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DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
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USE OF STANDARD FREQUENCY TRANSMISSIONS IN CHECKING STANDARD OSCILLATORS.

This pamphlet gives methods of frequency measurement for utilizing the standard frequency signals transmitted by the National Bureau of Standards. The references at the end give other methods, which range from those using very simple apparatus giving results accurate to one per cent, to those using complicated and expensive apparatus giving results accurate to better than a part in a million.

Radio Signals of Standard Frequency.- The National Bureau of Standards transmits standard-frequency signals, for adjusting and calibrating frequency standards and other apparatus, one day each week from the Bureau's station, WWV, in a suburb east of Washington, D.C. These weekly transmissions are by continuous-wave telegraphy at 5000 kilocycles, and are accurate at all times to better than 1 cycle per second (1 part in 5,000,000). Announcements of details of the schedules of transmission are given in the newspapers and radio magazines and in the Bureau of Standards Technical News Bulletin and the Radio Service Bulletin. Copies of the current schedule may also be obtained upon request from the Bureau of Standards, Washington, D.C. At the date of this pamphlet, the transmissions are made every Tuesday, continuously from 2 to 4 P.M., and from 8 to 10 P.M., Eastern Standard Time.

The transmissions consist mainly of continuous, unkeyed carrier frequency. For the first five minutes the general call (CQ de WWV) and announcement of the frequency are transmitted. The frequency and the call letters of the station (WWV) are given every ten minutes thereafter.

Method of Measurement

The commonest use of the standard frequency transmissions is to determine accurately the frequency of a piezo oscillator. The apparatus necessary is (1) the piezo oscillator, (2) a continuously variable radio-frequency generator which is approximately calibrated, (3) an audio-frequency generator, and (4) a radio receiver. A frequency meter of resonance type is also useful as an auxiliary but is not necessary.

The fundamental frequency of a piezo oscillator is fixed by the dimensions of the quartz plate used. The vacuum-tube circuit arrangement in which the quartz plate is connected gives numerous harmonics for each fundamental frequency. The generator, which is continuously variable, can be adjusted to any frequency, and likewise gives a series of harmonics for each fundamental frequency to which it is adjusted. If the frequency of the radio-frequency generator is varied over a wide range, beat notes are produced at a number of settings of the generator by the interaction of various harmonics of the fundamental frequency of the piezo oscillator with a harmonic of the fundamental frequency of the generator. The beat notes may be heard in a pair of head phones suitably connected to the generator or to the piezo oscillator. Any frequency present in the piezo oscillator can beat with a corresponding frequency present in the radio-frequency generator, which makes it possible to set the generator at a number of frequencies which are directly related to the fundamental frequency of the piezo oscillator. Providing the harmonic relationship is known, measurements can be made at a great number of frequencies in terms of a single standard frequency.

If f is the fundamental frequency of the piezo oscillator which is being used and F the fundamental frequency of the auxiliary generator which gives zero beat, then

$$af = bF$$

where a and b are integers (1, 2, 3, 4, etc.)

The procedure is simplest when the ratio of 5000 kc to the nominal frequency of the piezo oscillator to be standardized is a fairly small integer, less than 100. For instance, secondary standards whose fundamental frequencies are 50, 100, 200, 500, or 1000 kc can be measured very readily in terms of the 5000-kc transmissions, and these secondary standards may be advantageously used in turn to calibrate other apparatus. It is however possible to use the 5000-kc signals to establish accurately any desired frequency.

Examples of Measurement Method

Suppose it is required to measure the frequency of a piezo oscillator, the approximate frequency of which is 700 kc, in terms of the 5000-kc standard frequency signals.

If the radio-frequency generator is set at 100 kc, the 50th harmonic (5000 kc) will beat with the 5000-kc transmission, and the 7th harmonic (700 kc) will beat with the fundamental of the piezo oscillator.

The 5000-kc standard frequency signal is received first and identified with the receiving set in the generating condition. The radio-frequency generator is then turned on and adjusted to near 100 kc. This should give a beat note with the frequency generated by the receiving set. The regeneration of the receiving set is then reduced until the set just stops generating. A beat note should then be heard which will in general be of less intensity than that previously heard. This is the beat between the frequency of the radio-frequency generator and the frequency of the incoming wave. This beat note should be reduced to zero frequency by adjusting the radio-frequency generator. For most precise work this adjustment should be made by using a beat frequency indicator or other means of indicating exact zero beat. A simpler and equally accurate substitute is to bring in a tuning fork as described below. However, for a simple discussion of the steps involved in the measurement, it will be assumed that an accurate zero-beat setting is obtained.

The radio-frequency generator is therefore precisely adjusted so that it has a frequency of 100 kc. Without changing its adjustment, couple the piezo oscillator to it loosely. A beat note should be heard in the telephones in the output of the piezo oscillator unless the frequency given by the piezo oscillator is an exact multiple of 100 kc. Suppose, for example, it is 700.520 kc. In this case a beat of 520 cycles per second will be heard. To determine the value of this note, the audio-frequency generator must be used.

The frequency of the beat note and the frequency of the audio-frequency generator may be compared by using single phone units from each source and rapidly interchanging them at the ear. If sufficient intensity is available from the two sources then the two audio frequencies will combine and beats may be heard by the ear when the audio-frequency generator is closely adjusted. For exact zero beat the frequency of the adjustable audio-frequency generator gives the difference in frequency between the 7th harmonic (700 kc) of the generator adjusted to 100 kc and the fundamental of the piezo oscillator.

Fig. 1 gives a diagrammatic representation of the frequencies used. It is necessary to determine whether the piezo oscillator is higher or lower than 700 kc. This can be done by varying the frequency of the radio-frequency generator. If increasing the frequency of this generator results in decreasing the beat note, then the piezo oscillator is higher than the reference frequency, that is, the audio frequency is to be added to 700 kc. If the reverse is true, then the audio frequency is to be subtracted.

Use of Audio-Frequency Note in Measurement

A change in the method described above which does not require a beat indicator, is to adjust the radio-frequency generator to have a known frequency difference with the incoming wave by means of matching with that of a tuning fork of known frequency such as 1000 cycles per second. This method is more complicated in calculation because a record must be made (1) as to whether the radio-frequency generator was adjusted higher or lower than zero beat, (2) the frequency difference, and the harmonic relations between, (3) the standard signal and the radio-frequency generator, and (4) between the radio-frequency generator and the piezo oscillator. The harmonic relations, however, come in to any method of measurement of this kind. The measurements involving the use of the tuning fork for adjusting the generator to give a beat note 1000 cycles per second below the 5000-kc signal would be made as follows, and are shown diagrammatically in Fig. 2. Set generator from approximate zero beat at 100 kc to 99.98 kc. The 50th harmonic is 99.98 x 50 = 4999.0 kc (beats with 5000 kc in receiver which is not oscillating and gives a 1000-cycle note). The 7th harmonic of the generator (99.98 x 7 = 699.86 kc) may now be heard beating in the telephones of the piezo oscillator which is known to be approximately 700 kc. If this value were exactly 700 kc, a note of 700-699.860 kc or 140 cycles would be heard. However, the beat note produced is matched with a corresponding note from the audio-frequency generator. If the piezo oscillator had the frequency of 700.520 kc as assumed previously, the audio-frequency note measured would have been 700.520-699.860 = 0.660 kc or 660 cycles per second.

Whether to add or subtract the audio note of 660 cycles to the known frequency of 699.860 kc would be decided as follows when the radio-frequency generator was set lower than the standard frequency signal. If lowering the frequency of the radio-frequency generator increases the beat note (660 cycles in this case), add the beat note frequency, or if increasing the frequency of the radio-frequency generator decreases the beat note, add the beat note frequency.

Fig. 1

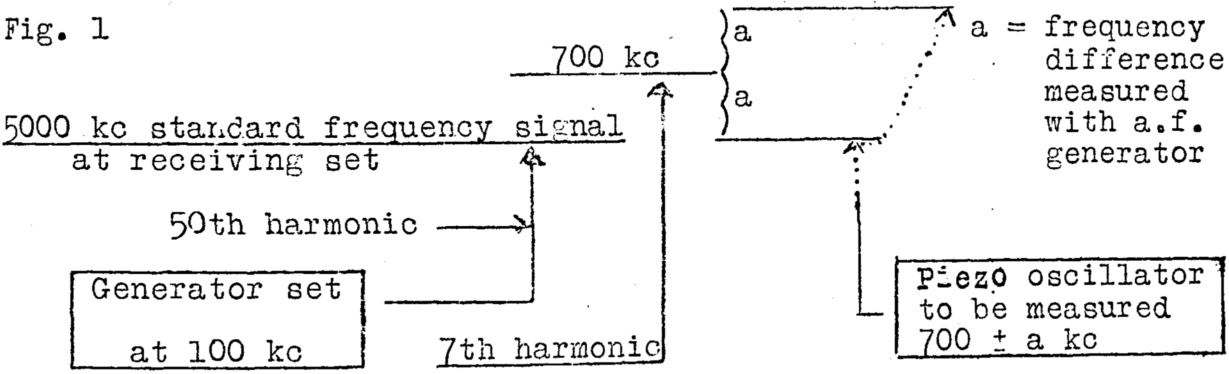


Fig. 2

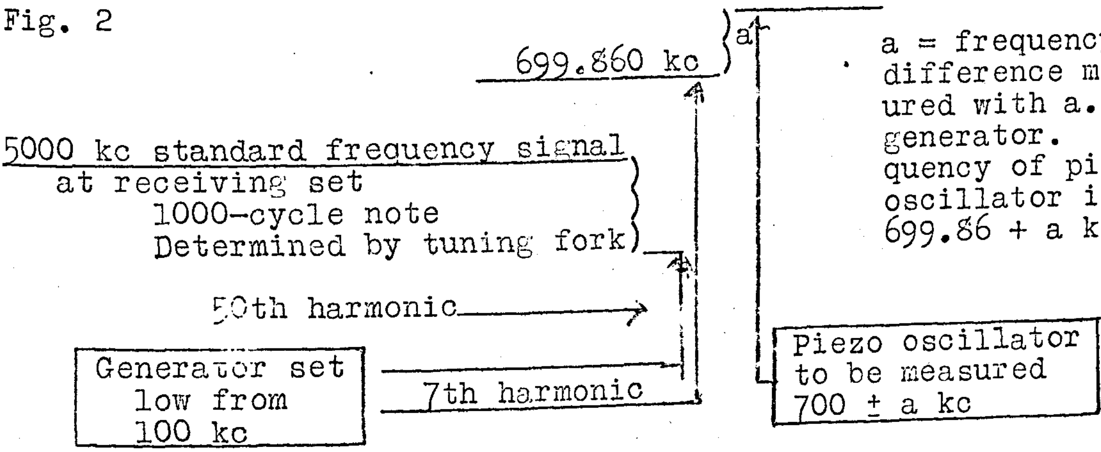
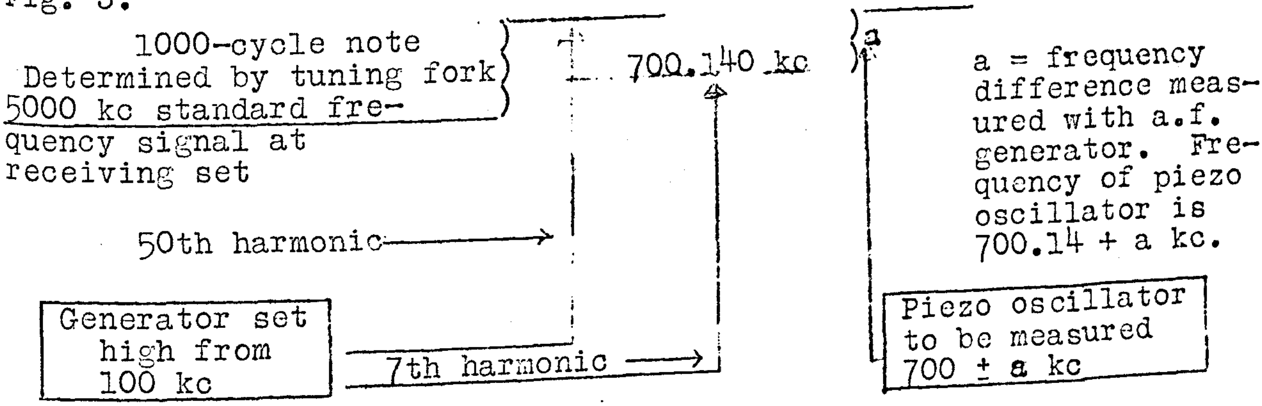


Fig. 3.



The measurement could also be made by adjusting the generator to 100.020 kc using the thousand-cycle tuning fork, as in Fig. 3. The 50th harmonic is 100.020 x 50 = 5001 kc which beats with the standard frequency signal of 5000 kc and produces a 1000-cycle note. A certain audio-frequency note is produced in the telephones of the piezo oscillator, which is matched with a similar note from the audio-frequency oscillator as before. If lowering the frequency of the radio-frequency generator reduces the audio-frequency note heard, subtract it from the known frequency of 700.140 kc, or if increasing the frequency of the radio-frequency generator increases the audio note, subtract it. The audio-frequency note heard with a piezo oscillator having the assumed frequency would be 380 cycles, hence 700.14 + 0.380 = 700.520 kc.

The example which has been cited is one of the simplest cases which would be encountered. The frequency of 700 kc which bears a comparatively simple relationship to the 5000-kc standard frequency signal, was selected to indicate the fundamental method. In order to be able to measure any broadcasting frequency in terms of the 5000-kc standard frequency signal it is necessary to set the radio-frequency generator to approximately 10 kc and then proceed as before. In this case the beat between the 500th harmonic of the 10-kc generator and the 5000-kc standard frequency signal is so weak that it is almost inaudible unless considerable audio-frequency amplification is used. In order to strengthen the beat note, two radio-frequency generators can be used, one set on 100 kc and the other on 10 kc. The 100-kc generator is coupled to the receiving set as indicated, and the 10-kc generator is set by means of a visual beat indicator so that its 10th harmonic (100 kc) produces a zero beat with the 100-kc generator. One of the manual adjustments can be eliminated by using a multivibrator which steps the 100 kc down to 10 kc, in place of the 10-kc generator. The accuracy of the measurements will be considerably improved if this is done.

The methods described above are capable of giving very accurate values of frequency if properly carried out. A much simpler procedure by which less accurate values may be obtained is to calibrate a frequency meter in terms of the standard frequency signals and then measure the piezo oscillator by means of the frequency meter.

Other frequency measurement methods are given or suggested in the articles of the reference list appended.

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(Note.- These publications are not issued by, nor available from, the Bureau of Standards, except where noted. They can be consulted in public libraries which maintain files of periodicals).

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