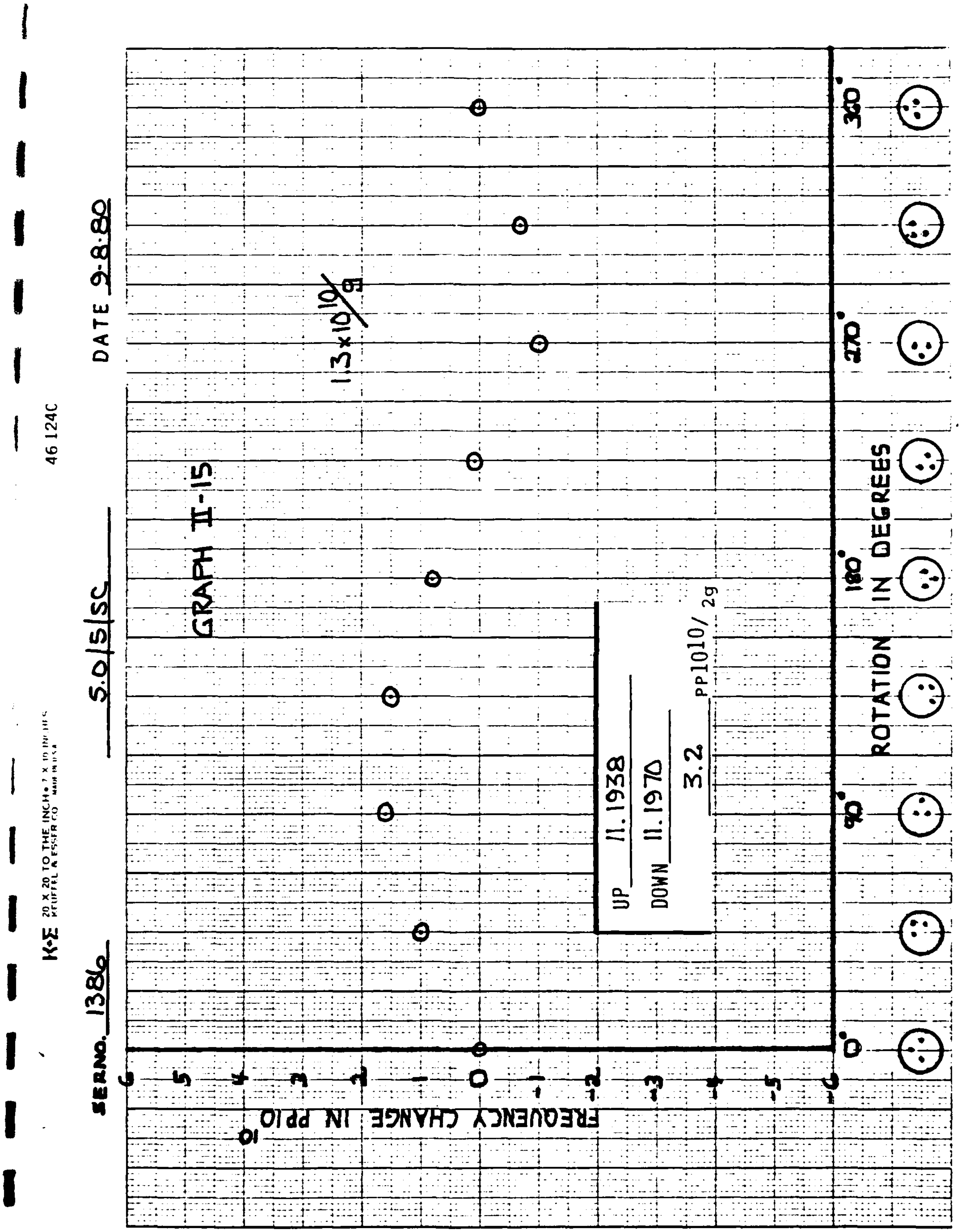

K·E 20 X 20 TO THE INCH
46 124C
SER NO. 1383
5.0/5/5C
DATE 9-8-80
GRAPH II-12
UP 18.0104
DOWN 18.0076
2.8 PP10^10/2g
5.6x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES

K•E 20 X 20 TO THE INCH 46 1240

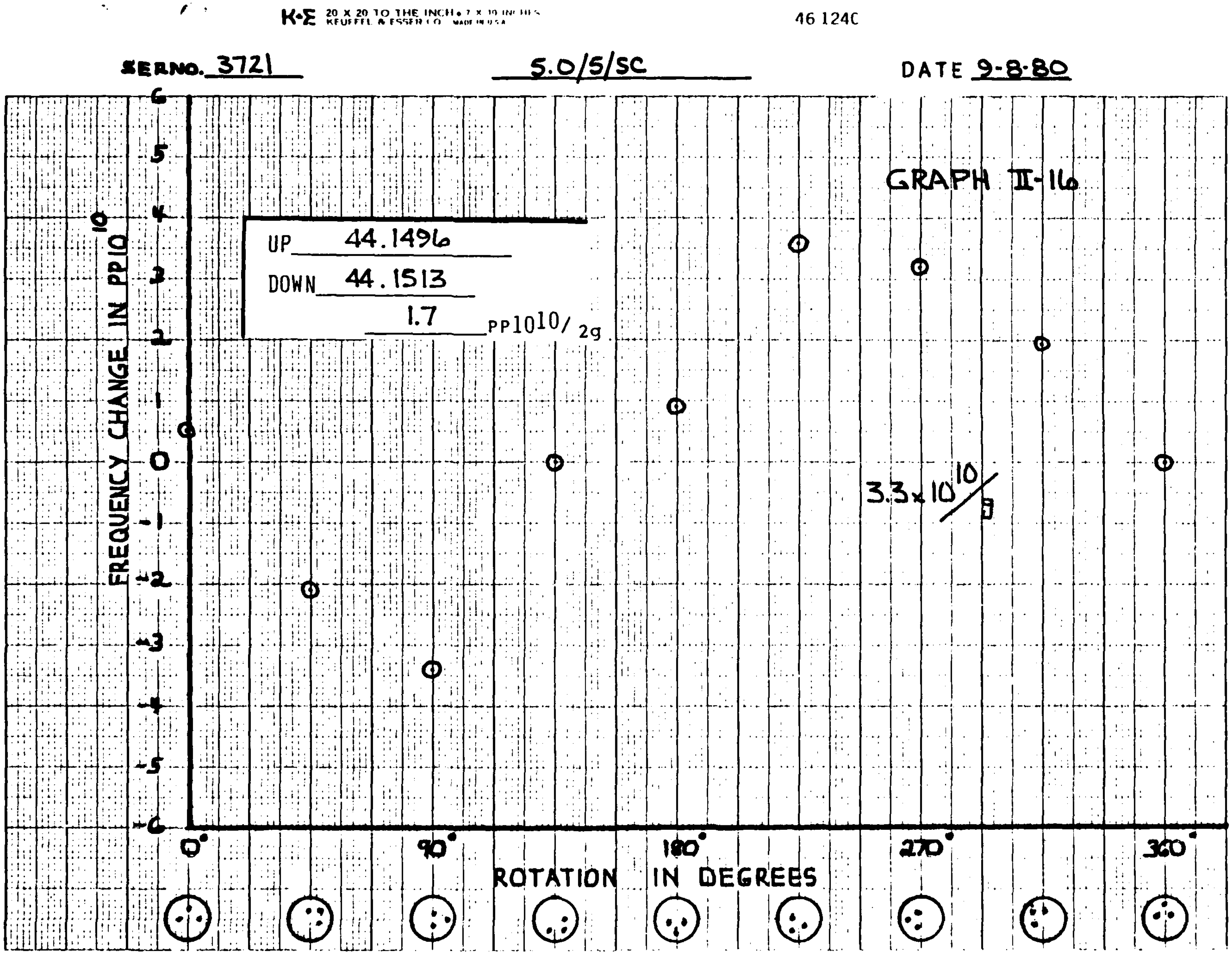
SER NO. 1384 5.0/S/SC DATE 9-8-80




K·E 20 X 20 TO THE INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SER NO. 1385
S.O/5/SC
DATE 9-8-80
GRAPH II-14
4.5x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
UP 28.2217
DOWN 28.2214
0.3 PP1010/2g
0°
90°
180°
270°
360°
ROTATION IN DEGREES



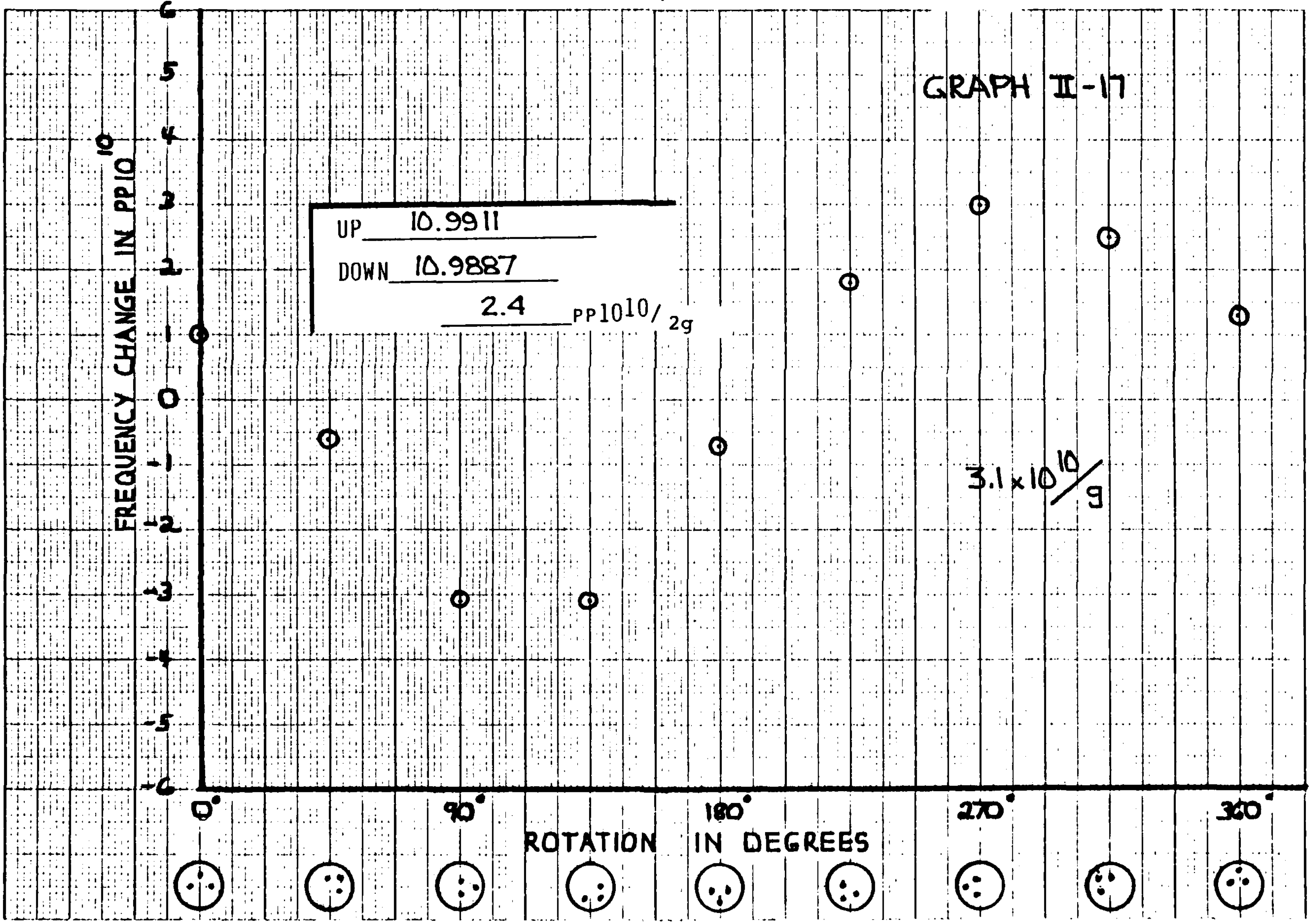
SER NO. 1386
5.0/5/SC
DATE 9-8-80
46 124C
GRAPH II-15
1.3×10^10/g
UP 11.1938
DOWN 11.1970
3.2 pp10^10/2g
FREQUENCY CHANGE IN PP10^10
ROTATION IN DEGREES
0°
90°
180°
270°
360°
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6



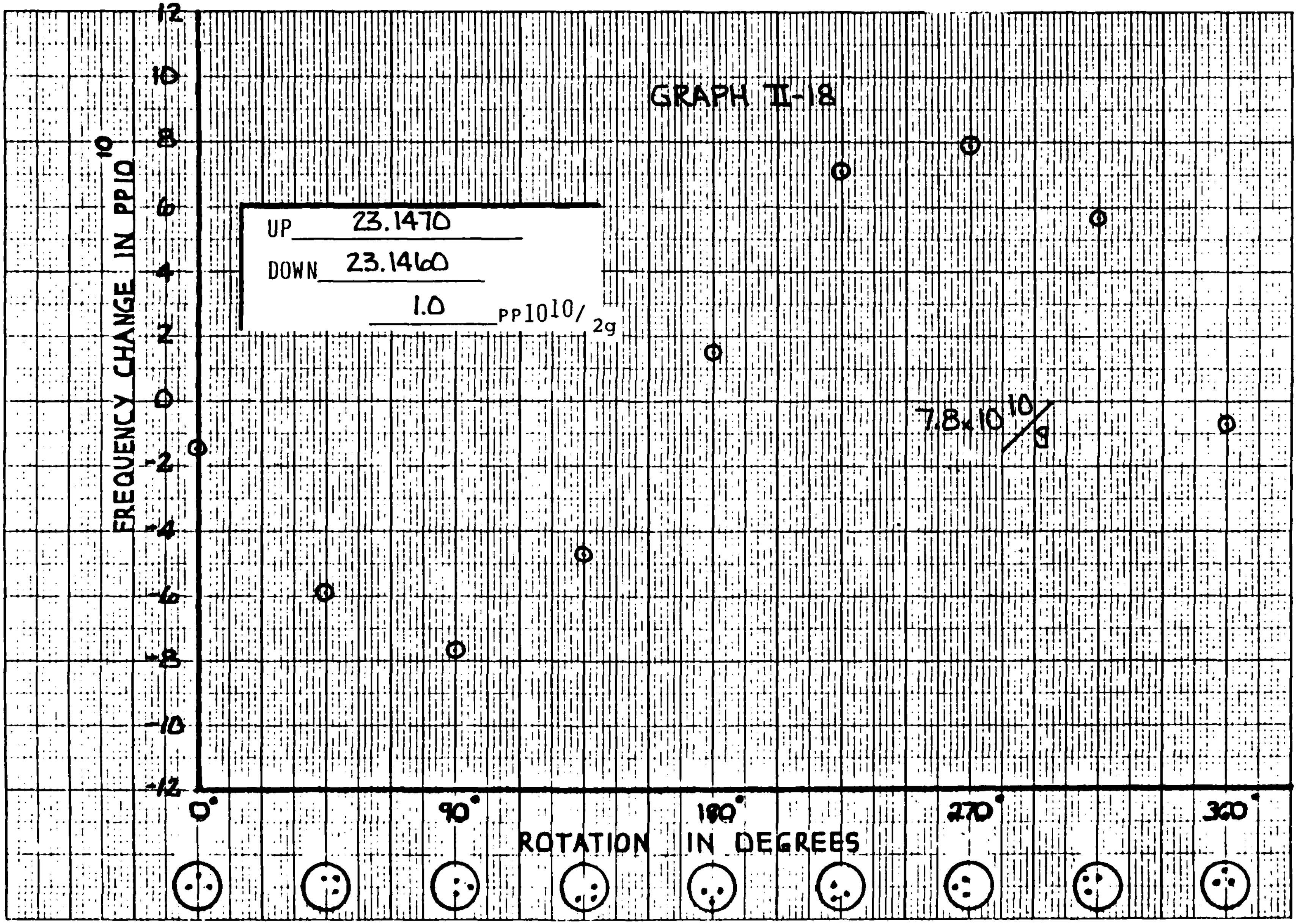
K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
SER NO. 3721
5.0/5/SC
DATE 9-8-80
GRAPH II-16
UP 44.1496
DOWN 44.1513
1.7 PP10^10/2g
3.3x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES

K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3725 5.0/5/5C DATE 9-8-80

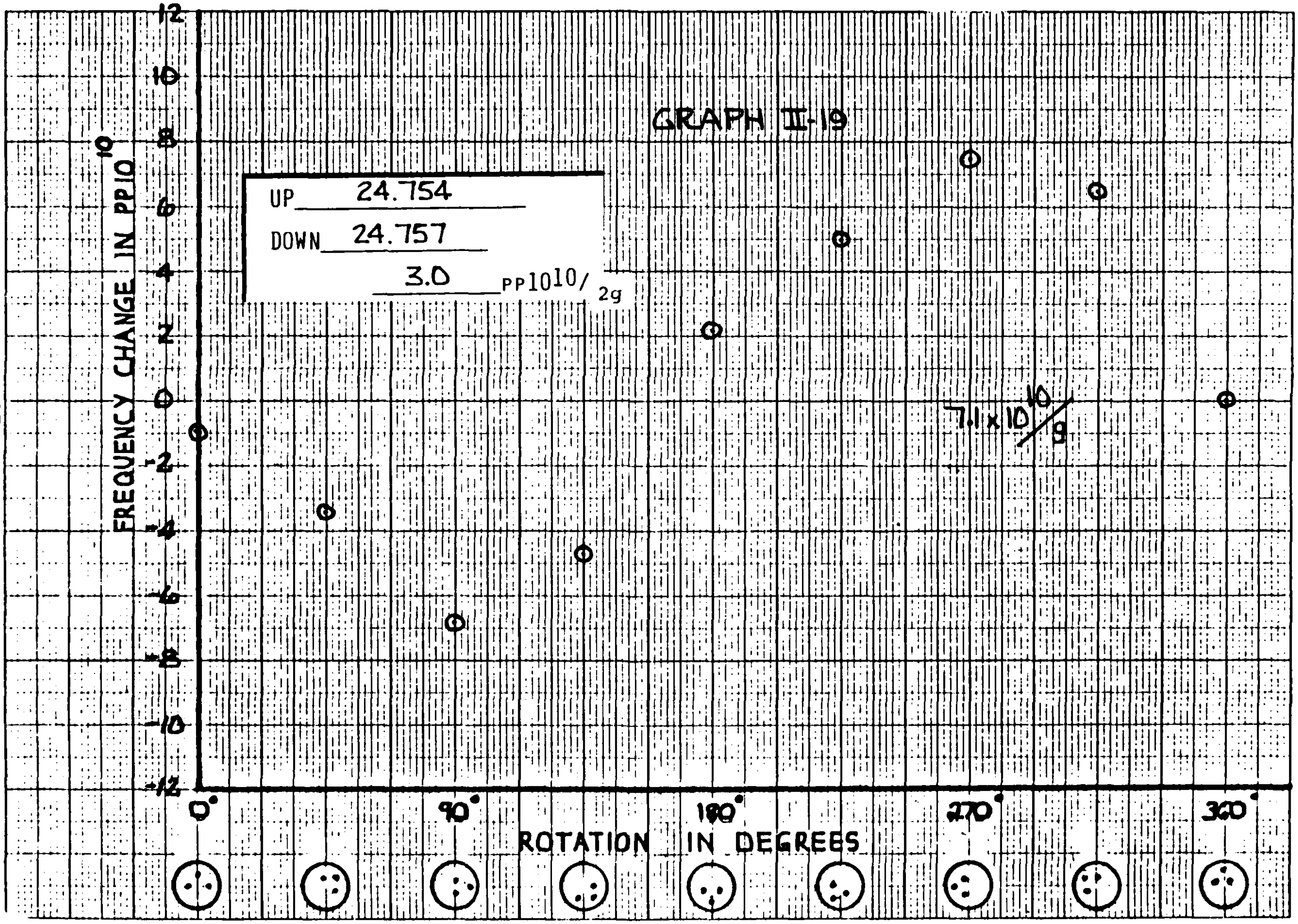


SERNO. 3726 5.0/5/SC DATE 9-8-80



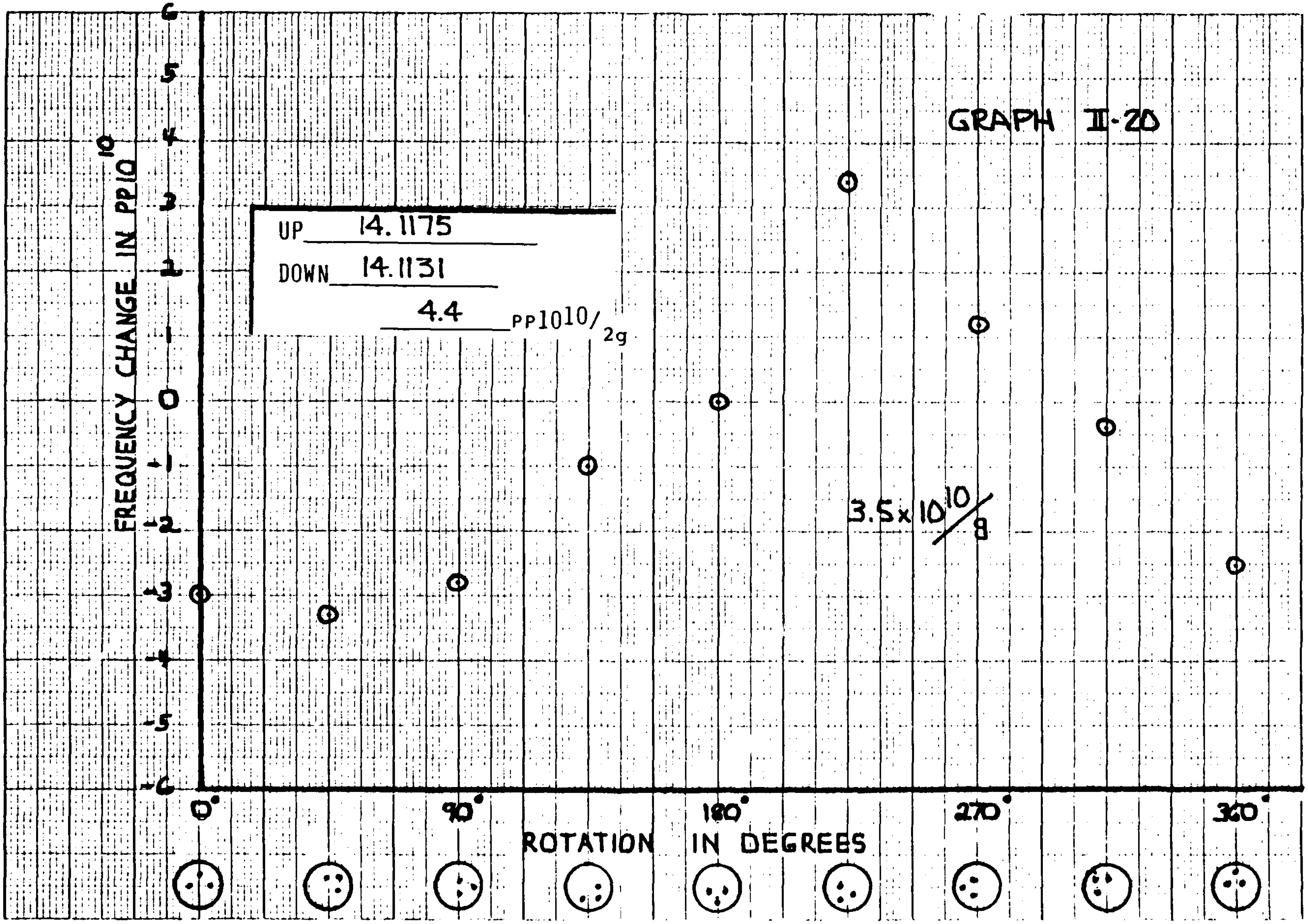
K•E KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3728 5.0/S/SC DATE 9·8·80



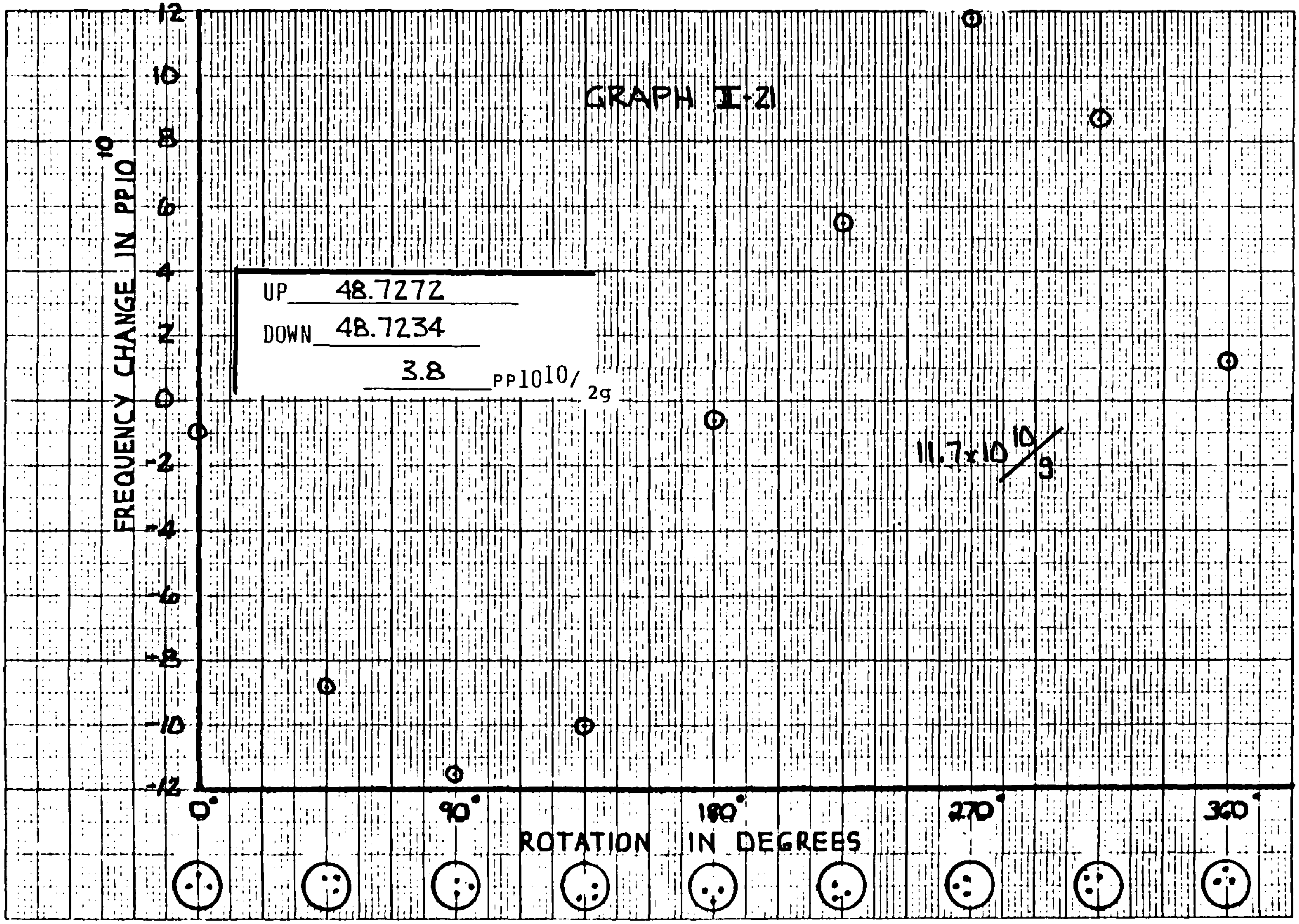
K·E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3729 5.0/5/SC DATE 9-8-80



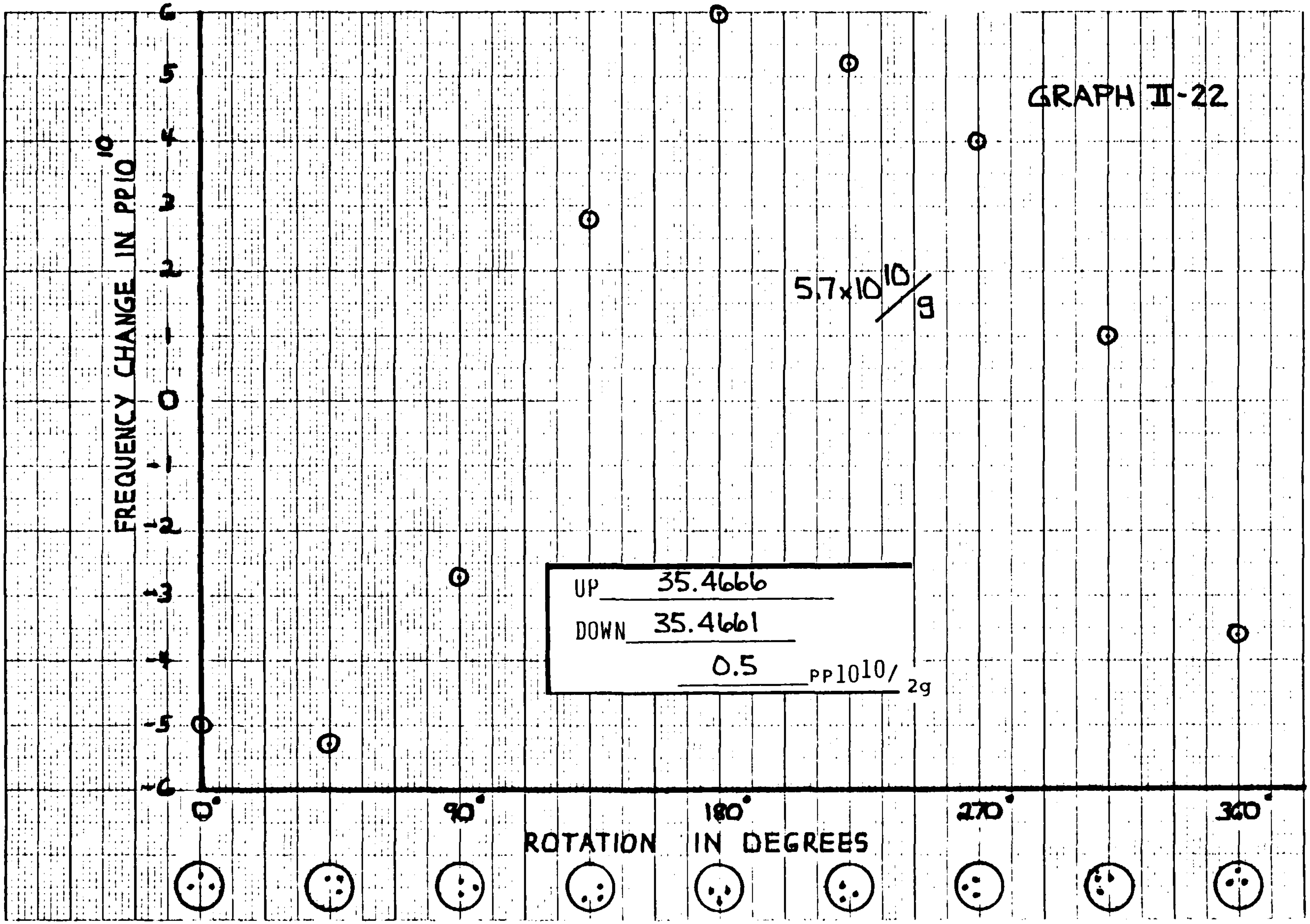
K+E KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER.NO. 3653 5.0/5/SC DATE 9-8-80



K+E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3655 5.0/5/SC DATE 9-8-80



K·E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

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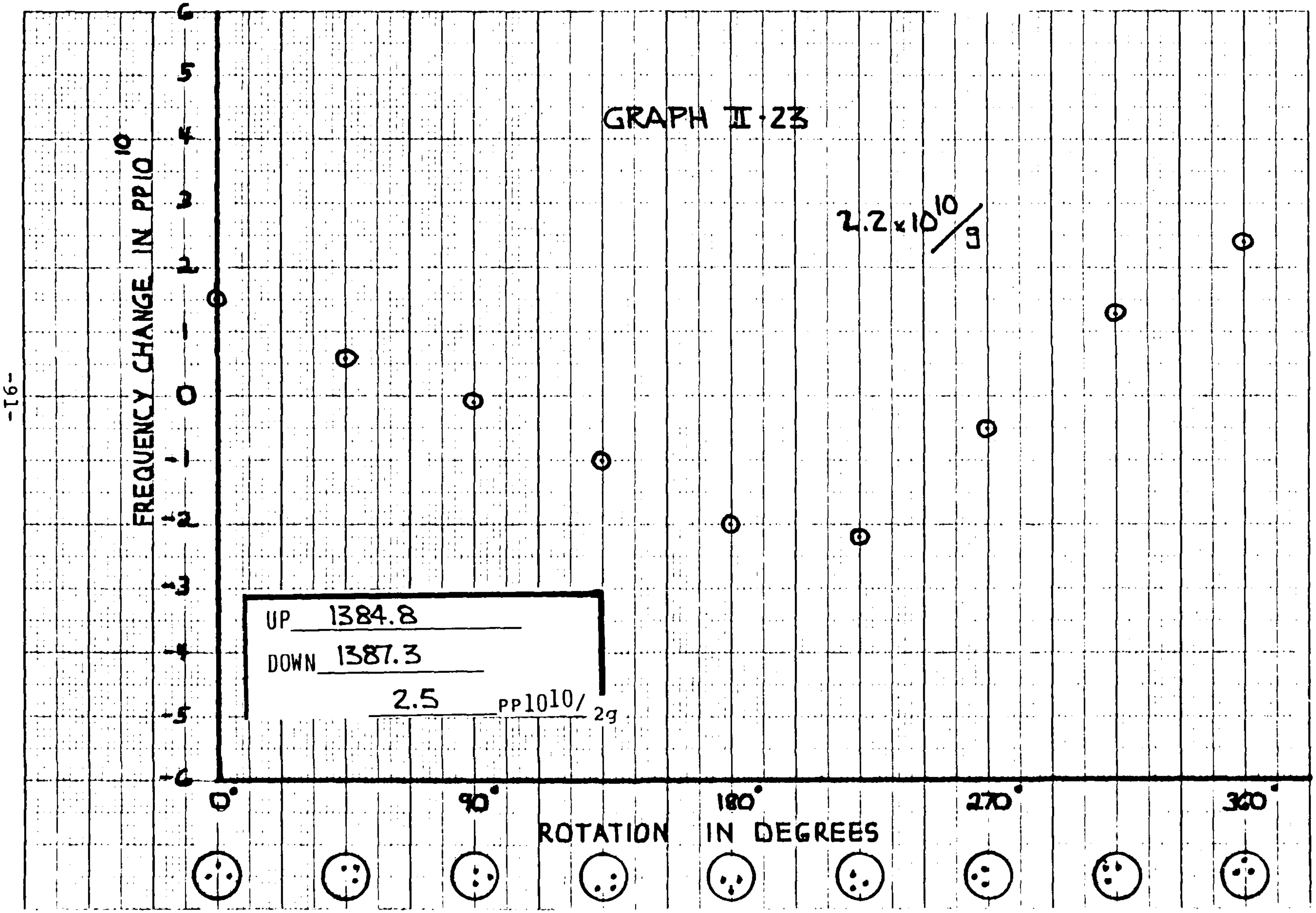

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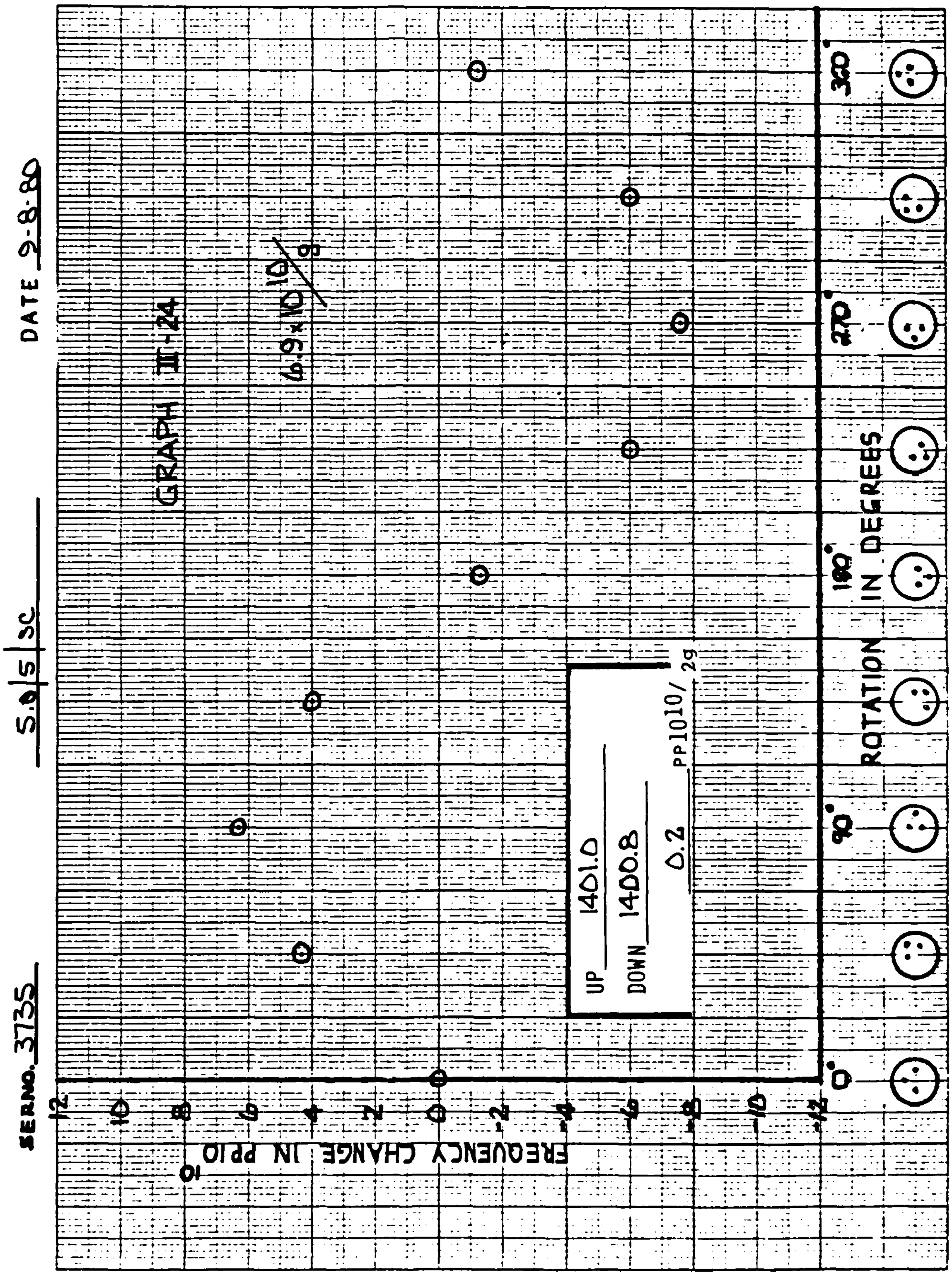

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46 1240
GRAPH II-24
6.9x10-10/g
UP 1401.0
DOWN 1400.8
0.2 PP1010/2g
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
FREQUENCY CHANGE IN PP1010
0°
90°
180°
270°
360°
ROTATION IN DEGREES

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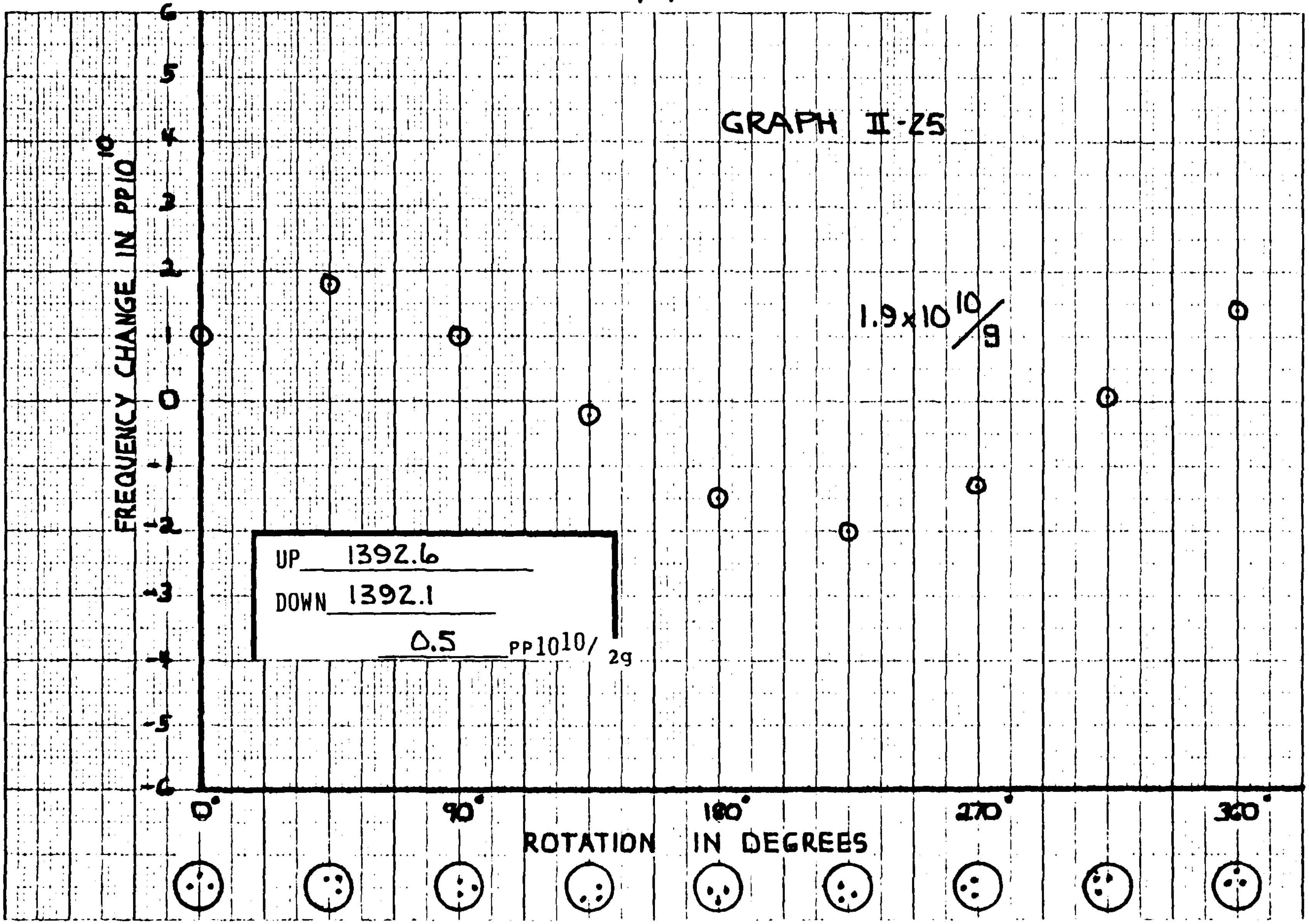

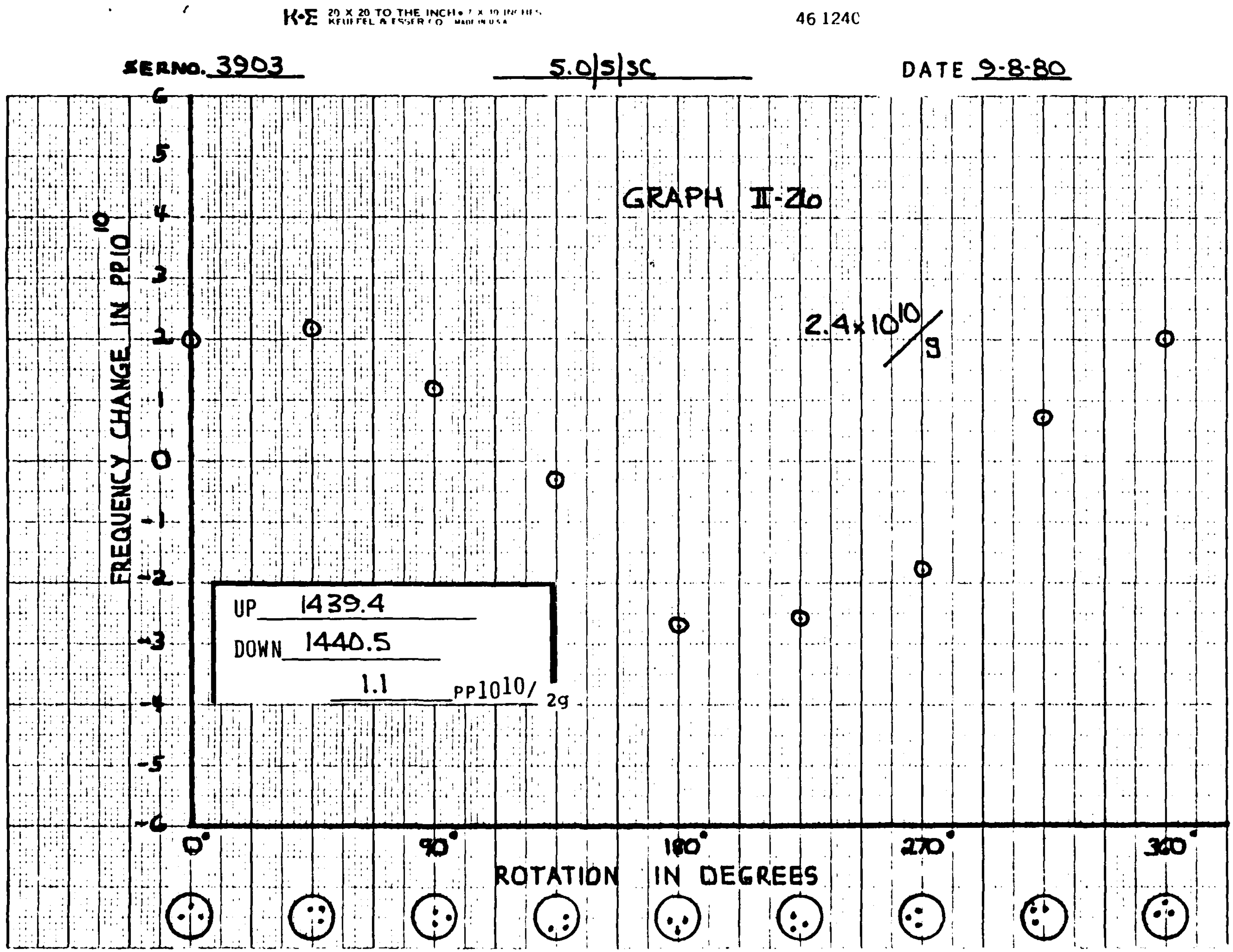

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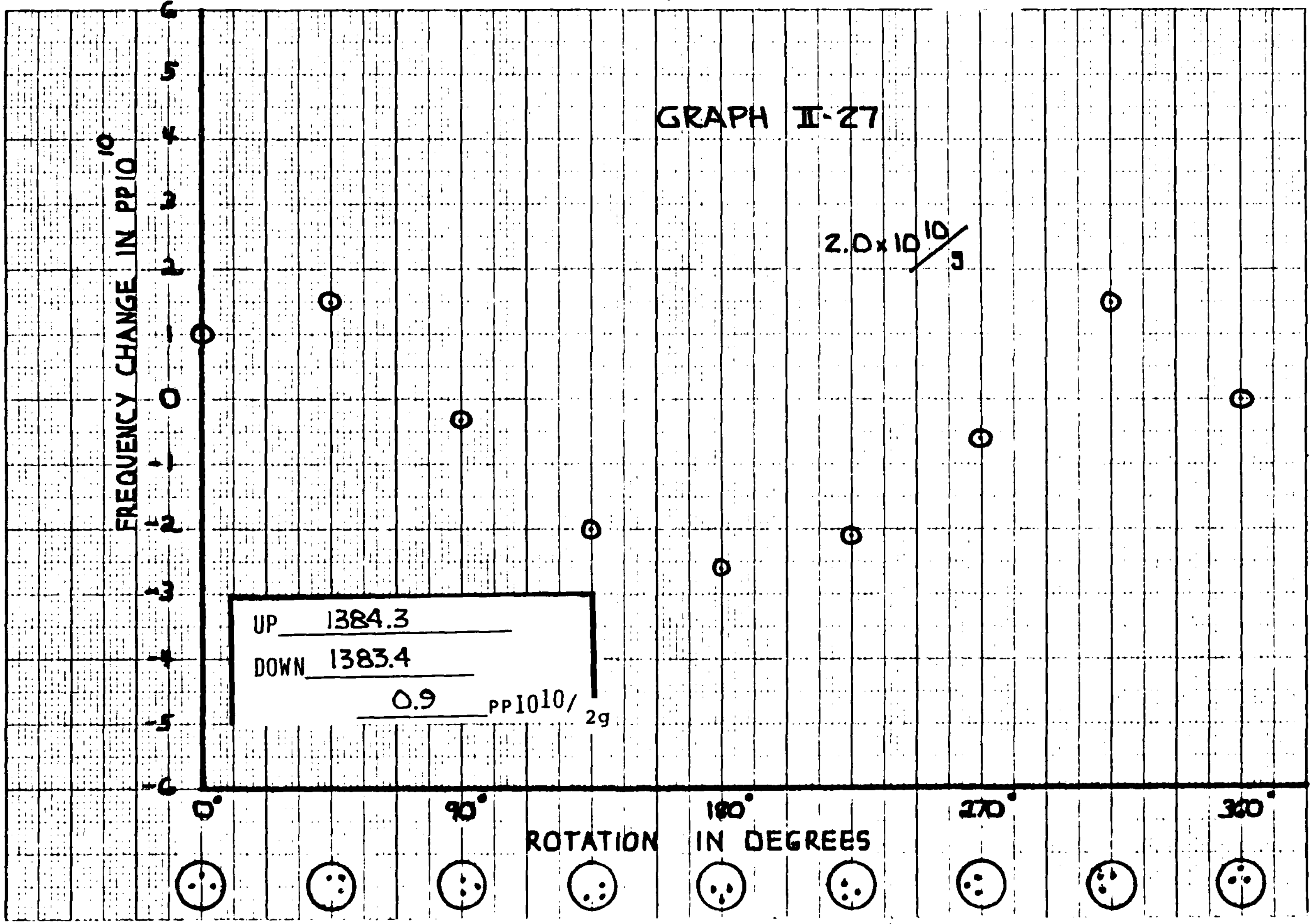
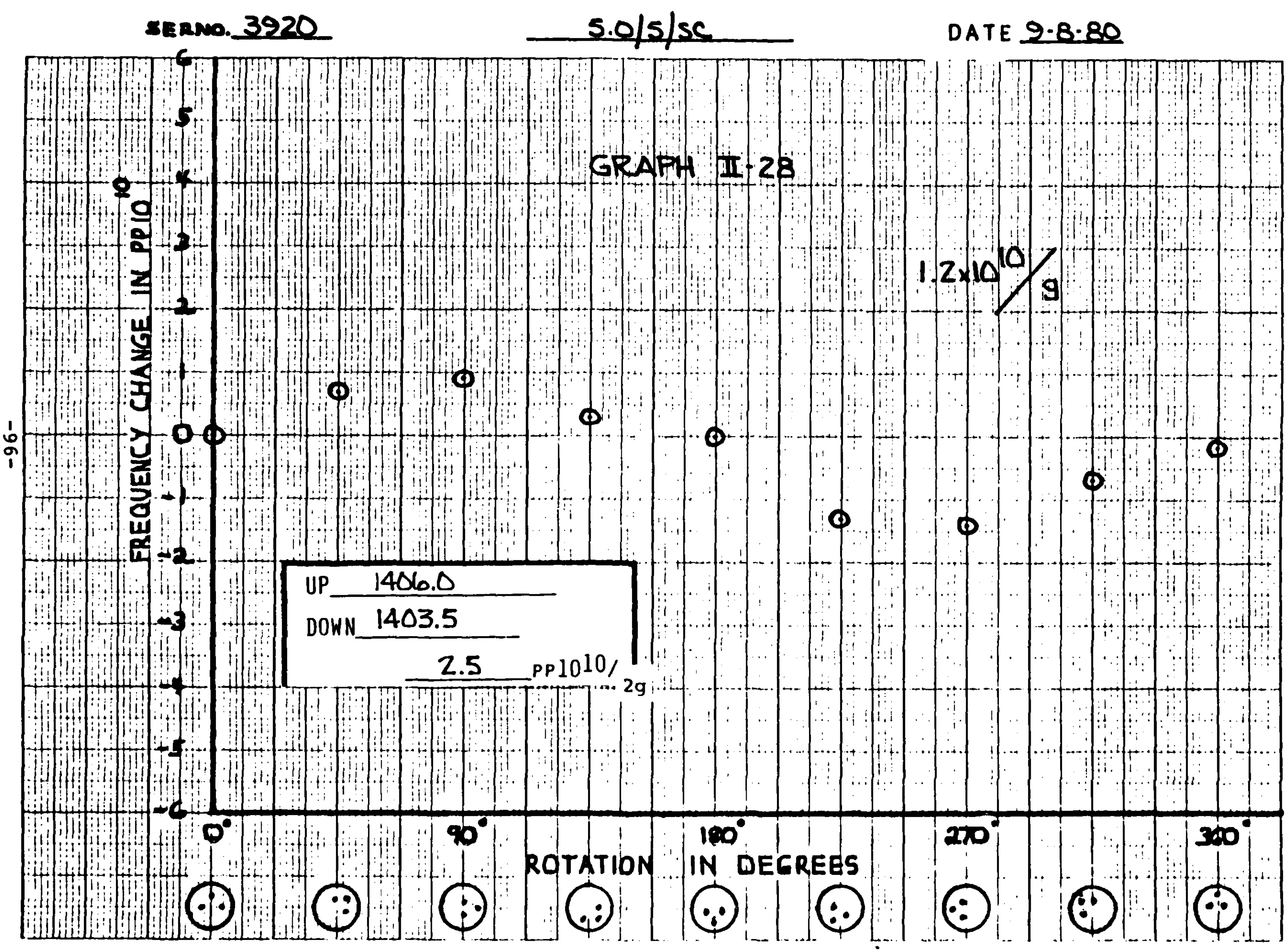
46 1240
SER NO. 3903
5.0|5|SC
DATE 9-8-80
GRAPH II-20
2.4x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
UP 1439.4
DOWN 1440.5
1.1 PP1010/2g
0°
90°
180°
270°
360°
ROTATION IN DEGREES

K•E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

SER NO. 3910 5.0|5|SC DATE 9-8-80

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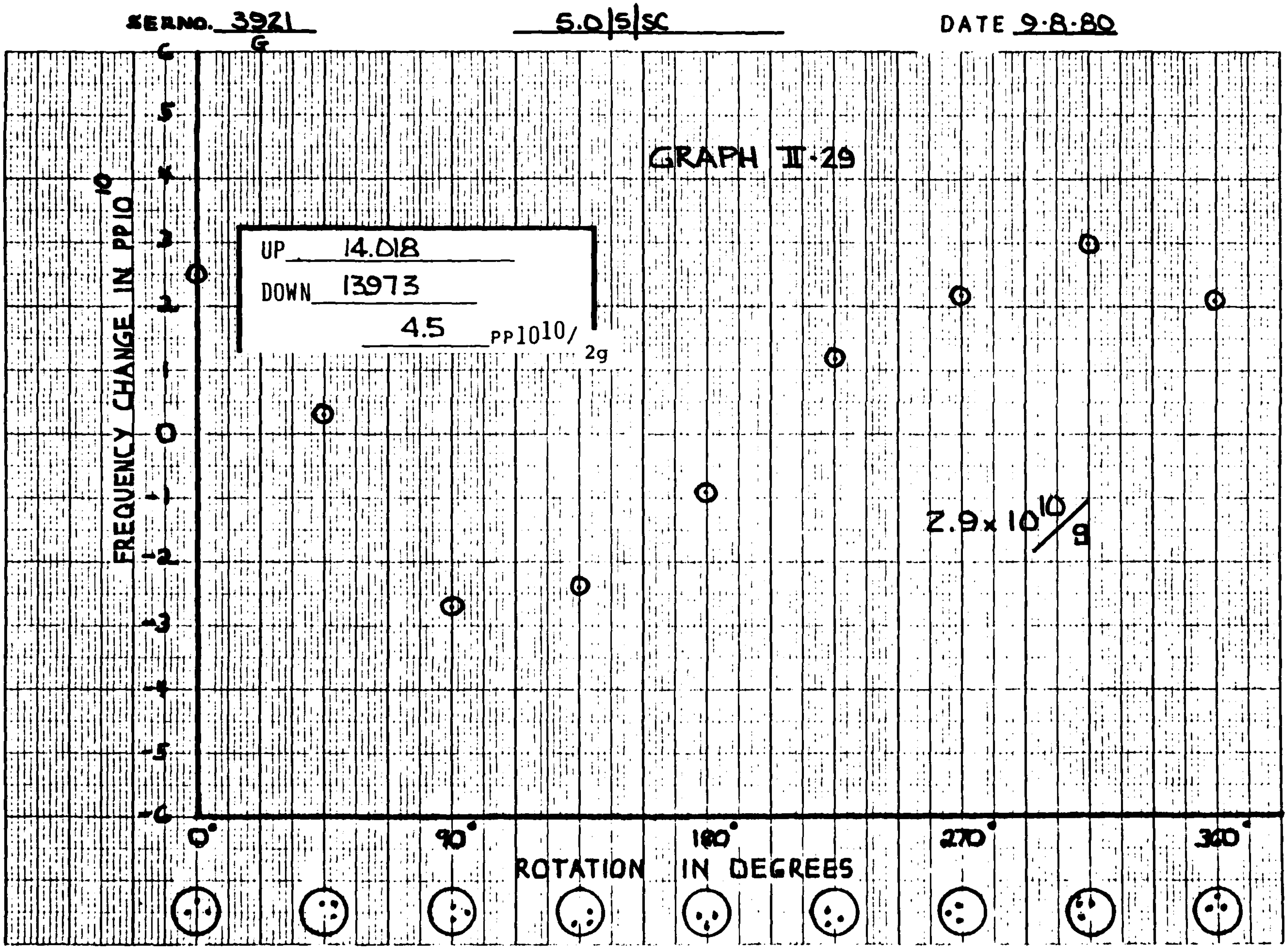
46 1240
SER NO. 3920
5.0/5/SC
DATE 9-8-80
GRAPH II-28
1.2x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
UP 1406.0
DOWN 1403.5
2.5 PP10^10/2g
0°
90°
180°
270°
360°
ROTATION IN DEGREES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SER NO. 3921 G
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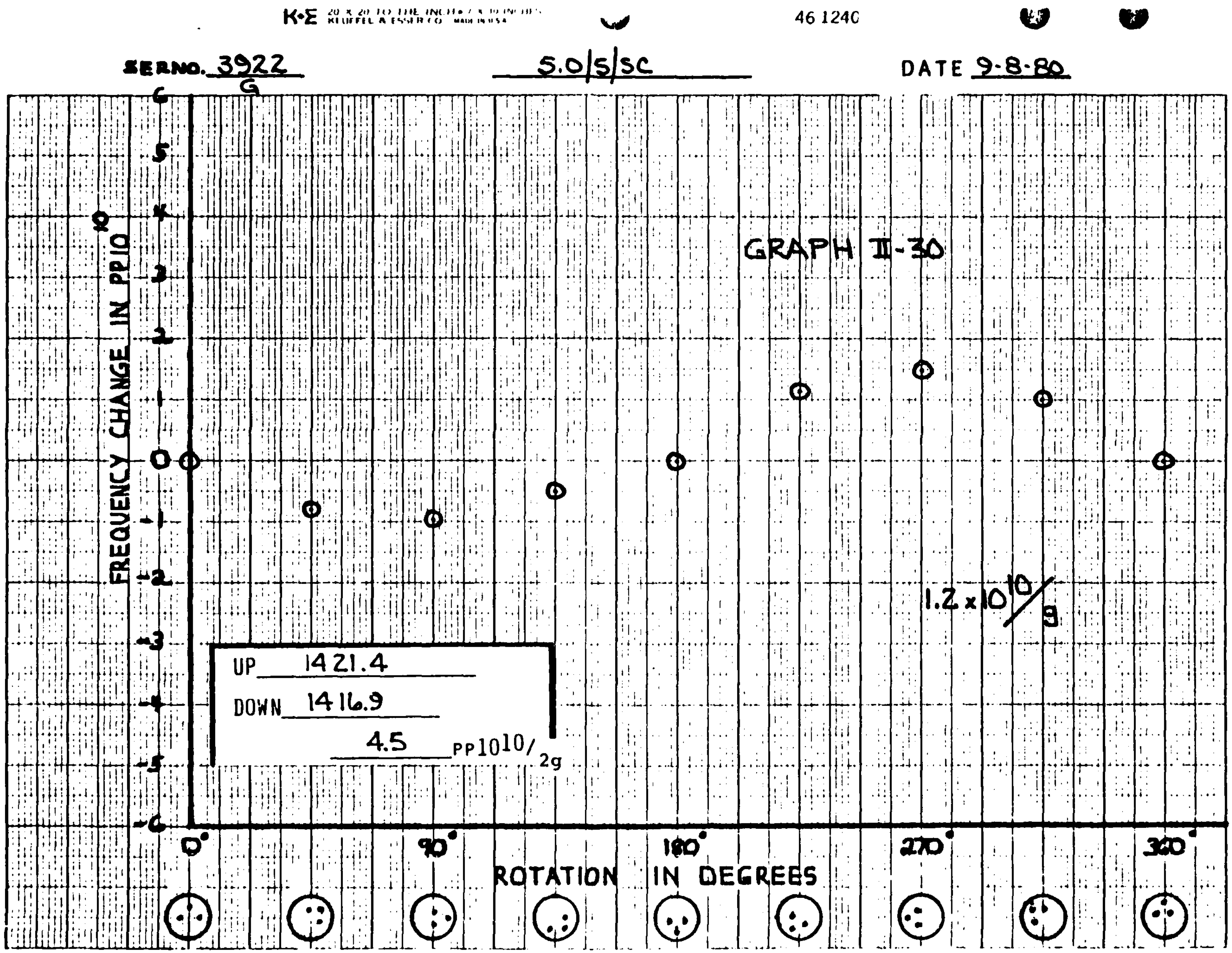
DATE 9-8-80
GRAPH II-29
UP 14.018
DOWN 13973
4.5 PP1010/2g
2.9x10^10/g
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0°
90°
180°
270°
360°
ROTATION IN DEGREES


K•E 20 X 20 TO THE INCH
46 1240
SER NO. 3922 G
5.0/5/SC
DATE 9-8-80
GRAPH II-30
FREQUENCY CHANGE IN PP10^10
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1.2 x 10^10/g
UP 1421.4
DOWN 1416.9
4.5 PP10^10/2g
0°
90°
180°
270°
360°
ROTATION IN DEGREES

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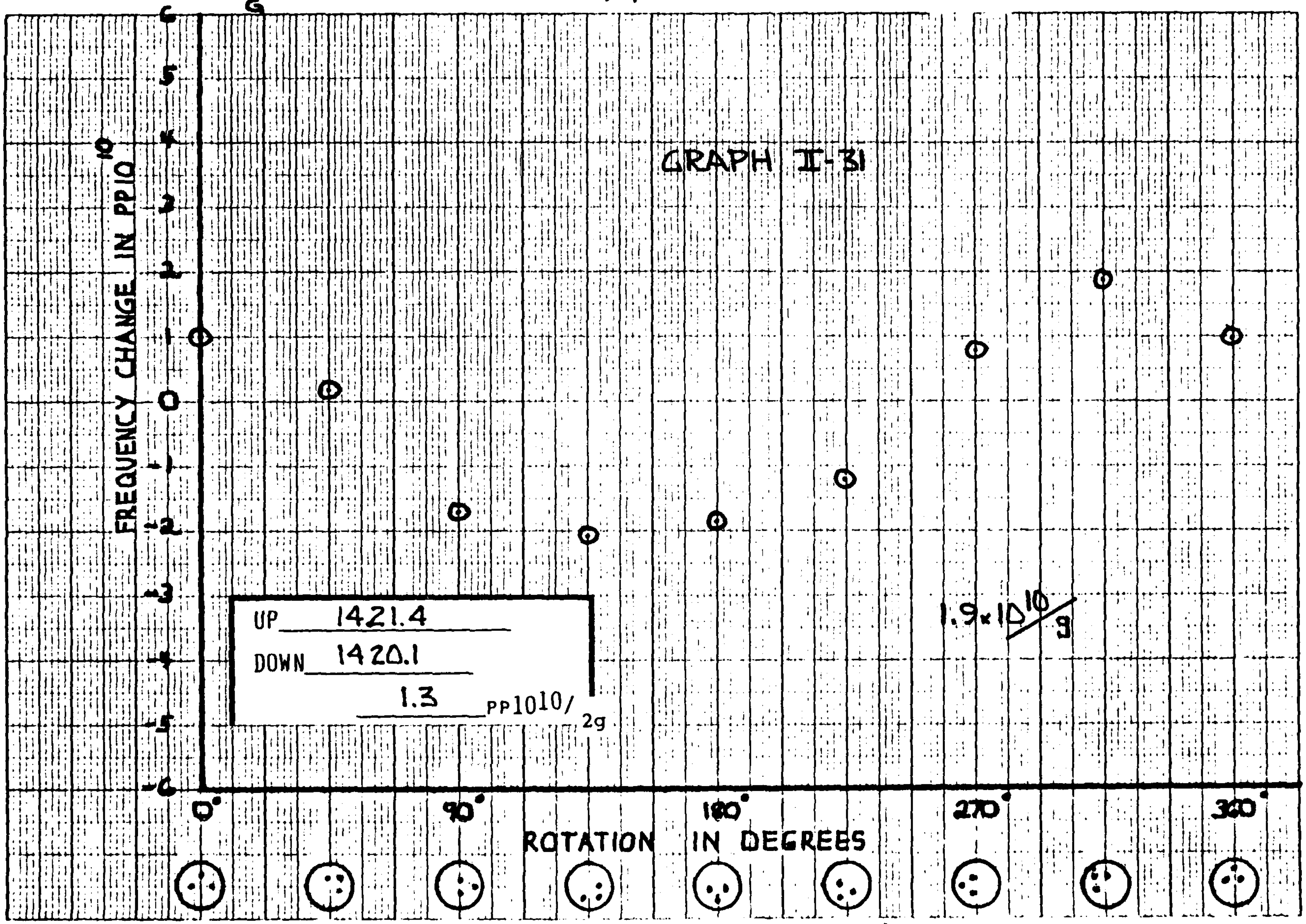

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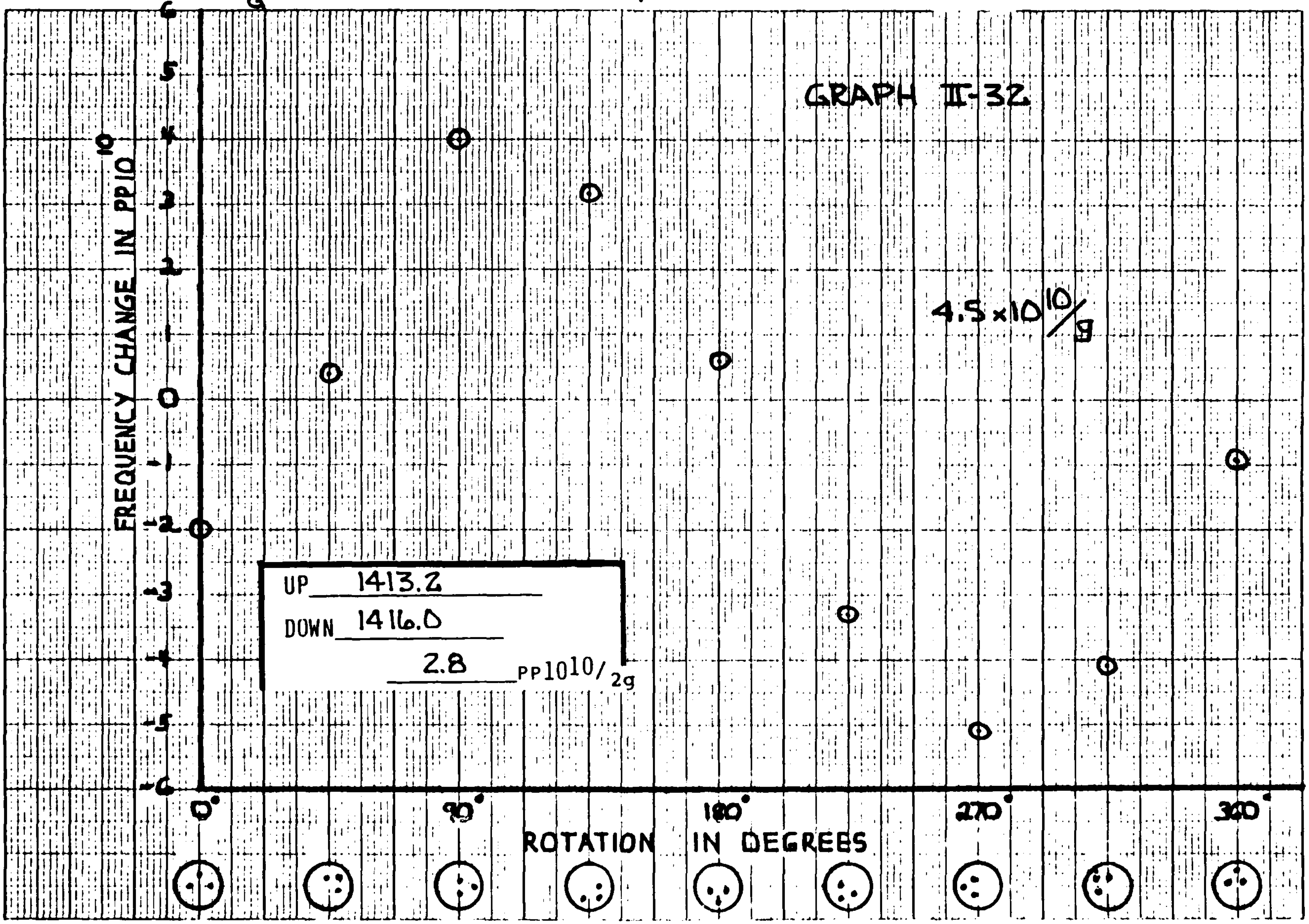

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