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SYSTEMS SI INCORPORATED

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ORLANDO, FLORIDA

TIGHTER TOLERANCE CRYSTAL UNITS

Report No. 2

Contract No. DA 36-039-AMC-02335(E)
DA Project No. 3A99-15-007
Second Quarterly Progress Report
15 September to 15 December 1963

Prepared For

United States Army Electronics
Research and Development Laboratory
Fort Monmouth, New Jersey

Systems Incorporated
2400 Diversified Way
Orlando, Florida

TIGHTER TOLERANCE CRYSTAL UNITS

Report No. 2

Second Quarterly Progress Report
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DA Project No. 3A99-15-007

Object of Research

To Develop a Tighter Tolerance Quartz Crystal Unit in the Frequency Range of 17 to 32 Mc.

In Accordance With

Signal Corps Technical Requirement SCL-7725
Dated 7 January 1963

Prepared For

United States Army Electronics
Research and Development Laboratory
Fort Monmouth, New Jersey

Prepared By:

W. H. Horton
S. B. Boor
R. B. Angove

15 January 1964

TABLE OF CONTENTS

I. PURPOSE

The purpose of this program is the development of miniaturized quartz crystal units in the frequency range of 17 Mc. to 32 Mc. having frequency tolerances which meet single sideband communications requirements over a limited temperature range without the use of temperature regulation or other power-consuming techniques.

II. ABSTRACT

Instrumentation problems associated with the construction of temperature compensated crystal units are discussed. Equipment which will provide the required level of measurement accuracy is described. Crystal characteristics (uncompensated) are described and a preliminary evaluation of the initial crystal design is made.

III. PUBLICATIONS, LECTURES, REPORTS AND CONFERENCE

On 10-11 December, 1963, a conference on "Tighter Tolerance Crystal Units," under Contract DA 36-039-AMC-20335(E), was held at USAELRDL, Fort Monmouth, New Jersey.

Present were:

Dr. G. Guttwein,	USAELRDL	Dr. W. Horton,	Systems Inc.
L. Nelson,	USAELRDL	S. Boor,	Systems Inc.
M. Bernstein,	USAELRDL		

Progress to date was reviewed, and the program for the next quarter was discussed.

The use of a pi transmission measurement was approved. The equipment to be used is of the type developed under Phase I of Contract DA 36-039-SC-90858 and is available at Systems Incorporated.

The use of HC-6/U crystal cans for the experimental models was approved.

Five nominal frequency groups were selected for the experimental models as follows: 17 Mc., 21 Mc., 25 Mc., 28 Mc., and 32 Mc. Ten units will be supplied in each group.

A conference is tentatively scheduled at Systems Incorporated during the second week of January 1964.

IV. FACTUAL DATA

4.1. Introduction

The need for passively compensated (tighter tolerance) crystal units meeting SCL-7725, and the basic analytical tools for accomplishing this task are described in the First Quarterly Progress Report [1].

The major effort during the second quarter has been devoted to instrumentation problems. The use of a transmission measurement system and a multi-crystal temperature chamber to determine frequency and resistance vs. temperature characteristics has been successfully demonstrated.

The pilot group of crystals at 25 Mc. previously fabricated [1] have been tested in the equipment. As a result of these tests, crystal production tolerances and yields have been estimated and design changes required prior to the manufacturing of further crystals have been deduced.

4.2. Frequency - Temperature Measurements

4.2.1. Introduction

The success of this program is dependent upon the ability to accurately and efficiently measure crystal frequency over the temperature range -27°C to +55°C. In order to be practical, the measurements must be rapid or of a multiple nature such that a minimum time is spent on each crystal. Measurements of both uncompensated crystals and the completed, compensated units are required.

Because of the accuracy and repeatability requirements of the frequency measurement, and the electrical properties of the compensated crystal units, it is necessary to use a pi network transmission type measurement rather than the CI Meter measurement originally specified. A more detailed description of the measurement equipment used is found in section 4.2.2. and Appendix A.

In order to accurately test several crystals simultaneously over the required temperature range, a multi-crystal temperature chamber has been designed. This unit is described further in section 4.2.3. Test procedures and results are described in section 4.2.4.

4.2.2. Crystal Measurement Equipment

As mentioned previously, a transmission measurement technique has been used in place of the CI Meter technique (TS 683) originally specified. The reasons for this are as follows:

1) Accurate measurements can be easily made at a remote location.

2) Accurate frequency measurements can be made over a wide range of crystal resistance values without requiring equipment adjustments during measurements.

3) Crystal power level can be easily controlled.

4) Crystal motional parameters can be determined.

The transmission test set used for the crystal measurements is described in detail in Appendix A. The test set, with a single relatively simple self-calibration, will accurately measure resonant frequency and resistance over a wide frequency and resistance range. For this reason, the set is particularly desirable for making rapid measurements of frequency and resistance on a group of similar crystals. In particular, a temperature run on a group of crystals can be readily accomplished by sequentially switching between different crystals throughout the run. In practice, it is more desirable to switch between pi networks rather than to switch directly at the crystal terminals for the following reasons:

1) Critical shunt reactances and lead lengths can be minimized.

2) The impedance level is more convenient for switching.

3) Coupling between different units can be minimized more readily.

4) An accurate calibration reference can be more easily provided.

4.2.3. Temperature Chamber Equipment

The temperature chamber required for this project must satisfy several conditions:

1) A temperature range of -27°C to +55°C must be covered and accurately measured.

2) A large thermal mass is required, both to guard against internal temperature gradients and to provide a large thermal time constant.

3) It should be possible to make relatively rapid temperature changes when desired.

4) The chamber should accommodate as many crystals as possible.

5) The transmission networks and switching must be designed to prevent unwanted coupling and leakage paths.

6) The chamber should accommodate crystals of varying sizes (from HC-18/U to HC-6/U enclosures).

In the actual design, some compromises in the above criteria were necessary, the major being in the ability to accept varying size crystal containers.

The chamber is most easily described by referring to figures 1, 2 and 3. Figure 1 is a picture of the temperature block, including its switch assembly, in an aluminum container. Figure 2 is a picture of the temperature block and switch assembly. Figure 3 is a picture of the switch assembly during fabrication.

The thermal block is an aluminum cylinder 4 inches high and 6 inches in diameter. This size represents a compromise between large mass and a size convenient for use in laboratory temperature chambers. The block will accept 11 crystal cans. Separate blocks are required for the HC-6/U and HC-18/U size cans. An insert will be used to accommodate HK-12 cans in the HC-6/U block.

The switch assembly, which fits on top of the temperature block, contains the transmission networks, appropriate crystal sockets, and the required switching. The circuit is symmetrical between input and output, with external connections made through 50 ohm coaxial cables. The cables are switched to one of ten pi transmission networks (the 11th position is used for temperature measurement), while the remaining nine networks are grounded. The switch sections, as well as the network sections, are shielded between input and output. Each network consists of a pair of series resistors to provide a proper line termination (50 ohms) and a pair of shunt resistors (3 to 6 ohms) from crystal socket to ground.

Two different switch assemblies are used to accommodate different crystal sockets. One assembly is built with modified nuvistor sockets to accept wire leads (HC-18/U type) and uses 3 ohm shunt resistors. The second assembly uses conventional sockets for HC-6/U crystal units. Larger values of shunt resistance (6.2 ohms) are used in this assembly, since the compensated crystal units will have a series resistance considerably higher than that of the uncompensated crystal.

The temperature measurement is accomplished using a thermistor (a Fenwal bead element) which is cemented to a crystal blank of the same size as the crystal being tested. The blank is placed in a sealed holder. The thermistor leads, attached to the crystal base, are wired to an external bridge. The resultant temperature sensor is calibrated in a conventional manner. In use, the sensor is placed in one of the 11 slots in the temperature block. Thus, the probe thermal properties are as nearly identical to those of the crystals under test as possible.

The temperature chamber, consisting of the switch assembly and block, can be placed in a standard laboratory temperature chamber or in a special aluminum casing for temperature runs. Although the chamber can be cooled in the aluminum casing by using dry ice, it is more easily cooled using a laboratory temperature chamber. After cooling, the chamber is placed in the aluminum casing. The air space between the chamber and the casing, coupled with the large thermal mass of the block, provides an extremely long thermal time constant. The rate of change of temperature can be increased by running hot air through the casing. The air enters the casing through a tube in the bottom, passes by the block, and leaves through sliding vent holes on top of the casing. Either cool or warm air can be used, depending upon the rate of temperature change desired or the ultimate temperature required.

The temperature range of -27°C to +55°C can be easily covered with this unit. Typically, the temperature chamber is cooled to about 5°C lower than the desired test limit. The unit is then placed in the casing where it rapidly cools the casing, thereby raising its own temperature 3 to 4°C. The temperature will then rise slowly, and approximately linearly, for several hours (with the casing at room temperature). Forced air can be applied to accelerate the process. At a certain point (dependent upon the rate desired) heated air is used. Approximately linear temperature vs. time curves have been obtained, covering the specified temperature range at rates varying from 30 minutes to over 8 hours. Although this range can be further expanded, other considerations, such as the time required for each frequency measurement, become limiting factors. In summation, the oven performs as designed and is adequate for the intended purpose.

4.2.4. Test Procedures and Results

The frequency-temperature characteristics of crystals are obatined by placing the crystals in the temperature chamber and using the transmission test set for the required frequency measurements. The test set is periodically calibrated by using a reference resistor in one of the 10 crystal positions in the block. Thus, nine crystal units, one resistor, and the thermistor sensor occupy the 11 slots in the temperature block. The network switch allows the selection of pi networks containing any of the nine crystals or the calibration reference resistor, as desired. The thermistor is permanently connected to provide a continuous temperature indication.

The validity of the measurement technique has been confirmed by interchanging the position of resistor and crystals without resulting in any change in the measurements. The equality of the thermal time constant of the temperature sensor and crystal has been checked by testing at various rates of change of temperature. Measurements taken during an 8 hour temperature run are essentially identical with data taken in a 30 minute run.

A typical temperature run is accomplished as follows: First, the test set is calibrated. Second, the block, including crystals and switch assembly, is cooled to approximately -32°C. Third, the assembly is removed from the cooler and placed inside the aluminum casing. Fourth, frequency and resistance data is taken for each crystal when the temperature reaches -27°C. Fifth, the temperature is raised (using forced air and heated air as necessary) and data is taken as rapidly as possible. The test set calibration is periodically checked during the run.

The time of the temperature run is dependent upon several factors, but is generally limited by the speed with which measurements can be made and the number of data points required. The data required can vary widely, dependent upon the units under test (normal crystals or compensated units) and the shape of the frequency-temperature curve. Some typical frequency-temperature curves (uncompensated units) are shown and discussed in more detail in the following section.

4.3. Crystal Design and Fabrication

No additional crystals have been fabricated during the past quarter, but rather, effort has been toward evaluation of the prototype units previously fabricated. A few of the crystals have been measured both point-by-point and continuously as a function of temperature. This data correlated very well with later data taken with the equipment described in section 4.2. Some typical crystal characteristics are shown in figures 4, 5, 6 and 7.

The crystal frequency-temperature curves obtained demonstrate close correlation with anticipated (theoretical) curves. Figure 4 is typical of the crystals having near design center (35°21') orientation angle. Figure 5 is typical of crystals which are slightly low in angle. Figure 6 shows a crystal which is slightly high in angle, and figure 7 shows a crystal which is (comparatively) very high in angle. The figures presented are representative of the distribution obtained; i.e., the average crystal was between 0.5 and 1 minute high in angle.

Using the arbitrary criterion that the uncompensated change should not exceed $\pm$ 2 parts in 10^6 from 0°C to +55°C (the original design goal), and accounting for the offset error described above, a yield of approximately 30% is anticipated. It is possible that this number can be significantly altered, but several additional fabrication runs are necessary before a more accurate prediction can be made.

Furthermore, the frequency-temperature characteristic of "acceptable" units has not yet been rigidly determined, pending further compensation network design. The data to date has substantiated an anticipated effect [1, pp. 20-21] resulting from the variable resistance compensation technique; i.e., the series resistance of the compensated units will exceed the requirements in SCL-7725.

V. CONCLUSIONS

1) The crystal test equipment now in use, particularly the transmission test set and temperature chamber, provides the means for making rapid, accurate temperature-frequency measurements. This equipment, coupled with more conventional test equipment, completes the instrumentation necessary on this program.

2) The crystals fabricated to date have shown a relatively small angular spread and were approximately correct in absolute value of angle. The preliminary production yield is within practical bounds and somewhat better than anticipated.

3) The crystal characteristics are, as predicted, amenable to compensation using the techniques described in the first quarterly report. These techniques, coupled with the instrumentation now available, provide the basic tools for constructing the compensated crystals.

VI. PROGRAM FOR THE NEXT INTERVAL

The program for the next quarter will include the following items:

1) Design the required compensation networks.

2) Determine the availability of all necessary components; critical items are expected to be both NTC and PTC thermistors, as well as miniature variable capacitors.

3) Fabricate 50 experimental models, using HC-6/U containers. Ten units in each of five nominal frequency groups will be supplied. The frequencies are as follows: 17 Mc., 21 Mc., 25 Mc., 28 Mc. and 32 Mc.

VII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

Personnel participating in the program during the second quarter are indicated below:

	Approximate Hours
W. H. Horton Vice-President, Engineering	Overhead
R. C. Smythe Assistant Vice-President, Engineering	20
S. B. Boor Chief Equipment Engineer	50
R. B. Angove Vice-President, Engineering Electronic Crystals Corporation	40

Appendix A. Filter Crystal Transmission Test Set

The equipment used for pi network and hybrid-coil bridge measurements on this program is a special transmission measurement test set developed in conjunction with the Frequency Control Division of the U. S. Army Electronics Research and Development Laboratory by Systems Incorporated on Signal Corps Contract DA-36-039 SC-90858 for filter crystal measurement in the frequency range from 0.8 Mc. to 100 Mc. The test set is shown in figure A-1 and a block diagram is shown in figure A-2.

The equipment consists of a signal source and broadband amplitude detector for transmission measurement and a phase sensitive detector and servo system for automatic control of the signal frequency. Three signals are available from the source. One signal is used directly for the transmission measurement, the second is used as a reference for the phase sensitive detector and the third signal is provided to drive a frequency counter. The source is mechanically tuned in a conventional manner, and also tuned electronically to allow automatic frequency control in a "locked" mode of operation or to allow sweep or manual vernier control in other modes of operation. Regulated power supplies (including a regulated DC supply for the heaters) are used to assure maximum signal spectrum purity. The signal source is designed as a plug-in unit. Two units cover the frequency range from 0.8 Mc. to 100 Mc.

The amplitude detector consists of a broadband transistorized RF amplifier, preceded by a voltage controlled attenuator.

The output of the amplifier is envelope detected to provide amplitude indication. The envelope signal is also used for servo control of the attenuator in a "log" mode to provide a quasi-logarithmetic gain characteristic.

The phase detector and servo unit consist of a broadband balanced phase sensitive detector followed by DC amplification and filtering which provides an appropriate choice of response characteristics so that stable operation can be achieved under the range of transmission bandwidths encountered. The reference signal for phase sensitive detection is derived from the signal source through a broadband phase shifter which provides continuous control over greater than 360° of phase shift from 0.8 Mc. to 100 Mc. When operating in the automatic frequency control mode, the phase shifter allows the frequency control loop to be locked at any desired value of phase shift associated with the device under measurement and provides a mechanism for precision vernier frequency adjustment. In this manner, the phase slope of the device under measurement determines the signal source frequency stability during measurement.

Accessories provided with the equipment include 3 ohm and 50 ohm pi networks, a capacitance bridge for C_o measurement and hybrid-coil bridge circuit for unwanted mode measurement. A bank of low-pass filters has also been developed to provide greater than 30 db of additional harmonic suppression over the 0.8 Mc.

to 100 Mc. frequency range for special cases* where even small amounts of harmonic distortion may cause measurement errors.

Measurements are accomplished by placing the crystal in a resistive pi network similar to that described by Gerber [2] and determining the frequency and transmission amplitude corresponding to a zero phase condition of the crystal. From the transmission amplitude, equivalent resistance at the zero phase condition can be determined.

The actual measurement is as follows: First, a zero phase resistor is placed in the pi network fixture. This resistor provides both the phase and amplitude standard for the measurements. Second, the amplitude detector gain is adjusted for a prescribed amplitude meter reading, thereby providing a resistance calibration point. Third, the phase shifter is adjusted for a null reading on the phase detector meter, thus providing a phase calibration point (zero on the meter corresponds to zero phase shift through the network). Fourth, the crystal is placed in the pi network fixture and the system is switched to the "locked" mode of operation. In this mode, the frequency of the signal source is automatically controlled to provide a null signal out of the phase detector, thus corresponding to the calibrated zero phase

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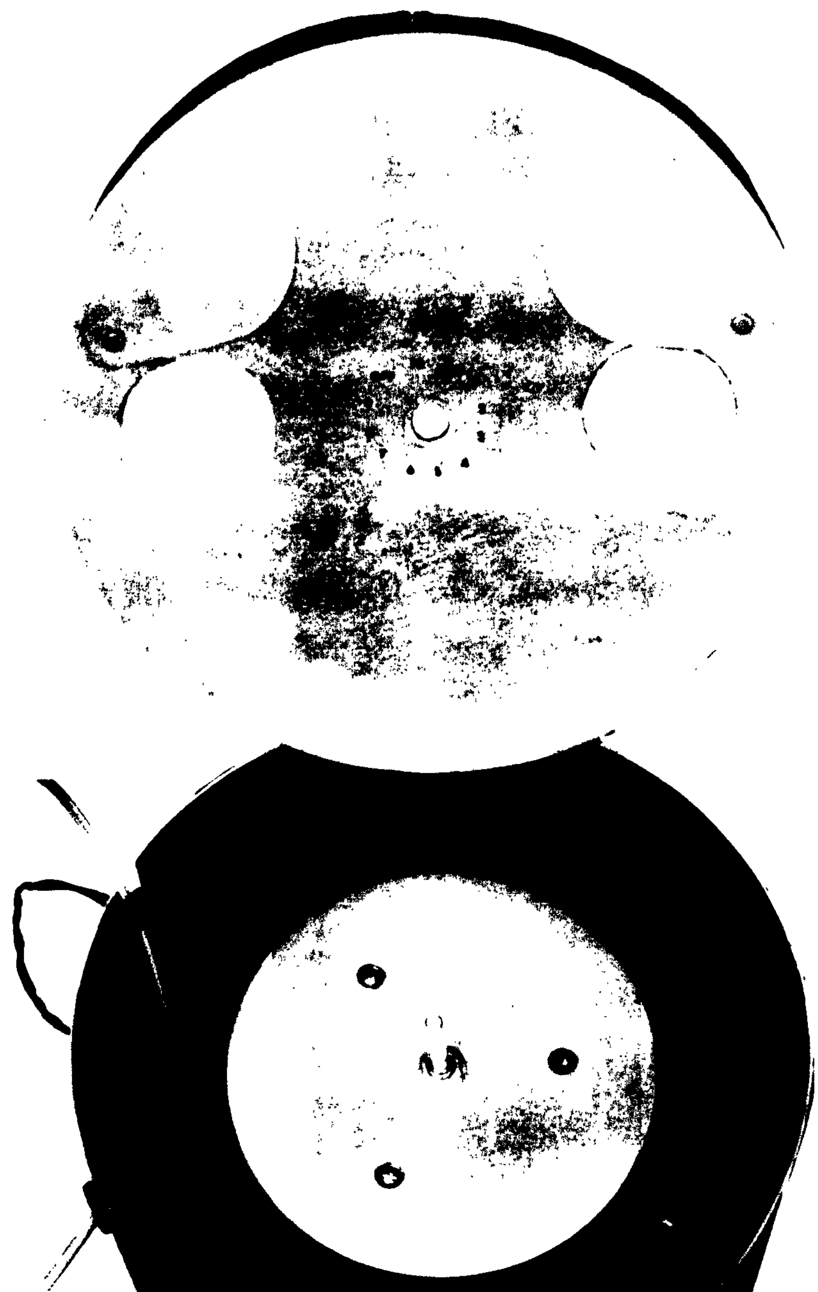
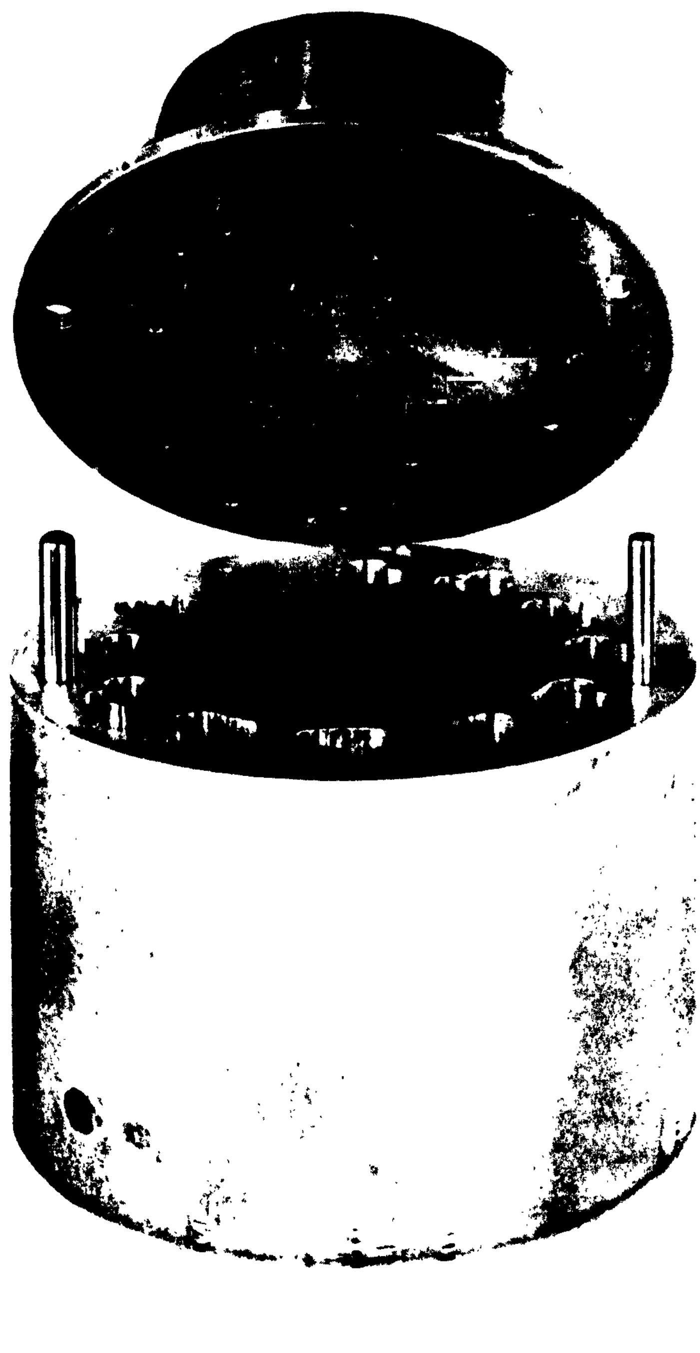
*It is possible to use a commercial bridge (such as the General Radio 1606A equipment) as the test transmission fixture in place of a pi or hybrid-coil fixture. In this mode of operation, the system is very sensitive to harmonic components of the signal and additional filtering has been found to be necessary in order to achieve high accuracy in measurement.

condition. The stability of the source frequency is determined by the crystal phase slope at the frequency corresponding to zero-phase (resonance) of the crystal. The amplitude detector reading under this condition is dependent upon the crystal effective resistance at resonance.



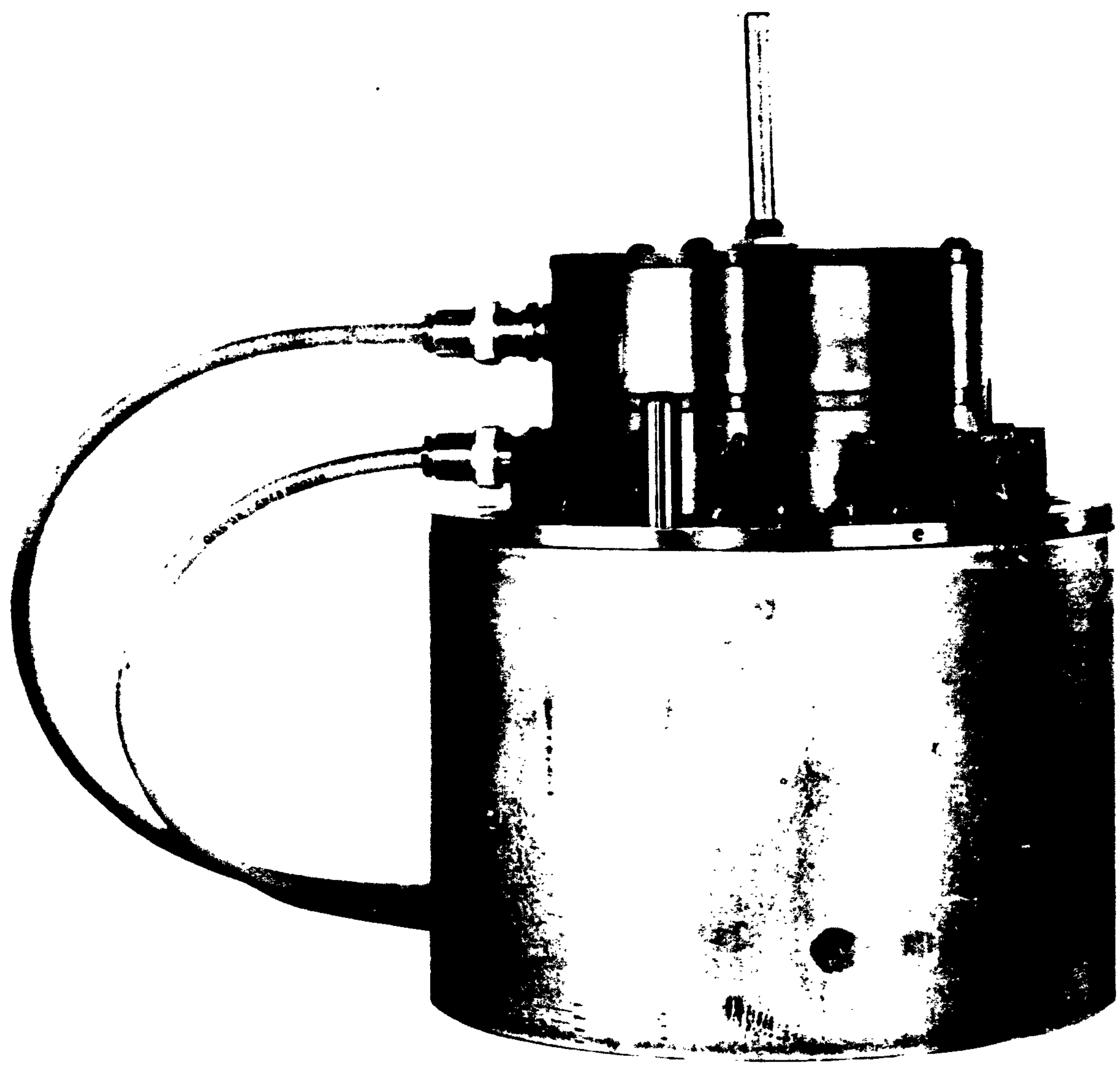
TOP VIEW
TEMPERATURE CHAMBER

FIG. 1.



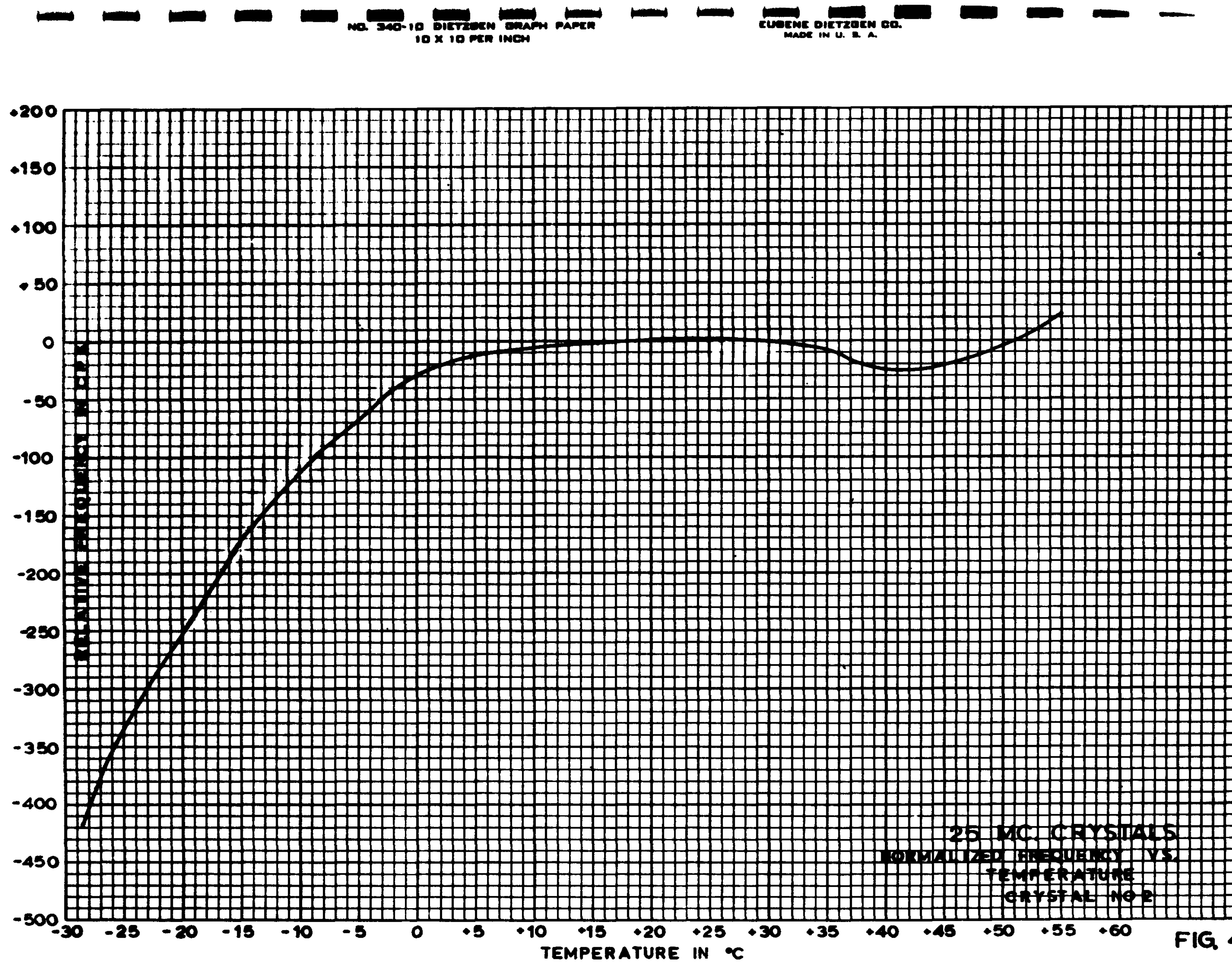
TEMPERATURE BLOCK
AND
SWITCH ASSEMBLY

FIG. 2.



SUB-ASSEMBLY TEMPERATURE BLOCK
AND
SWITCH ASSEMBLY

FIG. 3.



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RELATIVE FREQUENCY IN CPS
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+45
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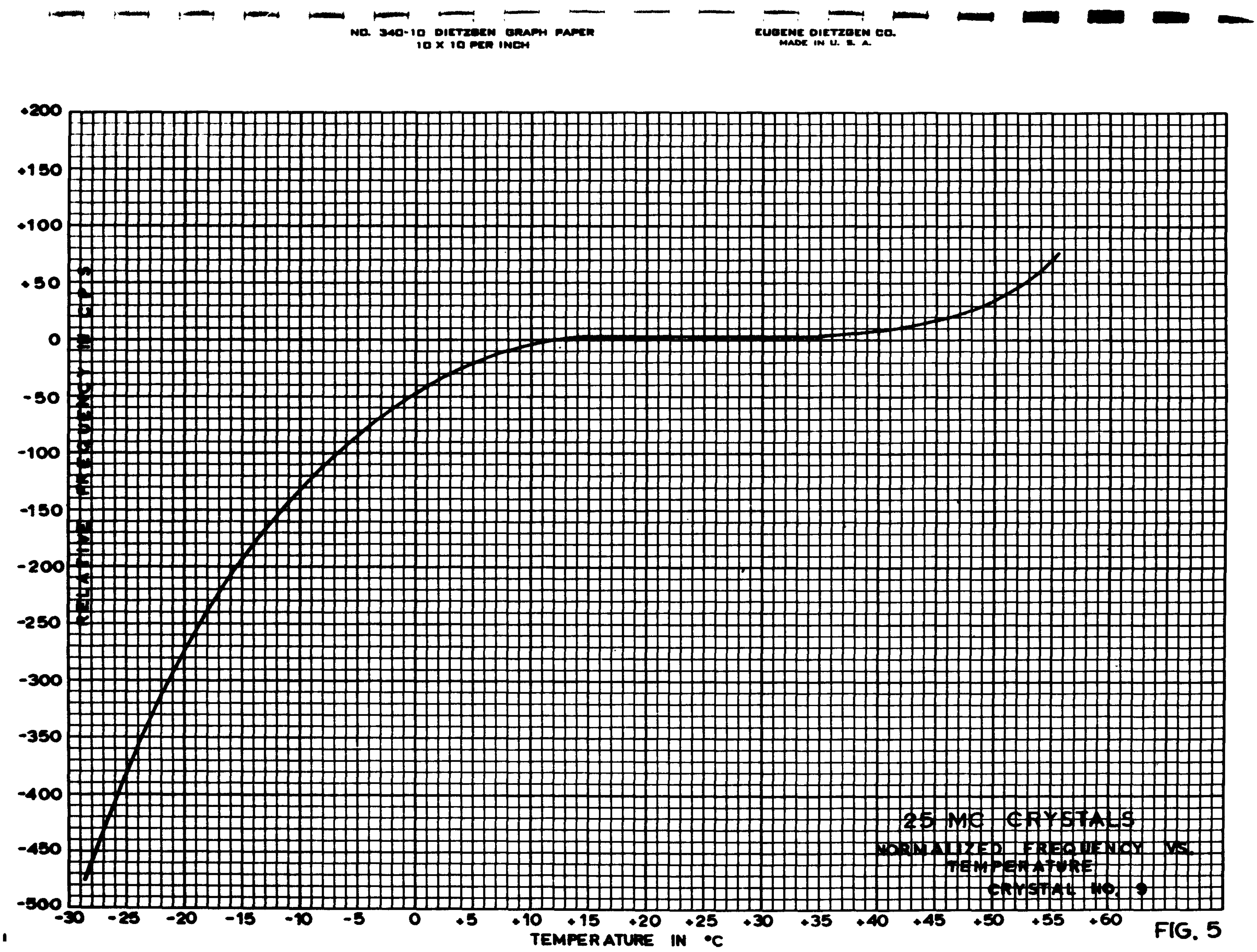
TEMPERATURE IN °C
25 MC CRYSTALS
NORMALIZED FREQUENCY VS.
TEMPERATURE
CRYSTAL NO 2

FIG. 4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+40
+45
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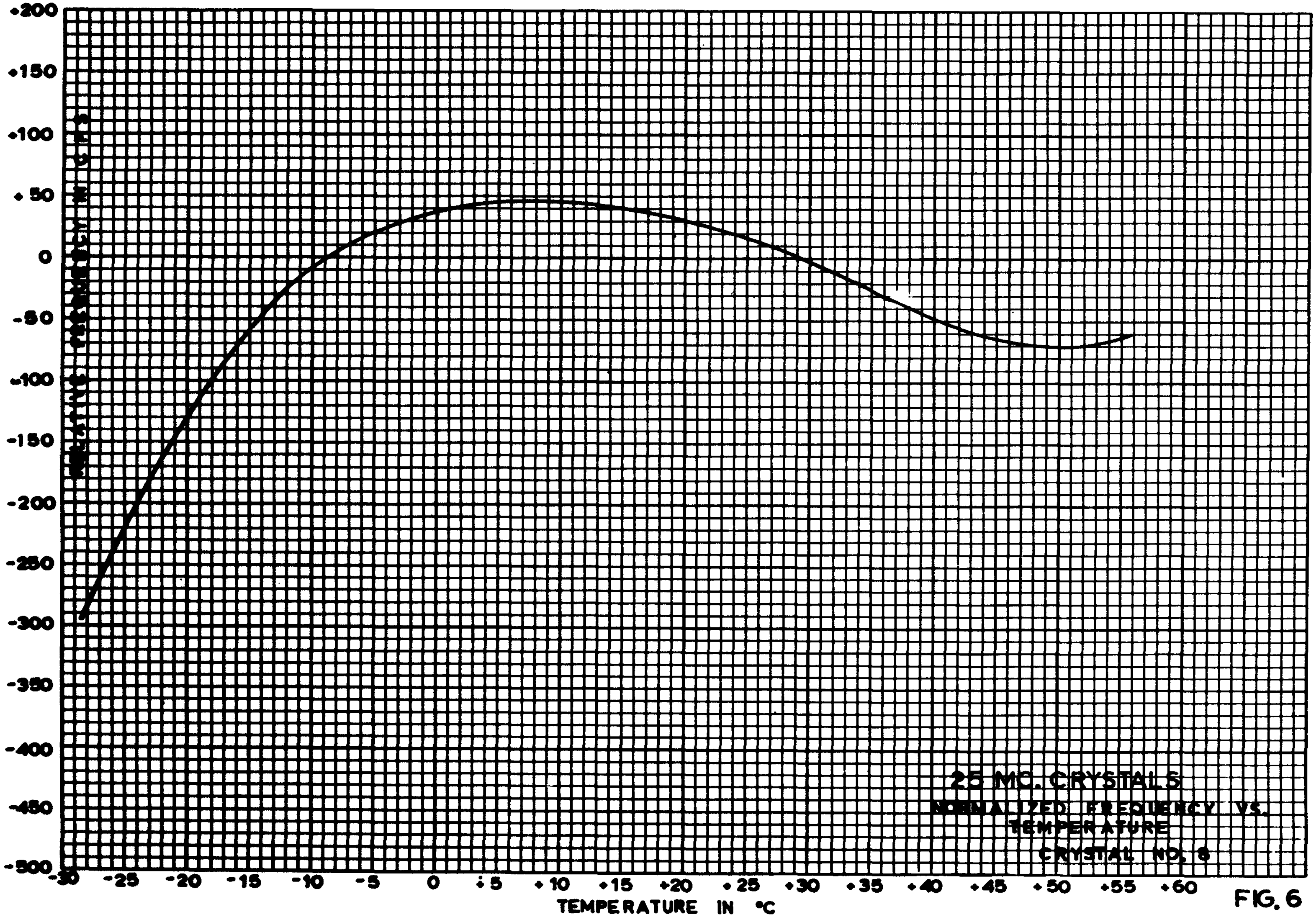
TEMPERATURE IN °C
25 MC CRYSTALS
NORMALIZED FREQUENCY VS.
TEMPERATURE
CRYSTAL NO. 9

FIG. 5



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+5
+10
+15
+20
+25
+30
+35
+40
+45
+50
+55
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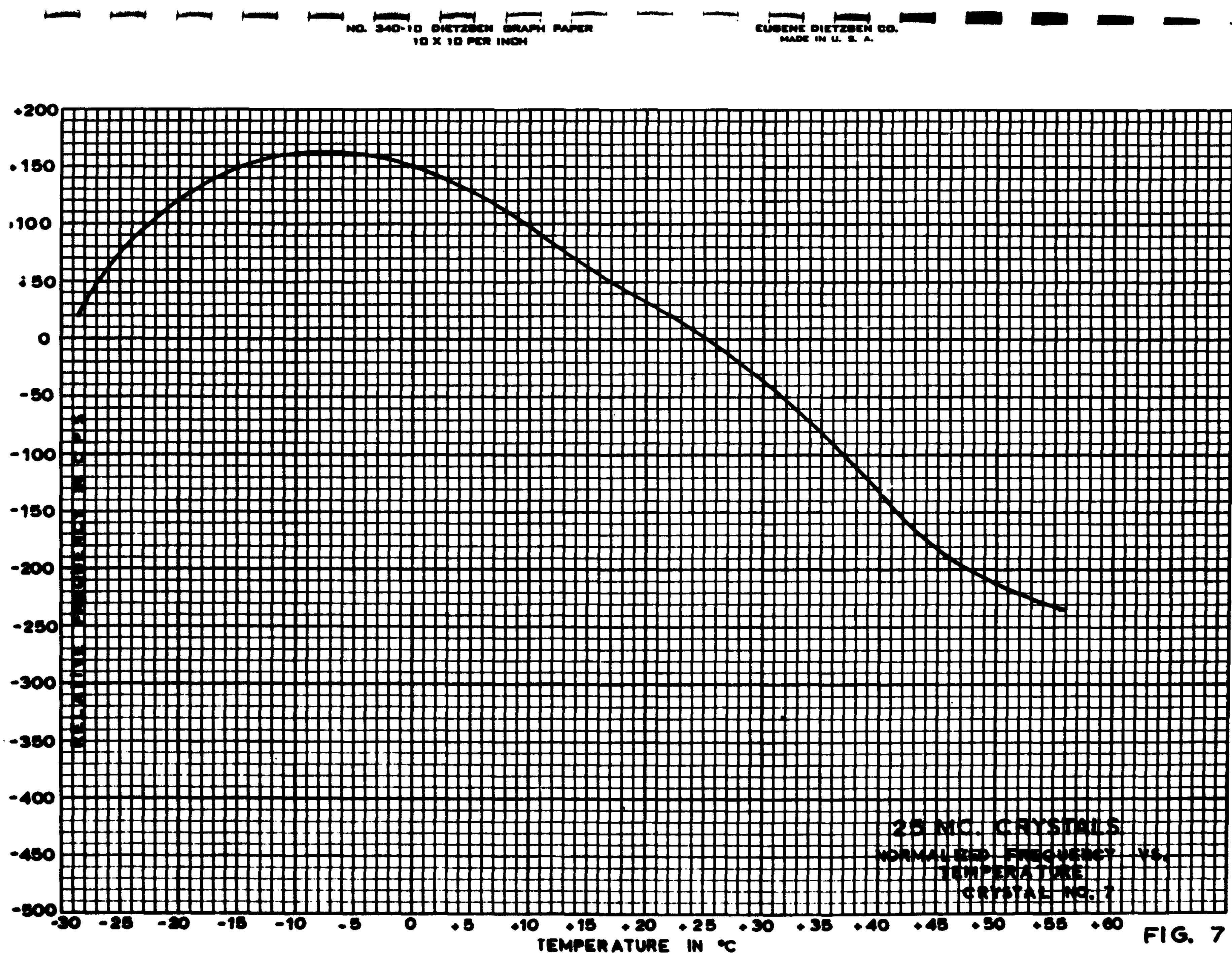
TEMPERATURE IN °C
25 MC. CRYSTALS
NORMALIZED FREQUENCY VS. TEMPERATURE
CRYSTAL NO. 6

FIG. 6



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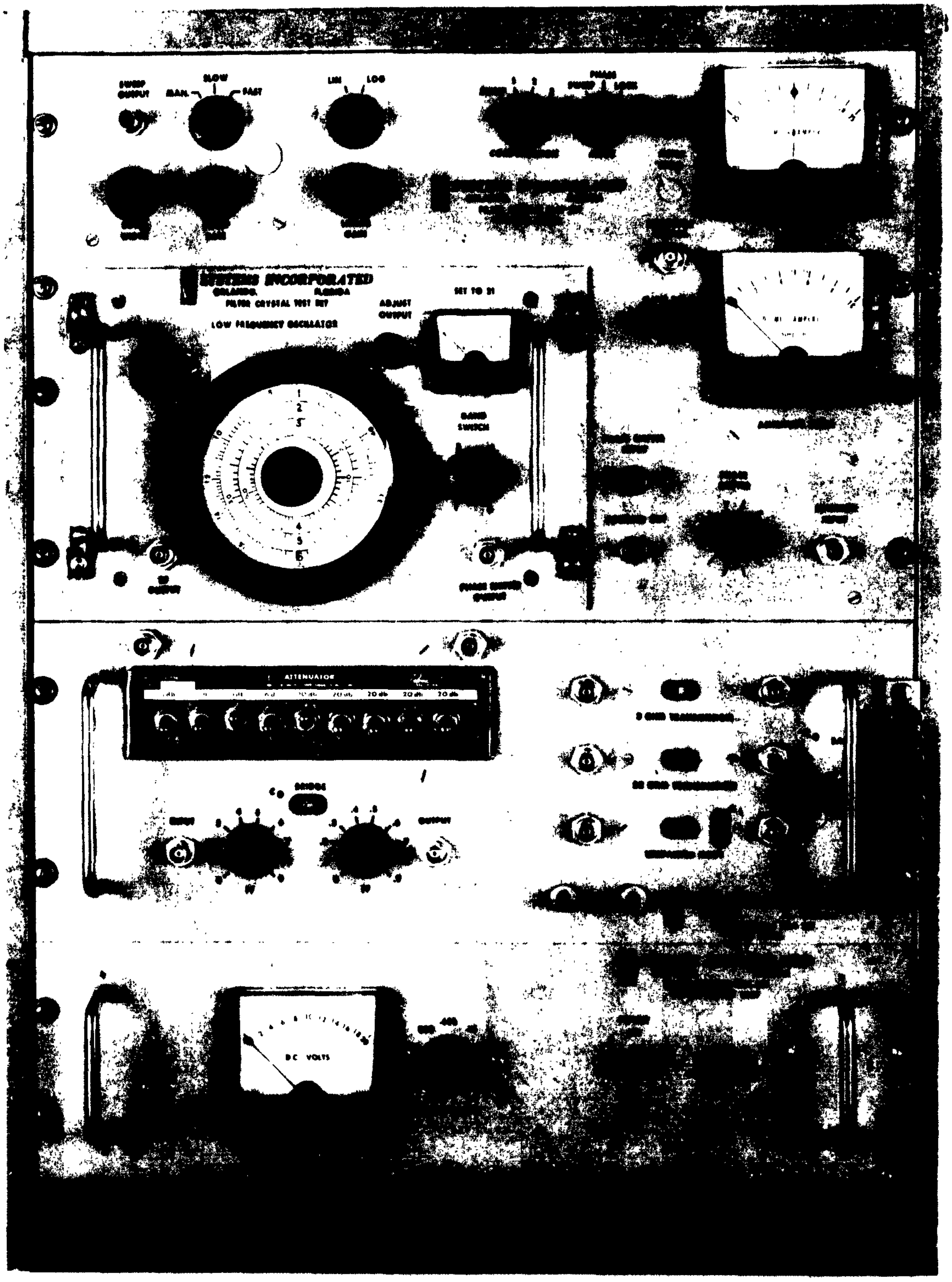
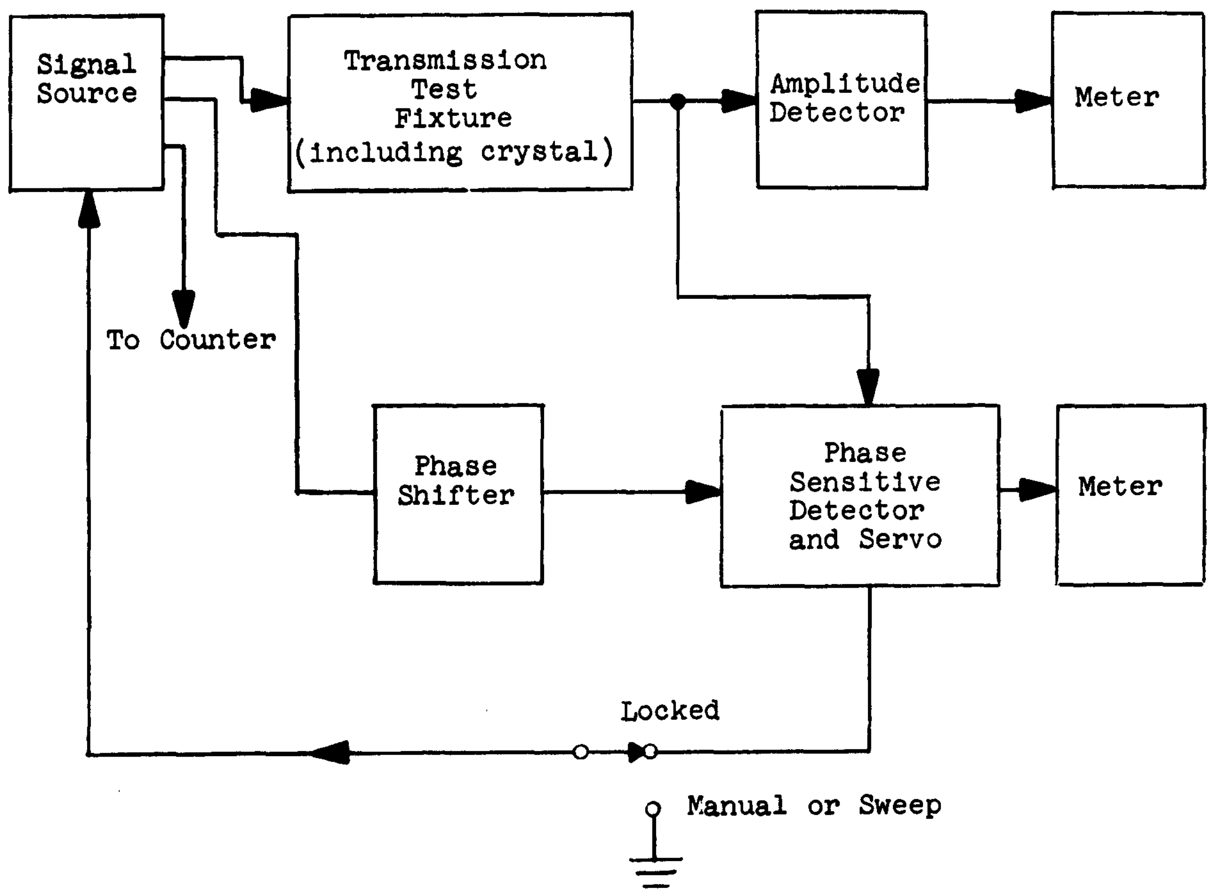
-500
-30 -25 -20 -15 -10 -5 0 +5 +10 +15 +20 +25 +30 +35 +40 +45 +50 +55 +60
TEMPERATURE IN °C
RELATIVE FREQUENCY IN C P S
25 MC. CRYSTALS
NORMALIZED FREQUENCY VS.
TEMPERATURE
CRYSTAL NO. 7

FIG. 7



FILTER CRYSTAL TEST SET

FIGA-1.



CRYSTAL TRANSMISSION TEST SET

Basic block diagram

Figure A-2

REFERENCES

[1] "Tighter Tolerance Crystal Units," Report No. 1 on Contract No. DA 36-039-AMC-02335(E), First Quarterly Progress Report, 15 June 1963 through 15 September 1963, Systems Incorporated, 15 October 1963.

[2] Gerber, E. A., and Koerner, L. F., "Methods of Measurement of the Parameters of Piezoelectric Vibrators," Proc. IRE, v. 46, no. 10, pp. 1731-1737; Oct. 1958.

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This contract is supervised by the Solid State and Frequency Control Division, Electronic Components Department, USAELRDL, Fort Monmouth, New Jersey. For further technical information, contact the Project Engineer, Mr. Lewis Nelson Telephone 535-2475 (New Jersey Area Code 201).

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~~SYSTEMS INCORPORATED~~

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By: W. H. Horton
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Second Quarterly Report
15 September through 15 December 1963

Contract No. DA 36-039-AMC-02335(E)
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