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THE FREQUENCY STABILITY OF PIEZO-ELECTRIC MONITORS

By JAMES K. CLAPP [*]

II

THE performance characteristics of a typical temperature-controlled piezo-electric oscillator will be considered with regard to the various factors listed in the first part of this article,[†] i.e., (1) temperature changes, (2) plate load, (3) tubes, (4) vibration, (5) supply voltages, (6) aging of circuit elements.

The data here presented cover the performance of the equipment when using typical quartz plates operating at frequencies in the broadcast band of from 500 to 1500 kc.[‡] The quartz plates were of the "30-degree" or "Y"-cut and were mounted in General Radio TYPE 376 Quartz-Plate Holders. The quartz plates and holders correspond to the production units classed as the TYPE 376-H Quartz Plates.

The changes in frequency, as observed, were referred to the frequency obtained when the assembly was operated under the conditions defined by:

"*Normal*" *operation*

Tube: Average UX-112A as determined by trial.
Temperature: 50° C.
Plate condenser: Set at lowest value for reliable oscillation.
Supply voltages: Filament 5.0 volts.
Plate 45.0 volts.

The observed frequency changes resulting from changes in any one variable, the others remaining constant, are indicated in the accompanying figures and are summarized below:

Temperature changes: (Figure 1)

The quartz plates employed were all of the "30-degree" or "Y"-cut type, having positive temperature coefficients, that is, the frequency of oscillation *increases* when the temperature of the plate is *increased*. The various plates did not differ widely in their temperature coefficients as indicated by the slopes of the curves of Figure 1. On the average, it should be noted from Figure 1, the variation in frequency for changes in temperature of ±0.1° C. (representing the control stability of a small temperature-con-

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[*] Engineer, General Radio Company.

[†] James K. Clapp, "The Frequency Stability of Piezo-Electric Monitors," *General Radio Experimenter*, V, October, 1930.

[‡] Kc. is here used to mean kilocycles per second.

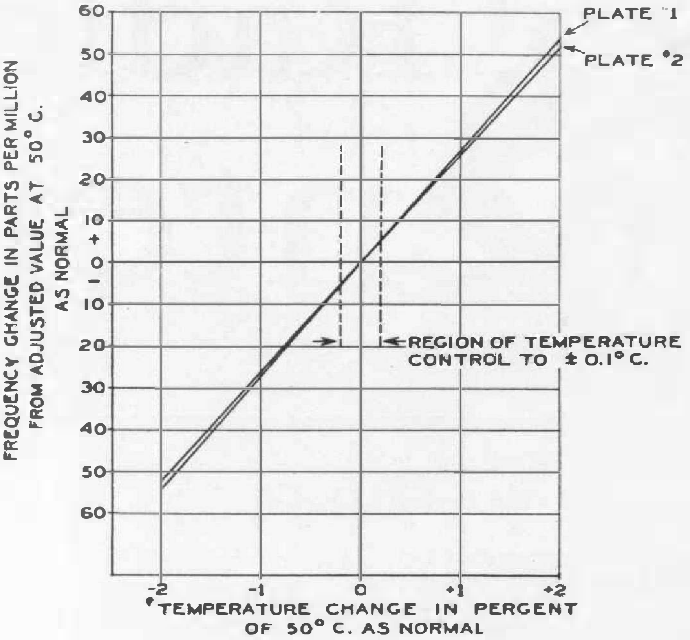


FIGURE 1. Variation in frequency of piezo-electric oscillator as function of temperature in region near 50° C.

trol unit of simple design) is within ±5 parts per million.

Plate-tuning changes: (Figure 2)

Other factors remaining constant, the frequency of oscillation is altered by changes in the tuning of the plate circuit of the tube. In the oscillator here employed (General Radio TYPE 575 Piezo-Electric Oscillator) the plate inductance is fixed and the capacitance is variable. The variations are plotted against per cent. of the higher value at which the system stops oscillating, which is practically the value at which the plate circuit is resonant to the crystal frequency. The frequency change resulting from the change of tuning capacitance is seen to be much more rapid as resonance is approached, that is, for the higher values of capacitance. As the driving tube circuits are not under temperature control in this case, it is desirable to operate the plate circuit in a manner to minimize the changes in frequency with any given change in the tuned circuit. For this reason, the assembly should always be operated with only enough capacitance to give reliable oscillation.

From the figure, it is seen that variations in the tuning capacitance of ±1.0 per cent. (resulting from arbitrary alteration of the condenser, or from aging or temperature effects) cause frequency changes of less than ±1 part per million.

Plate-voltage changes: (Figure 3)

Other factors remaining constant, changes in plate voltage produce the frequency changes shown in Figure 3. It is evident that minor changes in plate voltage produce very small changes in frequency. Within the region of ±1.0 volt from the normal of 45 volts, which is easily read on a small voltmeter, the frequency change is less than ±0.5 part per million. This change is not materially influenced by the setting chosen for the plate-tuning condenser.

Filament-voltage changes: (Figure 4)

Changes of filament voltage produce the changes in frequency shown in Figure 4. In this case, the frequency variation obtained depends upon the setting of the plate-tuning condenser to

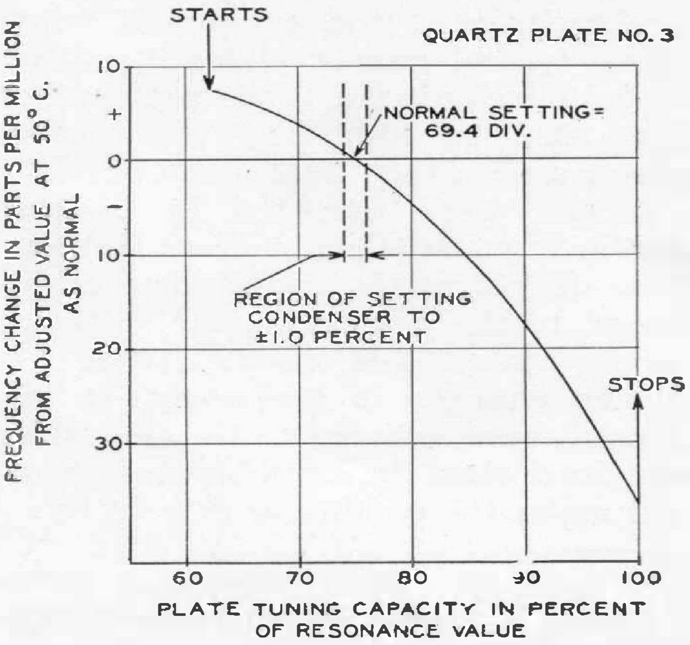


FIGURE 2. Variation in frequency of piezo-electric oscillator as function of plate-tuning-capacitance

some extent, but in the normal voltage region, the variations thus obtained are of no serious consequence. Within the region of ±0.1 volt from the normal of 5.0 volts (which is easily read on a small voltmeter) the frequency change is substantially less than ±0.5 part per million for all useful operating conditions in the plate circuit.

Tube changes: (Figure 5)

Changing tubes, each being operated under the "normal" conditions, results in frequency changes as shown in Figure 5. It is seen that four out of five tubes operate to give a frequency within ±2 parts per million of the value obtained with Tube No. 1.

Vibration

Ordinary vibration of buildings does not materially alter the frequency of the system. A violent pounding of the base of the assembly sometimes produces a momentary shift of frequency as great as 10 parts per million, but the shift remaining after the pounding is stopped is usually much less than this value. In the tests, the plate-holder was plugged into jacks rigidly mounted on the walls of the temperature-control unit, which in turn was rigidly mounted on the supporting base. In cases where unusual vibration exists, the frequency shifts may be reduced greatly by supporting the plate-holder in soft batting, making the connections through small flexible leads, instead of through the plugs and jacks.

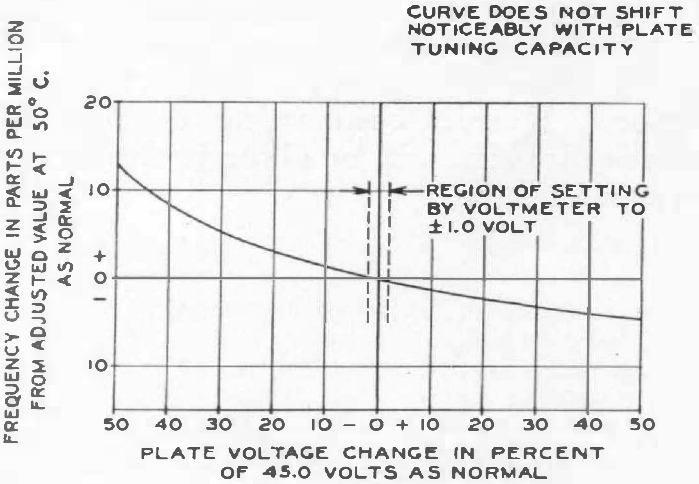


FIGURE 3. Variation in frequency of piezoelectric oscillator as function of plate voltage

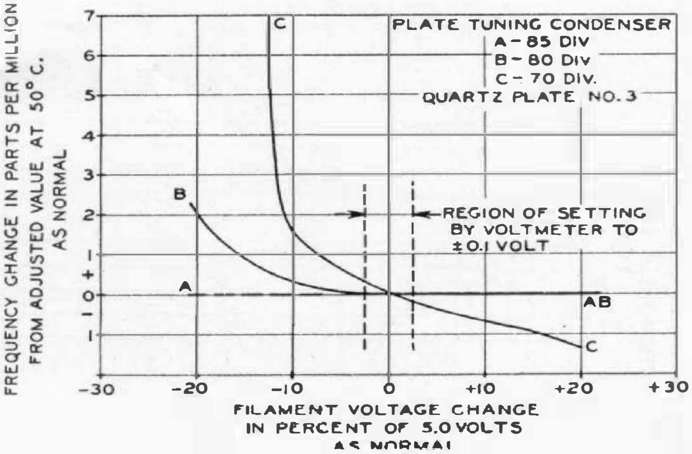


FIGURE 4. Variation in frequency of piezoelectric oscillator as function of filament voltage

Summary of All Effects

As an estimate of the absolute constancy of frequency of the system described, it may be assumed that all of the variations observed take place and that the effects are all in the same direction. Then we have the following summary:

Variable	*Range of Variation*	*Frequency Variation (parts per million)*
Temperature	±0.1°C.	±5
Plate capacity	±1.0 per cent.	±1
Plate voltage	±1.0 volt	±0.5
Filament voltage	±0.1 volt	±0.5
Tubes	(average)	±2
Vibration	(heavy shocks)	±3*
	Total	±12

* Remaining after shock.

This represents the range of frequency within which the type of oscillator considered would be expected to operate under practical service conditions. There is every reason to expect some of these effects to offset others under average conditions, even if the variables are altered by the full range indicated. If the variables are not al-

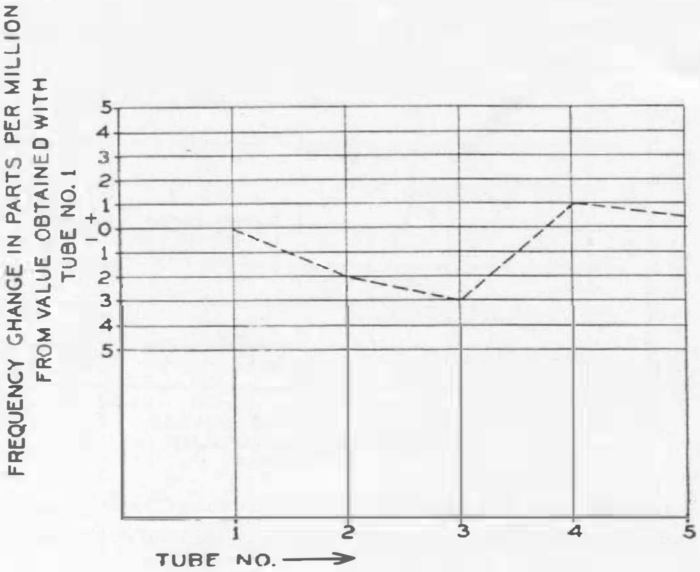


FIGURE 5. Variation in frequency of piezo-electric oscillator for different tubes, each operated under "normal" conditions

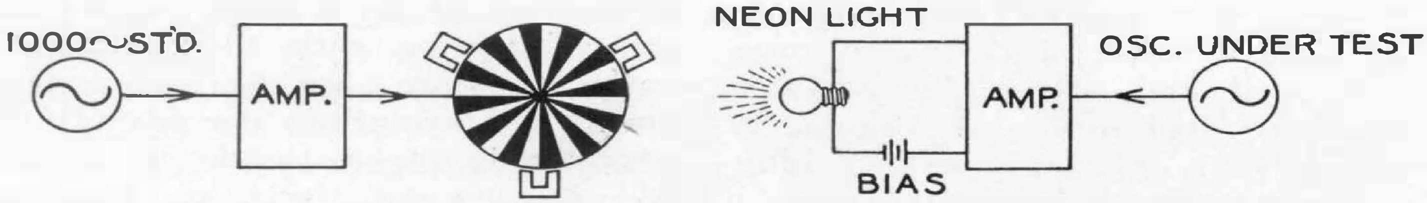
tered by the full range indicated, the frequency variation would naturally be reduced. All things considered, it seems reasonable to expect the frequency variations under service conditions to be less than ±10 parts per million. It should be borne in mind that the above conclusions are based entirely upon the premise that the oscillator system is operated at a *low power level* and that it is employed *only as a substandard or a heterodyne monitor*, that is, it is operated with such weak coupling to any associated apparatus that the effects of such equipment on the performance of the oscillator are entirely negligible. The conclusions refer only to the *variation* in frequency from the *adjusted value* and have no bearing on the accuracy of adjustment to a specified frequency.

It is believed that the effects of aging of any of the circuit elements, with the exception of the quartz plate and holder, can result only in changes of frequency of the order of magnitude encountered when arbitrary changes are made in these elements. Aging of the quartz-plate holder introduces, in the type of holder here used, very small changes in frequency which for the purposes under consideration are negligible. There seems to be little evidence that any aging effect takes place in the quartz plate itself. Changes in frequency which are often laid to this cause are undoubtedly due to changes in the plate-holder and not to changes in the quartz plate.

The combined piezo-electric oscillator and temperature-control unit (TYPE 575) used in this work is very well adapted for use as a simple laboratory standard. For such uses, it is convenient to employ a 100-kc. quartz plate. As these plates give somewhat different performance than plates in the broadcast-frequency range, data pertaining to them will be presented in a later article. Harmonics of the crystal frequency are available for calibration or monitoring purposes over a wide frequency range. In cases where it is desired to obtain calibration frequencies at intervals of less than 100 kc., use may be made of a multivibrator (such as the TYPE 592) of lower fundamental frequency, controlled by the 100-kc. crystal oscillator. By adjustment of the multivibrator a very large number of calibration frequencies may be obtained. Details concerning the use of the equipment will be given in the forthcoming article.

A STROBOSCOPIC FREQUENCY METER

By L. B. ARGUIMBAU [*]



24 FIGURE 1

8 = 12
12

AT the time the range of the General Radio low-frequency oscillator was extended to 25 cps.,[†] the need for more accurate and convenient methods of measuring audio frequencies made itself felt. After some consideration of other methods,[‡] it was decided to arrange for the stroboscopic comparison of unknown frequencies with a single primary standard. The method has proven so convenient that we believe a description of the details may be of interest.

In a previous issue of the *General Radio Experimenter*[§] a description was given of synchronous motors which can be driven by 60-cps. and by 1000-cps. signals. A motor of this type provides a shaft whose speed is determined exactly by the driving frequency. Thus, by its use a disc can be obtained whose angular speed is known with the precision of the source frequency.

It is well known that if any such rotating disc is illuminated solely by a light which flashes once every rotation, the disc will appear stationary, for the images received by the eye all correspond to one position. Similarly, if the wheel has n spokes spaced uniformly and is illuminated n times every revolution, it will again appear to stand still, since in this second case the images will all be seen when the spokes are in similar positions. An extension of this argument will show that a wheel of n spokes illuminated with a lamp flashing $(a \text{ x } n)$ times during each revolution will appear like a wheel having $(a \text{ x } n)$ spokes (where a is any integer). Similarly, if the lamp flashes n/b times per revolution (b is an integer), the wheel will still appear to have n spokes. In fact, if the light flashes any rational number a/b times per spoke period, the wheel will appear to have $(a \text{ x } n)$ spokes.[‖] A brief consideration will show that if the frequency of the light flash differs from $k\left(\frac{na}{b}\right)$ by $1/b$ cps., the $(a \text{ x } n)$ spoked pattern will appear to revolve at a rate of one spoke per second, where k is the speed of the wheel in revolutions per second.

Having these well known facts in mind, an obvious method of frequency adjustment presents itself, namely, the comparison of a lamp driven by an

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[†] Cps. is here used to mean cycles per second.

[‡] E.g., the use of calibrated tuned circuits and reeds, and Braun tube or string oscillograph comparisons with low frequencies derived from a primary standard.

[§] Harold S. Wilkins, "Synchronous Motor-Driven Clocks," *General Radio Experimenter*, V, October, 1930.

[‖] Provided, of course, that there is sufficient contrast to make the partially overlapping fringes visible. Practically this requires that a and b be small integers. Under favorable conditions a may be as high as 5, b as high as 10.

unknown source with an appropriate disc. For example, if a disc rotating at 10 revolutions per second is available and it is desired to set an oscillator at 300 cps., it is merely necessary to illuminate a wheel of 30 spokes once each cycle and adjust the oscillator until the spokes appear stationary. Such a flashing light can be readily secured by using a neon lamp biased so that it flashes only during a very small part of a half-cycle. A suitable arrangement for realizing the above condition is shown in Figure 1.

In our case it has been found most convenient to use the 1000-cycle output of a General Radio standard-frequency assembly * as a primary standard. Occasionally, however, other standard sources have been used.† Instead of using a spoked wheel several graduated discs have been made up each answering a specific frequency requirement. Two such discs (reduced in size) are shown in Figure 2. It will be noted that disc *A* covers a very wide range of frequencies, giving a large number of points. Starting with 10 cps. direct comparisons are possible (with a disc turning 10 revolutions per second) at 10-cps. intervals up to 100 cps. After this, direct comparisons are possible every 100 cps. up to 1000 cps., and then (with the exception of 1500 cps.) every 500 cps. up to 5000 cps. In addition to these fundamental points, all low rational fractions of these frequencies are available. Thus we have patterns for every 5 cps. up to 50 cps. and every 20 cps. from 100 cps. to 200 cps., etc.; likewise, all even kilocycle points up to 10 kc. are available. As a matter of fact, it is frequently more convenient to use such multiple patterns than it is to use the fundamentals. For example, when the lamp is lighted from a 60-cps. line, the 300-cps. pattern is immediately noticed, as well as the 60-cps. pattern; rotation of one spot in ten seconds for the 300-cps. pattern indicates a departure of 0.02 cps. or 1/30 of 1 per cent. in the line frequency. Disc B has been found very convenient for use in calibrating low-

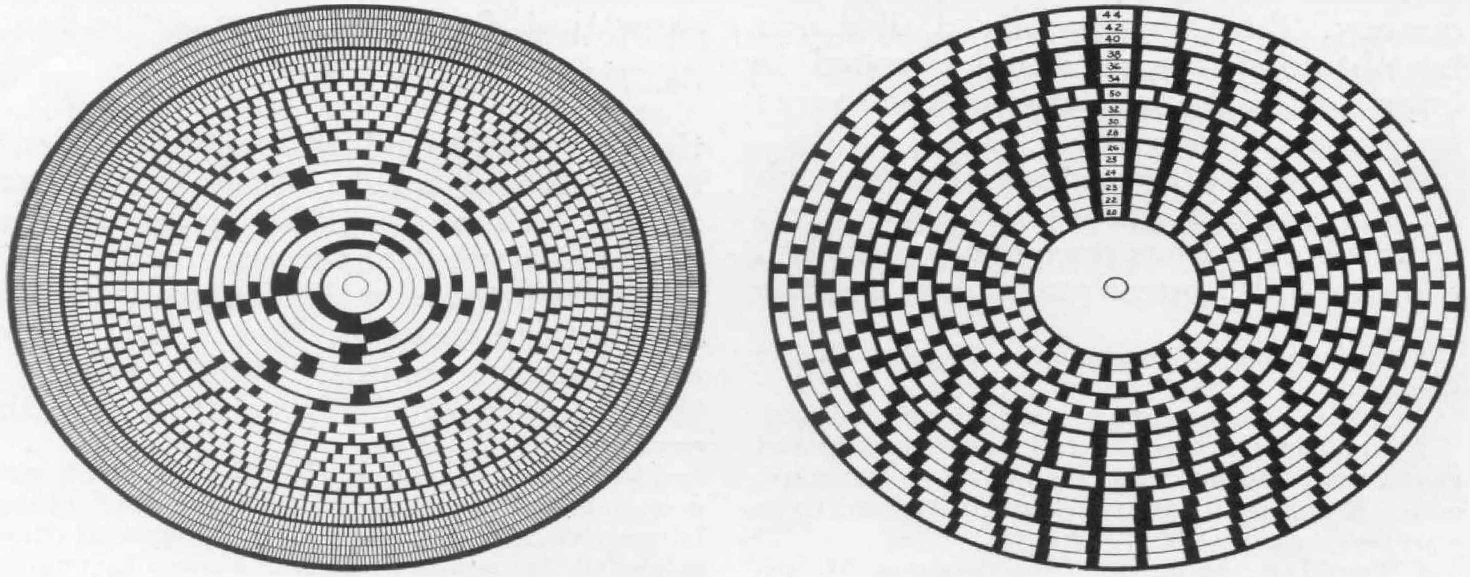

FIGURE 2. Typical 8-inch discs used with the frequency meter. Disc A (left) is for general use over the entire audio-frequency spectrum; Disc B (right) is very useful at commercial frequencies

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* James K. Clapp, "Frequency Determination," *General Radio Experimenter*, Vol. 3, March, 1929; "A New Frequency Standard," *General Radio Experimenter*, Vol. 3, April, 1929. See also L. M. Hull and J. K. Clapp, "A Convenient Method for Referring Secondary Frequency Standards to a Standard Time Interval," *Proceedings of the I. R. E.*, Vol. 17, February, 1929.

† Horatio W. Lamson, "Electrically-Driven Tuning Forks," *General Radio Experimenter*, V, September, 1930.

frequency tuning forks since a large number of such multiples are present. By its use in conjunction with a stop watch, any preassigned frequency in a restricted commercial range can be measured directly in terms of the primary 1000-cps. standard.

In addition to these discs, all of which operate on reflected light, a few have been made for use with transmitted light. Several factors, such as the relative size of the absorbing and reflecting sectors, the use of reflected or transmitted light, the effect of motor "hunting" and of disc irregularities, and the duration of the light flash had to be considered in design, but are hardly of sufficient interest to be mentioned here.

Several stroboscopic frequency meters have been built for experimental use in the General Radio laboratories. The first model which is in service in the calibration laboratory includes self-contained amplifier circuits and is intended for operation on a laboratory work bench. Another, also with self-contained amplifier, has been mounted on a castered table so that it can be used wherever needed.

FIGURE 3. This synchronous motor is portable and connected to subsidiary amplifier circuits by a flexible cable. The disc makes use of transmitted light

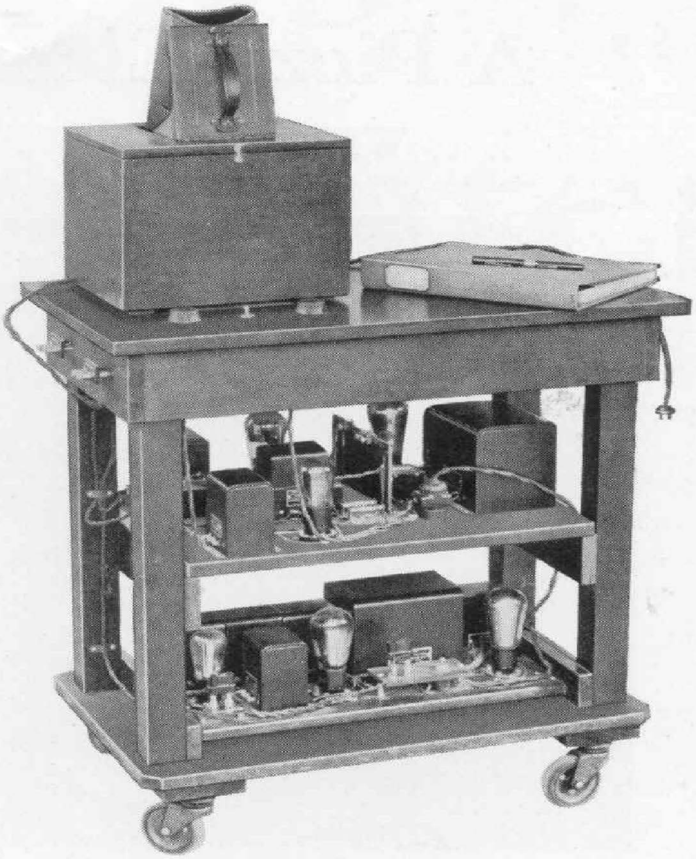

FIGURE 4. An experimental model of the stroboscopic frequency meter. Amplifier and power-supply circuits have been assembled with the synchronous motor on a castered table

In passing, it might be mentioned that a modified stroboscope has recently been built to provide a direct comparison between the primary standard and seconds pulses from a pendulum clock. This is done by watching the change in position of a single reflecting sector between successive seconds flashes.

Thus by the use of a synchronous motor in conjunction with a single standard it is possible to cover the range of audio, commercial, and finally of clock frequencies.

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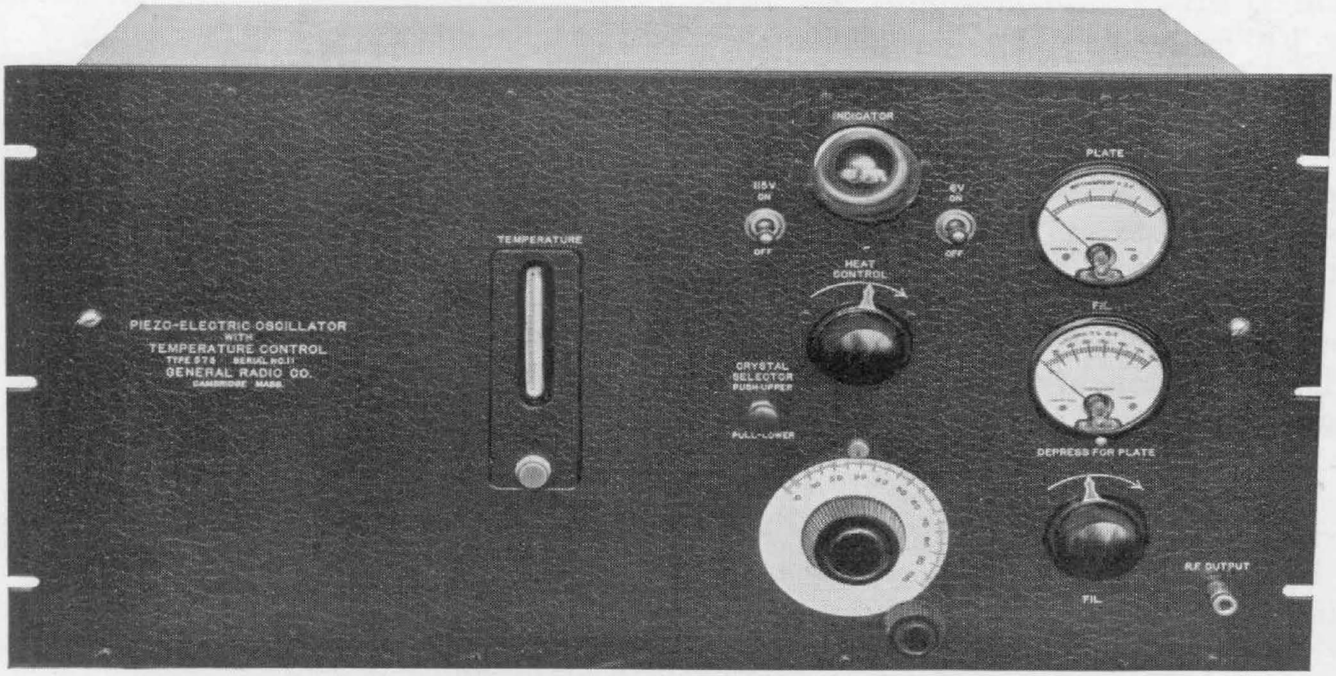
A Piezo-Electric Oscillator

WITH TEMPERATURE CONTROL



Type 575-A Piezo-Electric Oscillator with Temperature Control

THE temperature-controlled piezo-electric oscillator used by J. K. Clapp in the work on quartz plates described in this issue of the *Experimenter* is now commercially available. It consists in effect of a Type 275 Piezo-Electric Oscillator and a Type 547-A Temperature-Control Box assembled on a single panel for relay-rack mounting.

The characteristics of the new instrument are essentially the same as for the two individual instruments which were described on pages 57 to 59 of Catalog F. The assembly in a single unit, however, greatly improves the stability with which frequency can be maintained. Danger from mechanical vibrations has been reduced and essential leads have been materially shortened.

So effective is the new unit that users of General Radio Type 376 Quartz Plates and the Type 575-A Piezo-Electric Oscillator with Temperature Control may expect to maintain frequency to within about ten parts in a million.

Price $190.00

(without quartz plate, tubes, or battery)

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