

Bureau of Standards Section
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METHODS OF USING STANDARD-FREQUENCY RADIO TRANSMISSIONS

This pamphlet gives methods of frequency measurement for utilizing the standard frequencies transmitted by radio by the National Bureau of Standards. It is in three parts.

Part 1 gives methods of using the 5000-kc/s transmissions for the calibration of standard oscillators in simple cases where the frequencies have such numerical values as to be readily checked directly in terms of the transmissions.

Part 2 gives specific information for the use of the transmissions to check with great accuracy the frequency standard used in any broadcasting station (e.g., the monitor required by F.R.C. Rule 145). The discussion is divided into three sections, A, B, and C, progressing in difficulty of measurement. Section A deals with two frequencies, 1000 and 1250 kc/s; very little apparatus is required for measurements at these frequencies. Section B gives the method of measurement, using an auxiliary generator, for frequencies which are multiples of 50 kilocycles per second. Section C gives the method of measurement for any broadcast frequency (multiples of ten).

Part 3 is a bibliography, in which references to other methods of frequency measurement may be found, and devices for use in frequency measurements are described. The references give other methods, which range from those using very simple apparatus, giving results only moderately accurate, to methods using complicated apparatus giving results accurate to better than a part in a million.

The Standard Frequency Transmissions.—The Bureau of Standards transmits standard frequencies from its station WWV, Beltsville, Md., near Washington, D.C., every Tuesday. The transmissions are on 5000 kilocycles per second, and are given continuously for two hours during the day and two hours at night. (For the hours of transmission consult a current transmission schedule such as is published monthly in the Proceedings of the Institute of Radio Engineers, and QST, or which may be obtained on request from the Bureau of Standards. At this date, the schedule is from 12 noon to 2 P.M., and from 10 P.M. to midnight, Eastern Standard Time.) The transmissions can be heard and utilized by stations equipped for continuous-wave

reception throughout the United States, although not with certainty in some places. The accuracy of the frequency is at all times better than one cycle per second (one in five million).

The transmissions consist mainly of continuous, unkeyed carrier frequency, giving a continuous whistle in the phones when received with an oscillatory receiving set. 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.

Part 1. Checking Standard Oscillators

Method of Measurement.— While the standard frequency transmissions may be used for many standardization purposes, the most common use 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) a variable audio-frequency generator, and (4) a radio receiving set. A frequency meter of resonance type is also useful but is not essential.

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 radio-frequency 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 telephones 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 have a simple relation 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/s 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/s can be measured very simply in terms of the 5000-kc/s transmissions, and these secondary standards may be advantageously used in turn to calibrate other apparatus. It is, however, possible to use the 5000-kc/s 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/s, in terms of the 5000-kc/s standard frequency signals.

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

The 5000-kc/s 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/s. 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 50th harmonic 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/s. 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/s. Suppose, for example, it is 700.520 kc/s. 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/s) of the generator adjusted to 100 kc/s 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/s. 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/s. 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 of four factors, (1) as to whether the radio-frequency generator was adjusted higher or lower than zero beat, (2) the frequency difference, (3) the harmonic relation between the standard signal and the radio-frequency generator, and (4) the harmonic relation 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/s signal would be made as follows, and are shown diagrammatically in Fig. 2. Set generator from approximate zero beat at 100 kc/s. to 99.98 kc/s. The 50th harmonic is $99.98 \times 50 = 4999.0$ kc/s (beats with 5000 kc/s in receiver which is not oscillating and gives a 1000-cycle note). The 7th harmonic of the generator ($99.98 \times 7 = 699.86$ kc/s) may now be heard beating in the telephones of the piezo oscillator which is known to be approximately 700 kc/s. If this value were exactly 700 kc/s, a note of $700.000 - 699.869$ kc/s 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/s as assumed previously, the audio-frequency note measured would have been $700.520 - 699.860 = 0.660$ kc/s or 660 cycles per second.

Whether to add or subtract the audio-frequency note of 660 cycles to the known frequency of 699.860 kc/s 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.

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Fig. 1

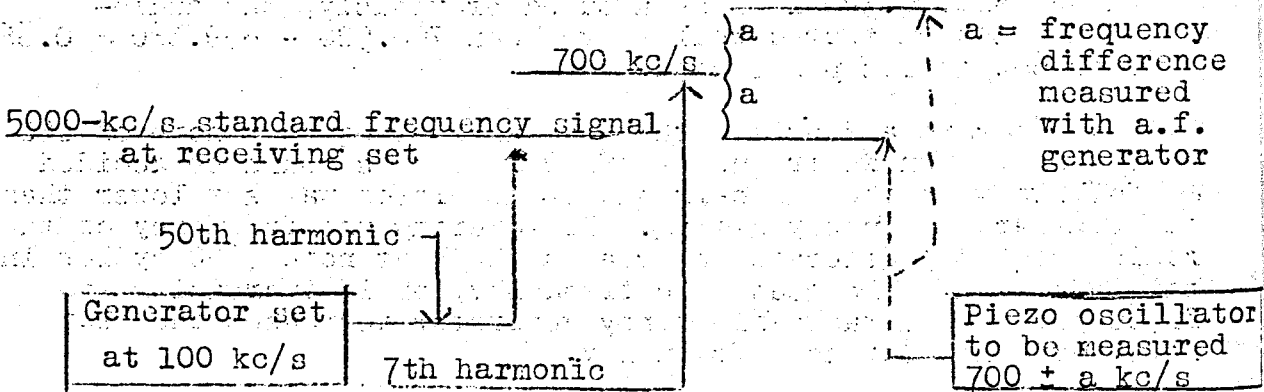


Fig. 2.

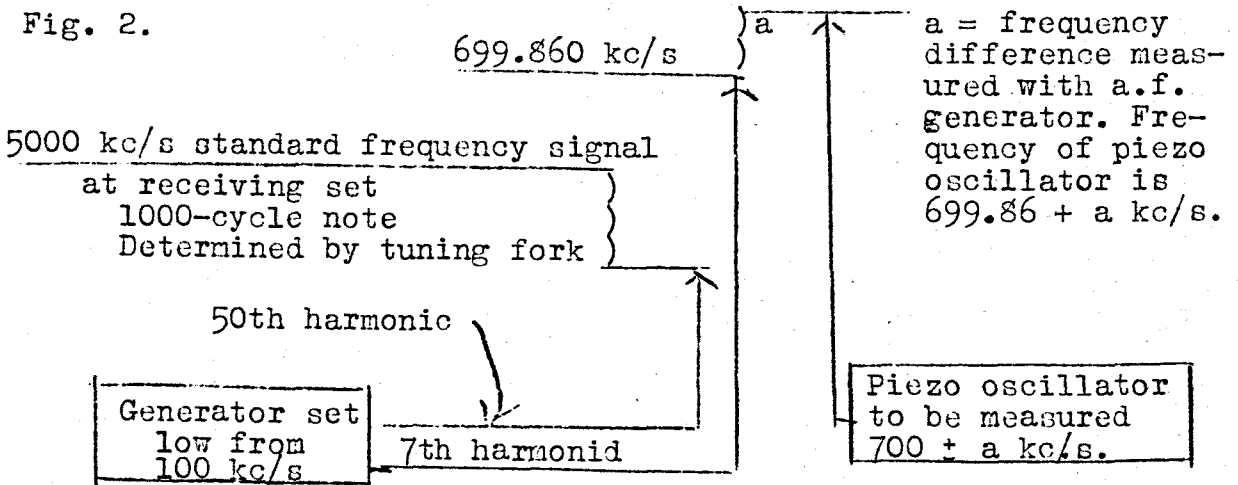
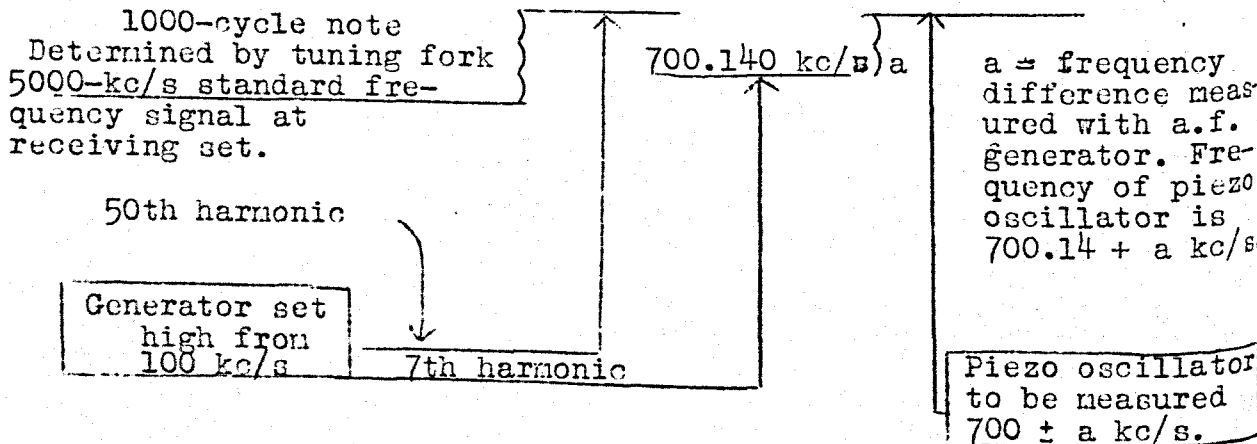


Fig. 3.



The measurement could also be made by adjusting the generator to 100.020 kc/s using the thousand-cycle tuning fork, as in Fig.3. The 50th harmonic is $100.020 \times 50 = 5001$ kc/s which beats with the standard frequency signal of 5000 kc/s 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/s, 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 $700.140 + 0.380 = 700.520$ kc/s.

Part 2. Checking Broadcast Frequency Standards.

A. Integral Sub-multiples of 5000 kc/s.

The frequencies which are integral sub-multiples of 5000 kc/s are most easily measured. There are only two broadcast frequencies, 1000 and 1250 kc/s, which bear this relation. The fifth harmonic of 1000 kc/s is 5000 kc/s. If a 1000-kc/s oscillator, whether a transmitting set or frequency standard, is coupled to a radio receiver tuned to 5000 kc/s at a time when the standard signal is being received, a heterodyne note will be produced which is equal to the frequency difference between the 5th harmonic of the 1000-kc/s oscillator and the standard signal. Assuming that the nominal value of the 1000-kc/s oscillator is known, all that remains in order to measure the frequency accurately, is to determine the frequency of the beat note and whether the frequency is higher or lower than the standard signal. This is done when the radio receiver is not in the generating condition. The most convenient method, if the beat note is in the audible range, is to match it with a known audio frequency produced by a calibrated audio-frequency oscillator. The direction of the deviation is most easily determined by making a slight change of known direction in the unknown frequency. If an increase in the unknown frequency increases the audio-frequency beat note the frequency is high. If an increase in the unknown frequency decreases the audio-frequency beat note, the frequency is low. Conversely, if a decrease in the unknown frequency increases the audio-frequency beat note the frequency is low, and if a decrease in the unknown frequency decreases the audio-frequency beat note, the frequency is high. If the audio frequency to be measured is between 5 and 200 cycles per second, the audio-frequency arrangement described in a previous Bureau publication¹ by N. P. Case can be used with a very high degree of accuracy.

¹ See reference (32), Part 3.

If the audio frequency is still lower and goes below the range of the audio-frequency amplifier, it is necessary to provide a carrier for this audio-frequency note. This is done by making the radio receiver generate and adjusting the resulting beat note so that it is approximately 1000 cycles per second. A fluctuation in the amplitude of this 1000-cycle note, which has a frequency equal to the frequency difference between the two radio frequencies, will then be heard. If it is only desired to readjust the unknown frequency to agreement with the standard signal, it is a simple matter to adjust to zero beat. The same method can be used for a frequency of 1250 kc/s. Precaution must be taken to make it possible to combine the signals with approximately equal intensity. Some difficulty in this respect may be expected if measurements are made when the transmitter is operating unless the harmonics are very completely suppressed.

A station frequency monitor which utilizes a piezo oscillator having a frequency of 1000 or 1250 kc/s can be measured or adjusted to frequency in a similar manner. If the radio transmitter is operating, the measurement can be made indirectly in terms of the transmitter in the following manner. Measure the frequency of the radio transmitter in terms of the 5000-kc/s signal and simultaneously read the frequency as indicated by the frequency deviation meter on the monitor. The two frequencies should agree. If they do not, adjust the frequency monitor until the deviation meter indicates the correct frequency deviation. It may be desirable to measure the frequency monitor directly against the standard signal at a time when the radio transmitter is not operating.

If the frequency monitor is of the type which is adjusted to exactly 1000 or 1250 kc/s, the measurement can be made the same as in the case of the radio transmitter. However, if the monitor is set high or low by 500 or 1000 cycles, it will be necessary to make use of an audio-frequency oscillator to determine the value of the audio beat frequency. In the case of a monitor which has a frequency of 999.500 or 1000.500 kc/s, the beat note to be measured would be 2500 cycles per second. As five cycles variation in the beat note is only 1 part in 10^6 , any audio-frequency oscillator which would be constant to 5 or 10 cycles per second would be adequate. In the case of a monitor which has a frequency of 999.000 or 1001.000 kc/s a 5000-cycle note would be produced. Similarly for 1250 kc/s, audio-frequency beat notes of 2000 and 4000 cycles per second would have to be measured. The general relation is that the audio-frequency note produced by heterodyning the monitor frequency and the 5000-kc/s standard signal is equal to the product of the number of cycles the monitor is set high or low and the ratio of 5000 to the nominal value of the monitor.

B. Measurements with Auxiliary Generator for Frequency Multiples of 50.

Measurements of any of these frequencies require the use of an auxiliary generator in addition to the high-frequency receiver. The auxiliary generator may be a piezo oscillator or it may be a manually controlled oscillator. If a piezo oscillator of the desired frequency is available, it is desirable to use one. In this case a distorting amplifier is necessary in order to bring out the harmonics so that the beat against the 5000-kc/s standard signal can be easily heard. This piezo oscillator should be provided with a vernier frequency adjustment² so that it can be readily adjusted to agreement with the 5000-kc/s standard in the manner previously described. After this is done the monitor or radio transmitter can be measured in terms of harmonics of the auxiliary generator. If a manually controlled generator is used, the $\frac{L}{C}$ ratio must be low so that the frequency can be easily adjusted to zero beat with the standard frequency, and readily held on that frequency.

There are two main factors which determine the frequency to which the auxiliary generator should be adjusted. The first is that its frequency must have an integral relationship with the standard frequency and the frequency to be measured. The second is that the harmonic which is heterodyned with the standard frequency must be of sufficient intensity to produce a beat note which is easily recognized. Taking both factors into account the best result is attained if the frequency of the auxiliary generator is the highest common factor of the standard frequency and the frequency to be measured. There is one other consideration in the case of a manually controlled auxiliary generator and that is, the lower its frequency, the less trouble is experienced in holding it at zero beat against the standard frequency. The following table indicates the broadcast frequencies which can be measured in terms of the 5000-kc/s standard frequency transmission by means of a high-frequency radio receiver and an auxiliary generator. It will be understood that the table gives all broadcast frequencies which are multiples of 50, but does not indicate more than one generator frequency for these frequencies except for 1000 and 1500 kc/s.

See reference (21), Part 3.

Frequency of Auxiliary Generator

| <u>500 kc/s</u> | <u>200 kc/s</u> | <u>100 kc/s</u> | <u>50 kc/s</u> |
|-----------------|-----------------|-----------------|----------------|
| 1000 | 600 | 700 | 550 |
| 1500 | 800 | 900 | 650 |
| | 1000 | 1100 | 750 |
| | 1200 | 1300 | 850 |
| | 1400 | 1500 | 950 |
| | | | 1050 |
| | | | 1150 |
| | | | 1250 |
| | | | 1350 |
| | | | 1450 |

As an example of this method of measurement, assume the frequency of the radio transmitter to be 1150 kc/s. The radio receiver, in the generating condition, is tuned until the 5000-kc/s standard frequency signal is heard. The auxiliary generator, set on approximately 50 kc/s, is then turned on and the frequency varied until a second audio frequency is heard on the output of the high-frequency receiver. If the radio receiver is then adjusted so that it does not generate, the auxiliary generator can be set to zero beat with the standard frequency signal. If the radio receiver is again made to generate, the auxiliary generator can be easily set to agreement with the standard frequency signal as previously explained. The rough adjustment to zero beat must be made when the radio receiver is in the non-generating condition, otherwise there is danger of setting to zero beat between the two audio frequencies or harmonics of the audio frequencies. If a piezo oscillator is used, this precaution is unnecessary. A detector-amplifier is set up so as to receive portions of the outputs of the auxiliary generator and the 1150-kc/s radio transmitter, Fig. 4. The output of the amplifier will give the audio beat frequency between the 23d harmonic of the auxiliary generator and the 1150 kc/s of the radio transmitter. If this audio-frequency is reduced to zero as indicated on a visual beat indicator the transmitter frequency will be in exact agreement with the standard frequency signal. One person can make this adjustment, as an aural indication may be used for the auxiliary generator and a visual one for the transmitter adjustment.

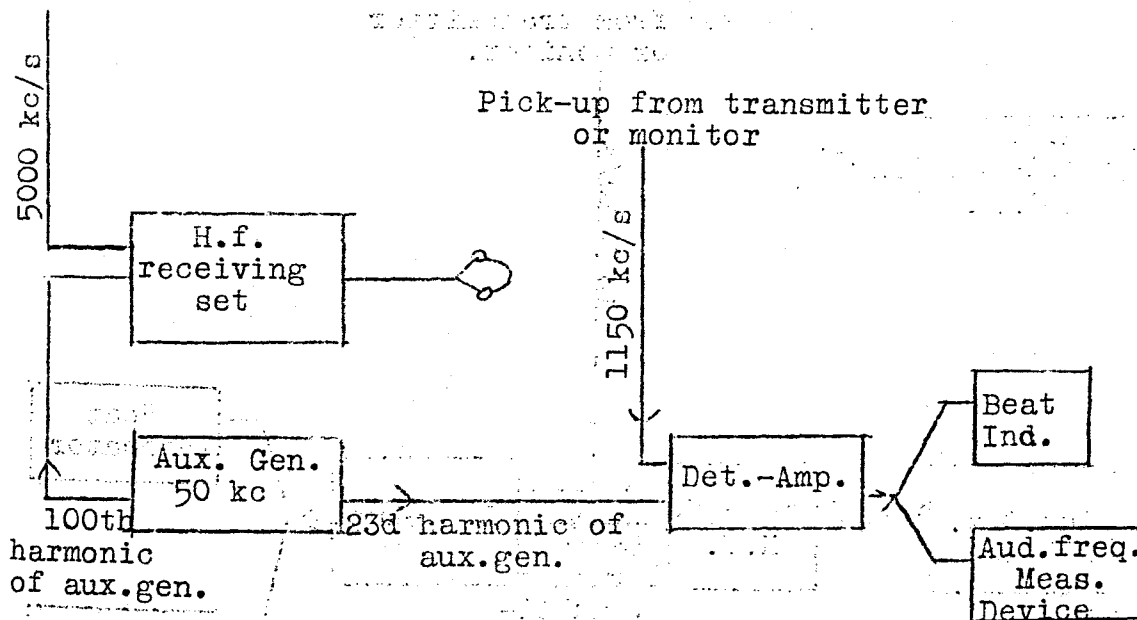


Fig. 4.

If a piezo oscillator is used as the auxiliary generator, it need only be checked against the standard frequency signal at intervals.

C. Measurement of Any Broadcast Frequency.

The methods of measurement given in the preceding paragraphs are applicable to twenty of the frequencies in the broadcast band. The highest common factor of 5000 kc/s and the remaining broadcast frequencies is 10 kc/s. The frequency of the auxiliary generator must therefore be 10 kc/s if the other broadcast frequencies are to be checked readily in terms of the 5000-kc/s transmissions. The beat note between the 500th harmonic of the 10-kc/s generator and the 5000-kc/s transmission would not be loud enough to be heard distinctly. The simplest solution, therefore, is to set the auxiliary generator on 100 kc/s and let it control a 10-kc/s multivibrator. The beat against the standard frequency signal could then be heard easily and the harmonics of the 10 kc/s would heterodyne equally well with frequencies in the broadcast band. It is evident that with this equipment all assigned frequencies in the broadcast band can be checked against the 5000-kc/s standard frequency signal, Figure 5.

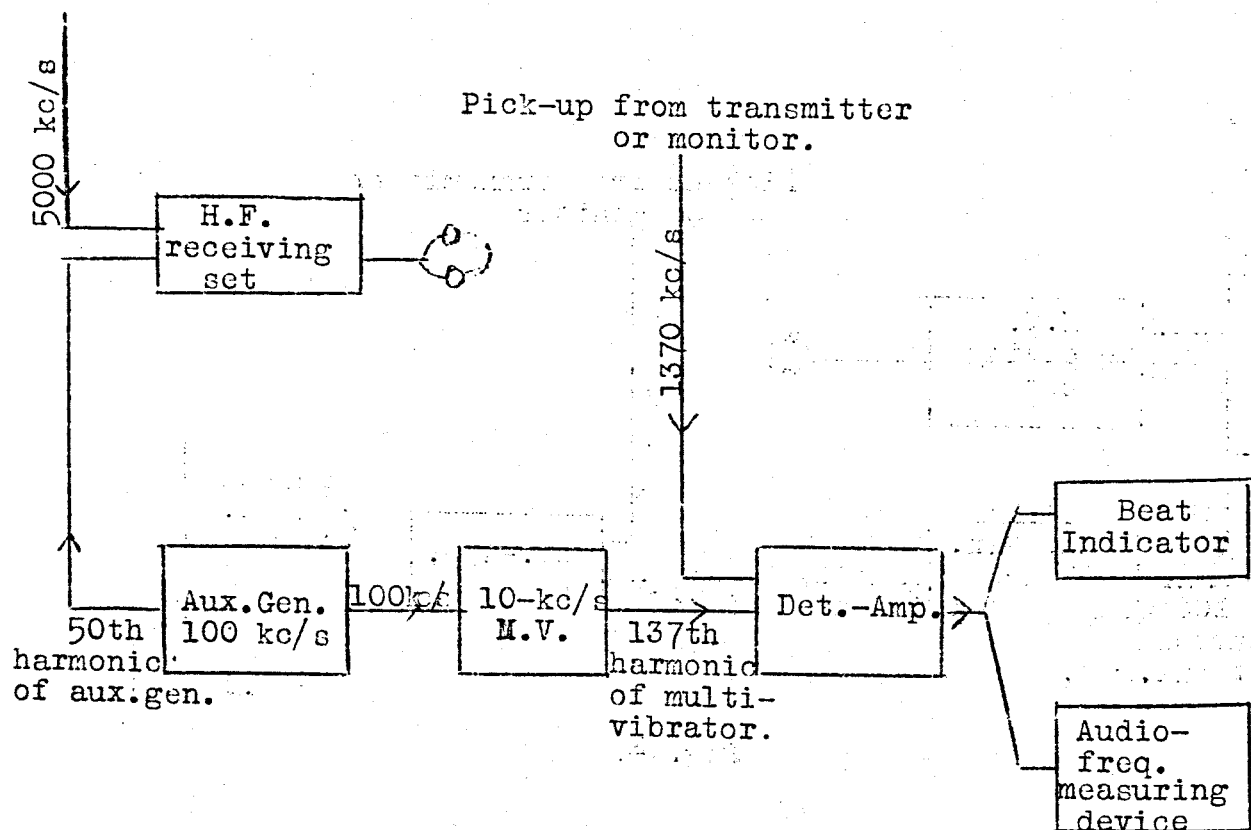


Figure 5.

There are some cases in which a frequency can be measured by more than one of the methods indicated. The question arises as to the advantages and disadvantages of the various possibilities or as to how existing equipment might be brought into use. The first method is applicable to only two frequencies. It provides the most accurate check for frequencies which are very near the harmonic value. For monitors, however, which are set high or low by 500 or 1000 cycles per second, the audio frequency which must be measured is so high that it is very difficult to determine its value. This method is further handicapped by the fact that if the measurements are made in the transmitting station when the power amplifier is operating, the harmonic which is picked up on the receiver may be so strong that it will block the receiver. If that is the case it would be necessary to locate the receiver at some distance from the transmitter and use a line between transmitter and receiver.

The second method requires an auxiliary generator and detector-amplifier in addition to the equipment used in the

first method. A small error may be introduced in this method in the adjustment of the auxiliary generator. If a piezo oscillator is used this error is negligible. The error is much greater if a manually-controlled oscillator is used. In either case, however, it should not be more than a few parts in a million. This method is applicable to 20 of the broadcast frequencies, and is much more satisfactory for checking monitors which are set off-frequency because the audio frequency to be measured equals the amount the monitor is set high or low. If a harmonic amplifier is coupled to the auxiliary generator so that sufficient voltage is provided, the measurement of the monitor can be read directly on the visual indicator provided with that unit.

It is necessary to use the third method in checking the remaining 76 broadcast frequencies. This method requires a high-frequency receiving set, auxiliary generator, 10-kc/s multivibrator, detector-amplifier, and audio-frequency measuring equipment. The accuracy of this method is the same as of the second method.

Part 3. Bibliography on Frequency Measurements and Associated Equipment.

Note.— The publications in the following list are in chronological order. They are not issued by, nor are they available from, the Bureau of Standards, except where noted. These publications can be consulted in public libraries which maintain files of periodicals, or copies may be secured from the publishers at these addresses:

- Annalen der Physik. J. Ambrosius Barth, Leipzig, Germany.
- Bell Laboratories Record. 463 West St., New York, N.Y.
- Bell System Technical Journal. 463 West St., New York, N.Y.
- Bureau of Standards Journal of Research. Superintendent of Documents, Government Printing Office, Washington, D.C.
- Bureau of Standards Scientific Papers. Superintendent of Documents, Government Printing Office, Washington, D.C.
- Electric Journal. 530 Fernando St., Pittsburgh, Pa.
- Experimental Wireless & Wireless Engineer. Iliffe & Sons, Ltd., Dorset House, Stamford St.; London, SE1, England.
- General Radio Experimenter. 30 State St., Cambridge, Mass.
- Journal Optical Society of America (formerly Journal Optical Society of America & Review of Scientific Instruments).
- American Institute of Physics, 11 E. 38th St., New York, N.Y.
- Marconi Review, Marconi Wireless Telegraph Co., Ltd.; Electra House, Victoria Embankment, London, England.
- QST. American Radio Relay League, W. Hartford, Conn.
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Boston, Mass.
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Exhibition Road, London, SW7, England.
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