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DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

April 28, 1930.

Letter Circular No.280 (Replacing LC171)

MEASUREMENT OF THE FREQUENCY OF DISTANT RADIO TRANSMITTING STATIONS.

Several methods of frequency measurement are possible in utilizing the standard frequency signals transmitted by the Bureau of Standards. These methods range from those using very simple apparatus giving results accurate to one or two per cent, to those using complicated and expensive apparatus giving results accurate to 0.01% or better. This pamphlet gives one method which is capable of giving a fair degree of accuracy with a relatively small amount of apparatus. The references at the end of this pamphlet give other methods.

General information on the principles of radio measurements is given in Bureau of Standards Circular No. 74, "Radio Instruments and Measurements," obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., price sixty cents.

Radio Signals of Standard Frequency.- The Bureau of Standards transmits radio signals of definitely announced frequencies, on or near the 20th of each month, for adjusting and calibrating frequency standards and other apparatus. The signals are transmitted from the Bureau's station, WWV, at Washington, D.C. The frequencies included are from 550 to 7600 kilocycles per second. Announcements of the dates and other details of the schedules of transmission are given in the newspapers and radio magazines, in the Proceedings of the Institute of Radio Engineers, and in the Bureau of Standards Technical News Bulletin and the Radio Service Bulletin. The latter two are monthly publications of the Department of Commerce; either is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., at 25¢ per year. Copies of the current schedule may also be obtained upon request from the Bureau of Standards, Washington, D.C.

These monthly transmissions of standard frequency signals from station WWV are by continuous-wave radio telegraphy. The schedule begins at 10:00 P.M., Eastern Standard time, and consists of eight frequencies approximately equally spaced over the frequency range to be covered.

A single frequency transmission lasts 8 minutes. There is then a 4-minute interval during which the transmitting set is adjusted for the next frequency. The wording used in the four parts of a single frequency transmission is as follows:

General Call (2 minutes)	"CQ CQ CQ DE WWV WWV WWV CQ CQ CQ DE WWV WWV WWV -...-STANDARD FREQUENCY SIGNALS -...- FREQUENCY (Statement of frequency in figures and then spelled) KILOCYCLES DE WWV WWV WWV"
Standard Frequency Signal (4 minutes)	"(long dash) WWV (long dash) WWV (long dash) WWV (LONG DASH)" (Long dash continues a minute.
Announcement of this Frequency (1 minute)	"CQ CQ CQ DE WWV WWV WWV FREQUENCY (statement of frequency in figures and then spelled) KILOCYCLES
Announcement of next Frequency (1 minute)	"QSW QSW (Statement of next frequency in figures and then spelled) KILOCYCLES .-... .-..,

At the end of the evening's transmissions, an announcement is given of the date and frequency range of the next scheduled transmissions.

The following is a sample schedule, the dates being correct for 1930.

Sample Schedule of Frequencies in Kilocycles Per Second.

Eastern Standard Time	Jan.20	Feb.20	Mar.20	Apr.21	May 20	June 20
10:00 P.M.	1600	4000	550	1600	4000	550
10:12	1800	4400	600	1800	4400	600
10:24	2000	4800	700	2000	4800	700
10:36	2400	5200	800	2400	5200	800
10:48	2800	5800	1000	2800	5800	1000
11:00	3200	6400	1200	3200	6400	1200
11:12	3600	7000	1400	3600	7000	1400
11:24	4000	7600	1500	4000	7600	1500

Note: For current schedule of transmissions, address request to the Bureau of Standards, Washington, D.C.

The standard frequency signals are carefully measured during transmission and the frequency sent is very accurately that which is given in the schedule. Consequently a high order of accuracy may be obtained by using these transmissions. If less accuracy is required, however, the transmissions of broadcasting stations may be used. Using several such stations and getting a mean value the result should not be in error by more than 0.1%.

Method of Measurement.

The measurement of a station frequency may be for either of two purposes, (a) to standardize a piezo oscillator, a frequency meter or other apparatus in terms of the station's frequency, or (b) to determine the station's frequency in terms of standard apparatus. The methods and instruments used are the same for either purpose. The method here outlined will be based on the measurement of the frequency of a piezo oscillator. If the frequency of the piezo oscillator is known accurately the same method can be used to measure station frequencies.

The apparatus necessary is (1) a 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 is also very useful but not necessary.

A piezo oscillator produces from one to three fundamental frequencies, which are 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. The interaction of a frequency from the piezo oscillator with a corresponding frequency produced by the generator gives a beat note which may be heard in a pair of head phones in either circuit. The generator may then be adjusted to zero beat, i.e., to the frequency of the piezo oscillator. The harmonics present in the piezo oscillator circuit and generator make it possible to obtain a large number of points. Any frequency present in the piezo oscillator can beat with a corresponding frequency present in the generator and so give a frequency point which is directly related to one of the fundamental frequencies of the piezo oscillator. 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.)

Example of Measurement Method.

In order to explain the method, a specific example will be used rather than a general discussion. Suppose it is required to measure the frequency of a piezo oscillator the approximate frequency of which is 720 kc at a time when the standard frequencies in the band 550 to 1500 kc are available.

If the radio-frequency generator is set at 60 kc, the 10th harmonic of it (600 kc) will beat with the 600-kc transmission, and the 12th harmonic (720 kc) with the fundamental of the piezo oscillator. If the radio-frequency generator is set to 80 kc, the 10th harmonic (800 kc) will beat with the 800-kc transmission and its 9th harmonic (720 kc) will beat with the piezo oscillator. The 1200 kc signals may be used in a similar manner.

Assume the 600 kc transmission is to be used. The 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 60 kc, which should give a beat note with the frequency generated by the receiving set.

As it is assumed that no shielding is used in either the receiving set or the radio-frequency generator, the receiving set is sensitive enough that telephone receivers connected to it will give the beat note produced by the interaction of the frequencies of the receiving set and the radio-frequency generator. 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 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 beat indicator which will operate at any of the harmonics which may be desired is a complicated device. It is questionable whether such a device could be relied upon to give the desired settings in the limited time available. A simpler and equally accurate substitute is to bring in a simple 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 60 kc. Without changing its adjustment, couple the piezo oscillator to it loosely. A beat should be heard in the telephones in the output of the piezo oscillator unless the piezo oscillator is exactly an even multiple of 60 kc. Suppose, for example, it is 720.520 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 12th harmonic (720 kc) of the generator adjusted to 60 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 720 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 720 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 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 generator was adjusted higher or lower than zero beat, (2) the frequency difference, and the harmonic relations between, (3) the standard signal and the generator, (4) between the 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 600 kc signal would be made as follows, and are shown diagrammatically in Fig.2. Set generator from approximate zero beat at 60 kc to 59.9 kc. The 10th harmonic is 59.9 x 10 = 599 kc (beats with 600 kc in receiver which is not oscillating and gives a 1000-cycle note). The 12th harmonic of the generator (59.9 x 12 = 718.8 kc) may now be heard beating in the telephones of the piezo oscillator which is known to be approximately 720 kc. If this value were exactly 720 kc a note of 720-718.8 or 1200 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 720.520 kc as assumed previously, the audio-frequency note measured would have been 720.520-718.8 = 1.72 kc or 1720 cycles per second.

Whether to add or subtract the audio note of 1720 cycles to the known frequency of 718.8 kc would be decided as follows when the generator was set <u>lower</u> than the standard frequency signal. If lowering the frequency of the generator increases the beat note (1720 cycles in this case), add the beat note, or if increasing the frequency of the generator decreases the beat note, add the beat note.

Fig. 1

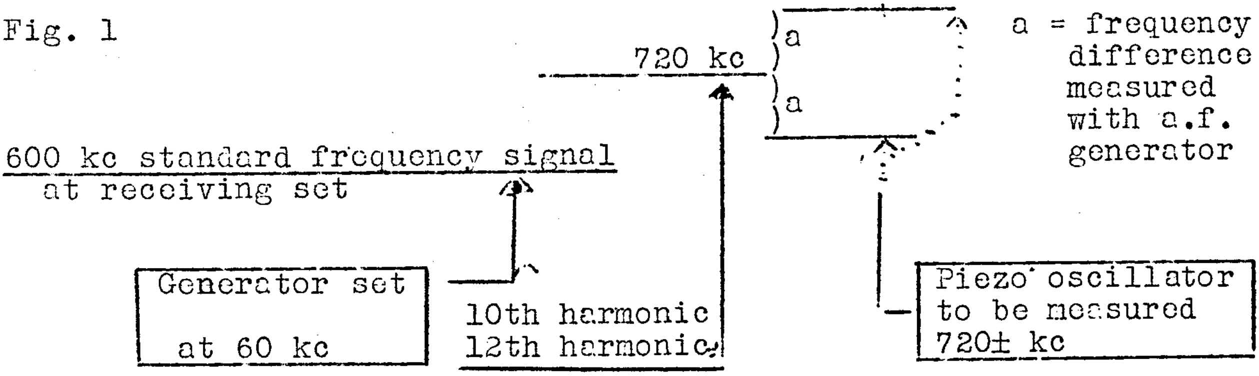


Fig. 2

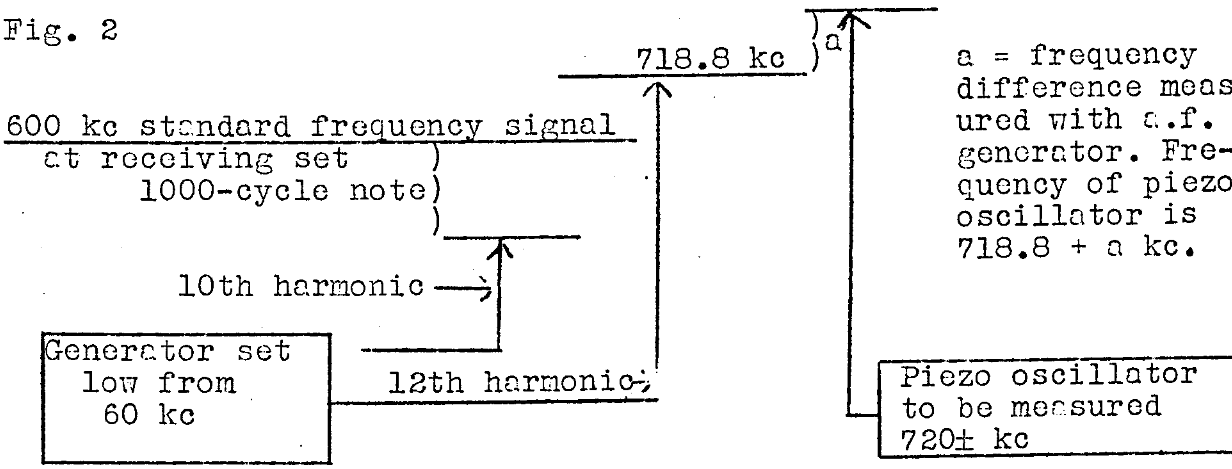
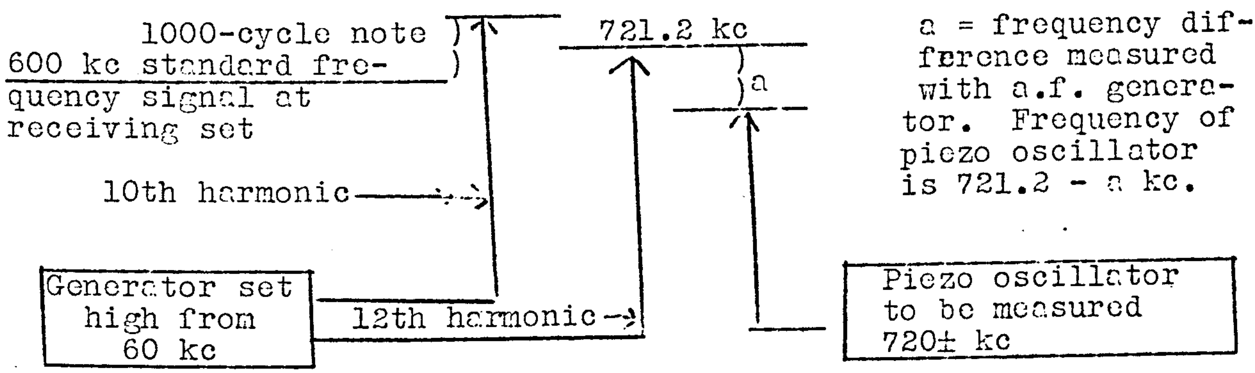


Fig. 3.



The measurement could also be made by adjusting the generator to 60.1 kc using the thousand-cycle tuning fork, as in Fig.3. The 10th harmonic is 60.1 x 10 = 601 kc which beats with the standard frequency signal of 600 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 generator reduces the audio note heard, subtract it from the known frequency of 721.2 kc, or if increasing the frequency of the generator increases the audio note, subtract it. The audio note heard with a piezo oscillator having the assumed frequency would be 680 cycles, hence 721.2 - 0.680 = 720.52 kc.

If other standard frequency signals are used with the tuning fork suggested above, the beat notes obtained may be too high to work with successfully. In such a case the generator frequency would have to be changed so that the harmonic beating with the piezo oscillator and the one beating with the standard are of a lower order. In general, the harmonic numbers employed should be small, as otherwise considerable audio-frequency amplification may be required and the beat notes may be too high for use.

For success in using the standard frequency signals, the measurements which are to be made should be planned in advance, with approximate adjustments for the generator and receiving set known, and the harmonics of the generator and piezo oscillator to be employed chosen in advance. The standard frequency signals are of relatively short duration, which does not permit of searching for suitable combinations of harmonics. Some signals may not be of suitable frequency to work in readily for the particular calibration or measurement to be made.

The methods described above are capable of giving very accurate values of frequency if properly carried out. Much less accurate values may be obtained by calibrating a frequency meter in terms of the standard frequency signals and then measuring the piezo oscillator by means of the frequency meter.

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

References to Further Information.

(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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