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DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON

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Circular
LC 498

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METHODS OF USING STANDARD-FREQUENCY RADIO EMISSIONS

The National Bureau of Standards broadcasts standard frequencies and other services by radio. The time schedules and other details of these services are given in the Appendix hereof. This Letter Circular pamphlet, in six parts, describes methods of utilizing all of these services except the ionosphere bulletins, which are treated in another Letter Circular, as stated in the Appendix.

Part 1 (page 2) gives methods of using the radio frequencies 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 emissions. The information is given specifically in terms of measurements upon the 5000-kc emissions, but there should be little difficulty in applying the methods to the 10,000-kc and 20,000-kc emissions, using higher harmonics of the auxiliary generator. Further amplification, and suitable increase in the frequency of the auxiliary generator, should enable one to use any of the emissions after some trial and adjustment of equipment.

Part 2 (page 7) gives details for the checking of broadcast frequencies. The discussion is divided into three sections, A, B, and C, progressing in difficulty of measurement. Section A deals with only 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 kc/s. Section C gives the method of measurement for any broadcast frequency (multiples of 10 kc/s).

Part 3 (page 12) describes methods of using the standard audio frequency furnished as a modulation frequency with certain of the emissions. It gives methods of checking a local frequency, controlling a source of audio or other frequency, and producing a standard of time rate.

Part 4 (page 16) describes the use of the standard time intervals or seconds pulses. The seconds pulses are of value in physical measurements, in geodetic, seismological and similar work, and in rapid checking of pendulums and chronometer rates, and wherever short time intervals of great accuracy are needed. They are not capable of giving solar time, as needed in navigation, for example, for which astronomical observations or the Navy's time signals are required.

Part 5 (page 17) describes the nightly emissions of the American standard of musical pitch, 440 cycles per second, provided for musicians, musical instrument manufacturers and others interested in standard pitch.

Part 6 (page 18) 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.

Part 1. Checking Standard Oscillators.

Method of Measurement.- While the standard frequency emissions may be used for many standardization purposes, the most common use is to determine accurately the frequency of a standard oscillator. The apparatus necessary is (1) the oscillator, (2) a continuously variable radio-frequency generator which is approximately calibrated, (3) a variable audio-frequency generator, and (4) a regenerative radio receiving set. It is desirable that the receiving set have automatic volume control. A frequency meter of the resonance type is also useful but it is not essential.

The fundamental frequency of a piezo oscillator is fixed by the dimensions of the quartz plate used. The usual vacuum-tube circuit arrangement in which the quartz plate is connected gives numerous harmonics for each fundamental frequency. The radio 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 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 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 the received radio frequency 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 emissions and these secondary standards may be advantageously used in turn to calibrate other apparatus. It is, however, possible to use the emissions 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 5,000-kc standard frequency emissions.

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

The 5000-kc standard frequency emission is received first and identified with the receiving set in the generating condition. The radio 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 generator and the frequency of the incoming wave. This beat note should be reduced to zero frequency by adjusting the radio 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 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 generator must be used.

The frequency of the beat note and the frequency of the audio 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 generator is closely adjusted. For exact zero beat the frequency of the adjustable audio 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 frequency is higher or lower than 700 kc/s. This can be done by varying the frequency of the radio generator. If increasing the frequency of this generator results in decreasing the beat note, then the piezo oscillator frequency 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.

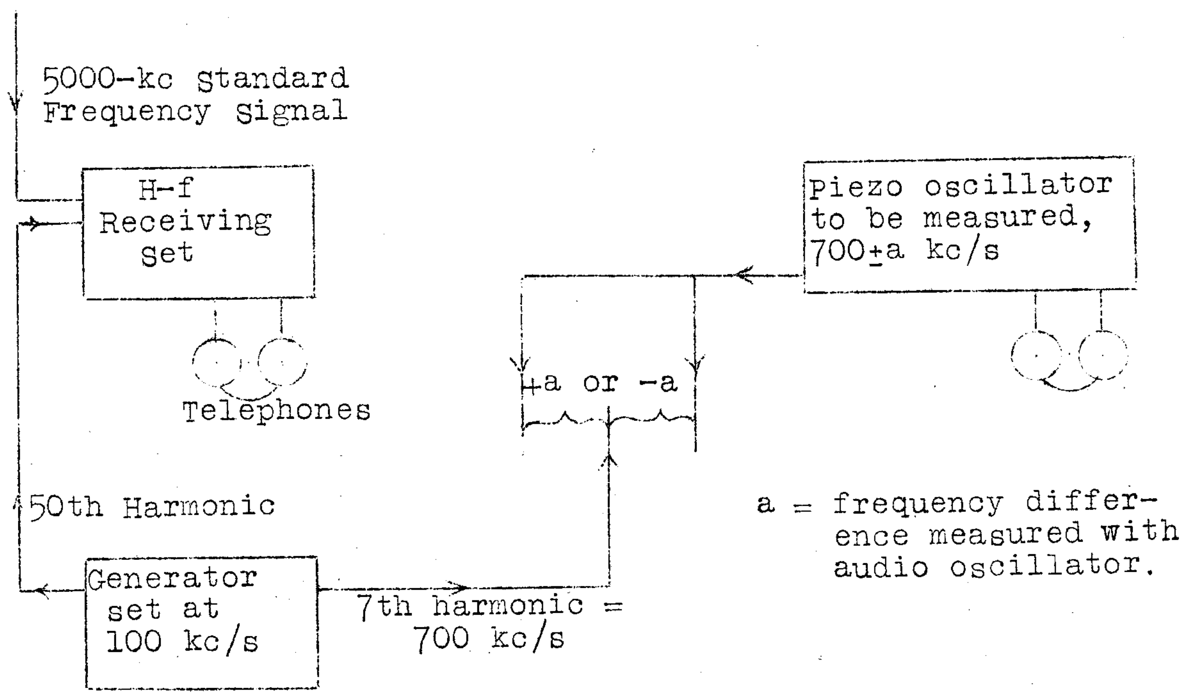

Fig. 1.

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 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 c/s. This method is more complicated in calculation because a record must be made of four factors, (1) as to whether the radio generator was adjusted higher or lower than zero beat, (2) the frequency difference, (3) the harmonic relation between the standard signal and the radio generator, and (4) the harmonic relation between the radio 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 1,000 cycles below the 5,000-kc 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 x 50 = 4,999.0 kc/s (beats with 5,000 kc/s 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/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, a note of 700.000 - 699.860 kc/s or 140 c/s would be heard. However, the beat note produced is matched with a corresponding note from the audio 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 c/s.

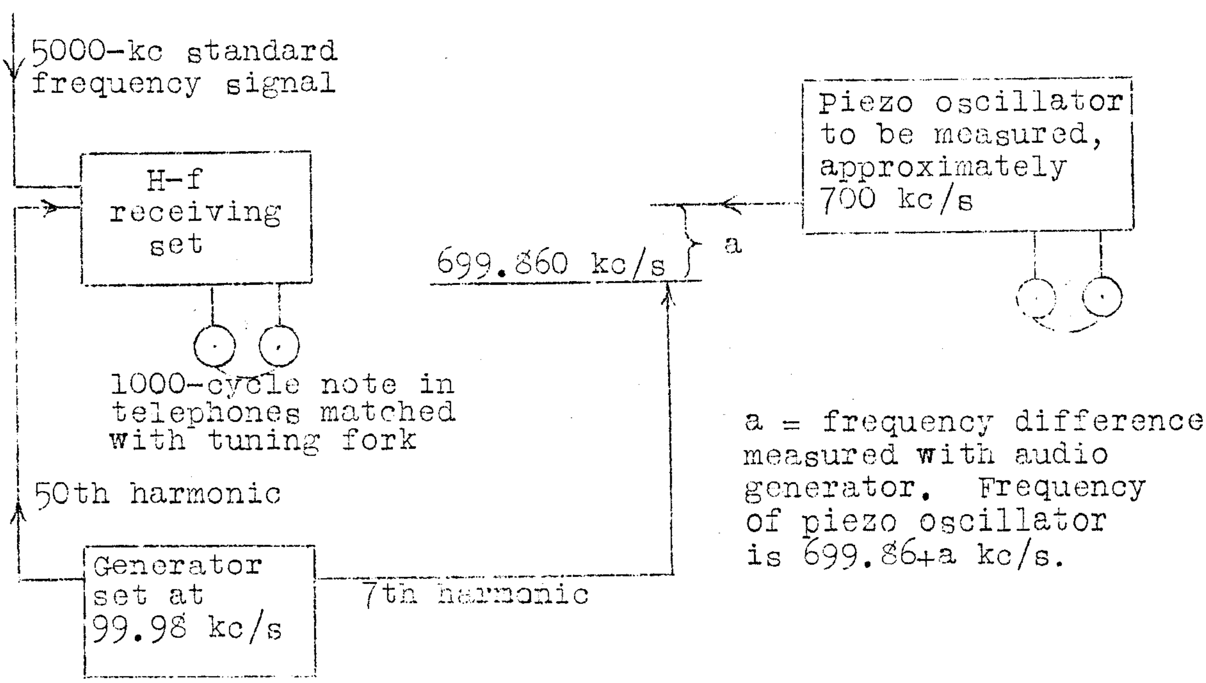

Fig. 2.

Whether to add or subtract the audio-frequency note of 660 c/s 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 generator increases the beat note (660 c/s in this case), add the beat note frequency, or if increasing the frequency of the radio generator decreases the beat note, add the beat note frequency.

The measurement could also be made by adjusting the generator to 100.020 kc/s using the 1000-cycle tuning fork, as in Fig. 3. The 50th harmonic is 100.020 x 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 oscillator as before. If lowering the frequency of the radio 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 generator increases the audio note, subtract it. The audio-frequency note heard with a piezo oscillator having the assumed frequency would be 380 c/s, hence 700.140 + 0.380 = 700.520 kc/s.

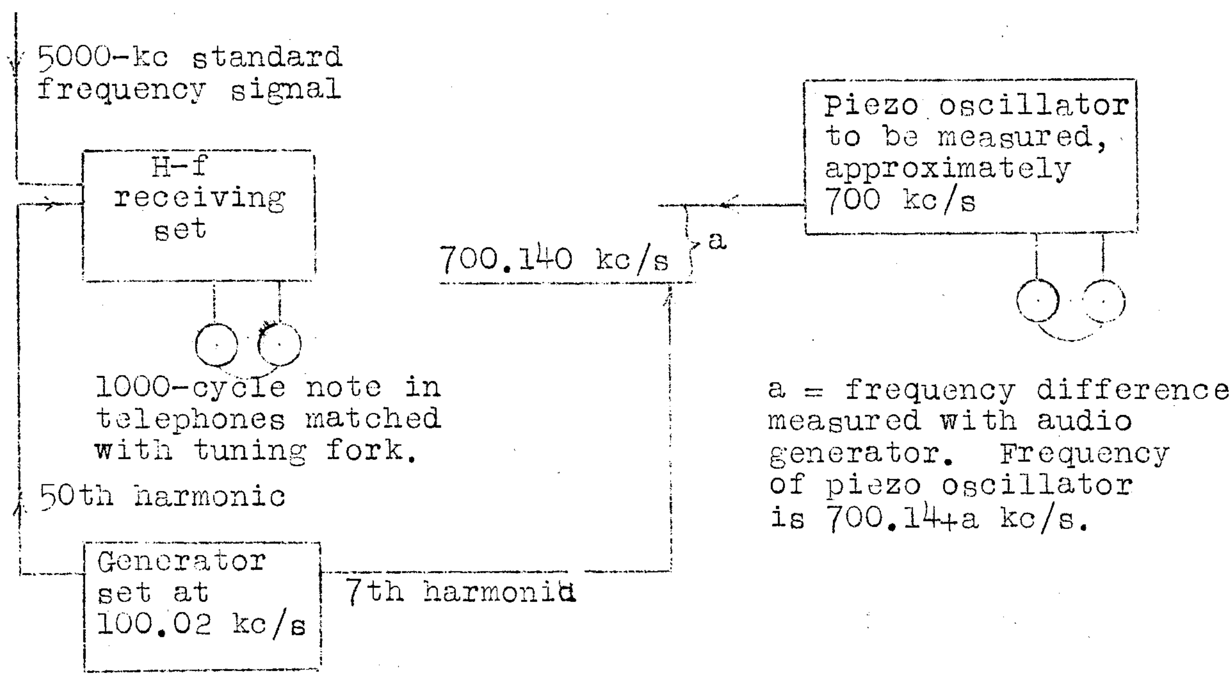

Fig. 3.

Part 2. Checking Broadcast Frequency Standards.

A. Integral Sub-multiples of Emission Frequency.

The frequencies which are integral sub-multiples of the emission frequency are most easily measured. For the emission frequency of 5000 kc/s there are only two broadcast frequencies, 1000 and 1250 kc/s, which bear this relation. If a 1000-kc 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 oscillator and the standard signal. Assuming that the nominal value of the 1000-kc 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 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 frequency of the beat note the unknown frequency is high. If an increase in the unknown frequency decreases the frequency of the beat note, the unknown frequency is low. Conversely, if a decrease in the unknown frequency increases the frequency of the beat note the unknown frequency is low, and if a decrease in the unknown frequency decreases the frequency of the beat note, the unknown frequency is high. If it is impossible to vary the unknown frequency in a known direction, then resort to an auxiliary generator must be made. If the beat frequency to be measured is below the range of available measuring equipment, it is necessary to provide a carrier for this frequency. This is done by making the radio receiver generate and adjusting the resulting beat note so that it is approximately 1000 c/s. 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 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 c/s, it will be necessary to make use of an audio 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 c/s. As five cycles variation in the beat note is only 1 part in 10^6, any audio oscillator which would be constant to 5 or 10 c/s 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 c/s would have to be measured. The general relation is that the audio-frequency note produced by heterodyning the monitor frequency and the 5000-kc 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.

The same principles may be followed for the 10,000 and 20,000 kc emissions.

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 standard signal can be easily heard. This piezo oscillator should be provided with a vernier frequency adjustment so that it can be readily adjusted to agreement with the 5000-kc 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 standard frequency emission 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.

Broadcast Frequencies Measurable with Auxiliary Generator

	Frequency of Auxiliary Generator in kc/s			
	500	200	100	50
Broadcast Frequencies, kc/s	1000 1500	600 800 1000 1200 1400	700 900 1100 1300 1500	550 650 750 850 950 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 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 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.

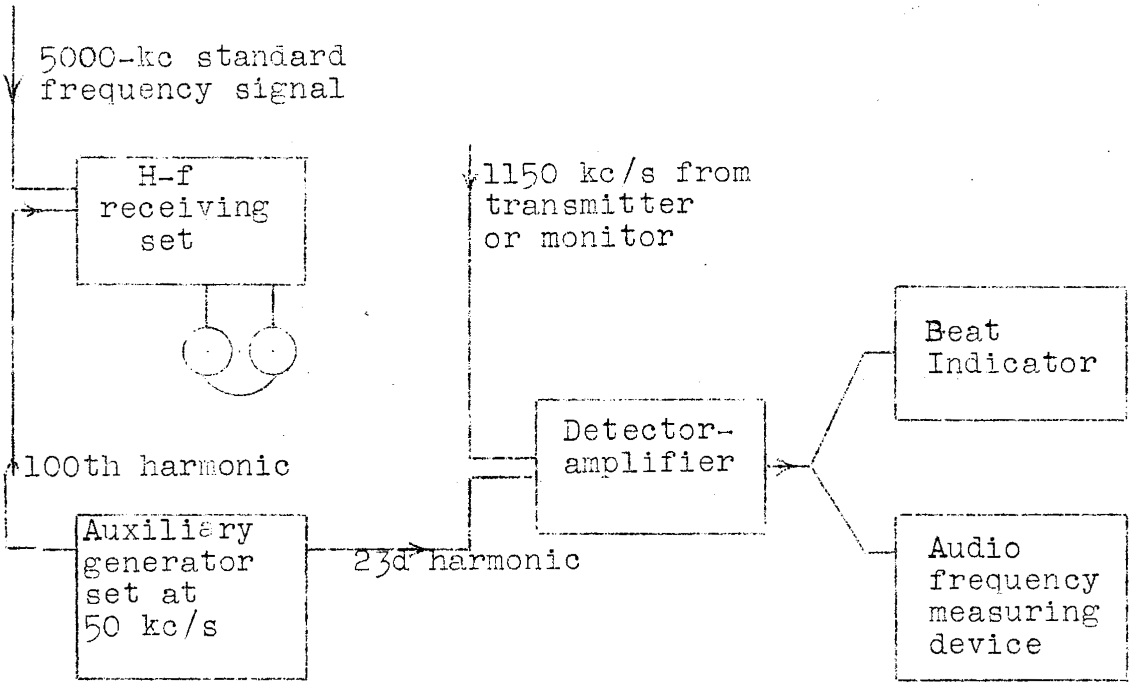

Fig. 4.

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 and the remaining broadcast frequencies is 10. 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 emissions. The beat note between the 500th harmonic of the 10-kc generator and the 5000-kc emission 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 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 standard frequency signal, Figure 5.

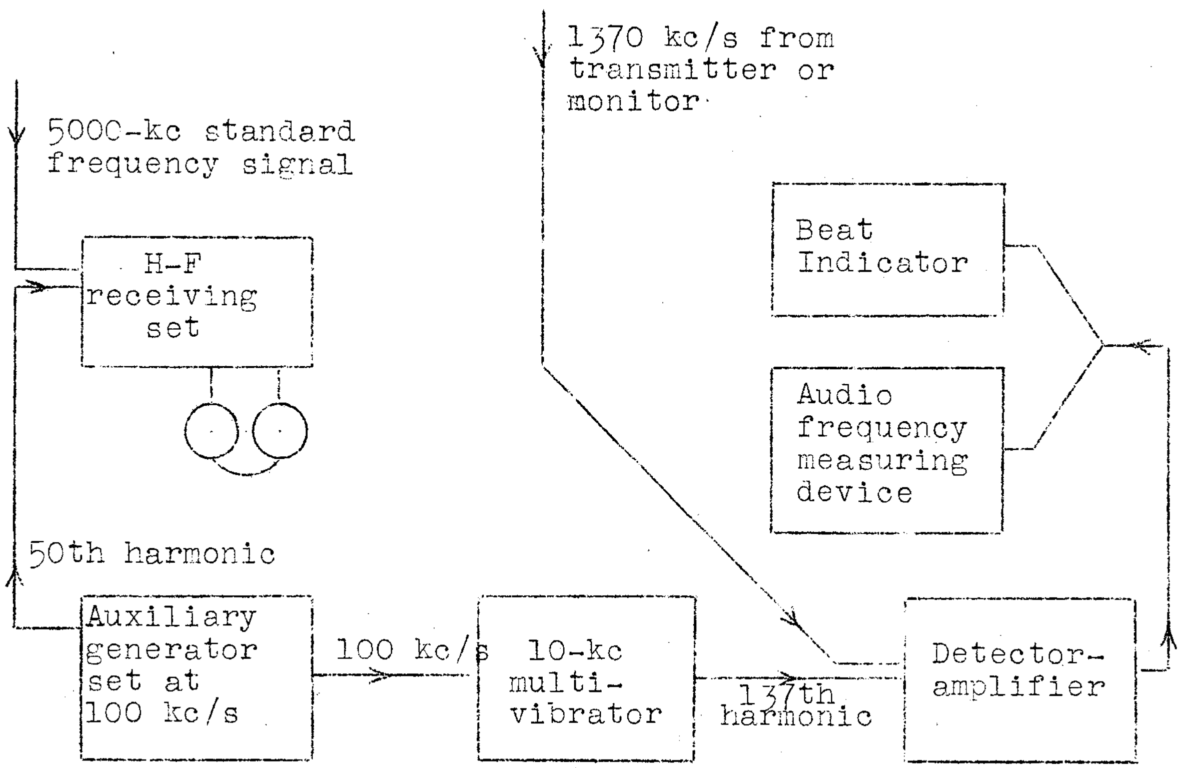

Fig. 5.

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 c/s, 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 multivibrator, detector-amplifier, and audio-frequency measuring equipment. The accuracy of this method is the same as of the second method.

Part 3. Standard Audio Frequencies.

The emissions each Wednesday are modulated by an audio frequency, 1000 cycles per second. The presence of the audio modulation frequency does not impair the use of the carrier frequency as a standard, to the same high accuracy as in the CW emissions. See the Appendix for further information about these emissions. The standard musical pitch, 440 cycles per second broadcast as described in Part 5 and also in the Appendix, may also be used as a standard frequency by the methods described in this section; however the description here given is in terms of the 1000 cycles per second.

The service may be utilized with very simple equipment. Using any receiving set capable of receiving the signals, the standard audio frequency is delivered at the output terminals of the set. This frequency may be used for comparison with a local frequency and thus accurately measuring the latter, for control of some type of frequency standard, or for production of an accurate standard of time rate. By the use of harmonic amplifiers or multivibrators to step up or down either the incoming standard frequency, the local frequency, or both, measurements may be made very conveniently as well as accurately. The following list gives a number of basic methods which have been found practicable.

Methods of Utilizing Received Audio Frequency

A. Checking a frequency.

1. Comparison of received and local frequencies, by timing change of cathode-ray oscillograph pattern.
   a. Direct comparison.
   b. Using harmonic amplifier, to step up.
   c. Using multivibrator, to step down.

2. Comparison, by recording both frequencies with an oscillograph and graphic recorder.
   a. Direct comparison
   b. Using harmonic amplifier, to step up.
   c. Using multivibrator, to step down.

3. Comparison, by recording beats on a graphic recorder.
   a. Direct comparison.
   b. Using harmonic amplifier, to step up.
   c. Using multivibrator, to step down.

4. Counting of beats between harmonics.

B. Control of a source of frequency

1. Tuning fork.
2. Audio-frequency oscillator.
3. Radio-frequency oscillator.

C. Production of a time rate standard.

In any of these methods, whether it will be more accurate and convenient to utilize the frequency directly or to use harmonics or subharmonics depends upon the magnitude and character of the frequency to be checked or controlled, the equipment available, and the circumstances of the radio reception. For some purposes a combination of two or more methods is useful.

The effects of fluctuations of amplitude and phase of the received audio frequency may be markedly reduced by the use of automatic volume control and filters. Filters also have the advantage of minimizing interfering electrical noise. An effective filter for 1000 cycles per second is a tuning fork or a vibrating steel reed; another is a synchronous motor-generator. For higher frequencies, magnetostriction bars or piezoelectric quartz plates are good filters.

When multiplying from 1000 c/s it is necessary to use very selective apparatus to remove 1000-cycle sidebands from the output of the multiplying device. For this purpose a quartz plate filter (at 50 kc/s, for example) has been found to be very good.

In methods A, either high or low standard frequencies may be produced by using harmonics or subharmonics and amplifying as desired. Standards of low audio frequency (e.g., 60 cycles per second) are easily produced by operating a synchronous motor on the amplifier output, with a-c generators of the desired frequency mounted on the same shaft. Such a motor-generator outfit may be of simple and fairly cheap type, somewhat like an electric clock.

In frequency comparisons, if the received standard frequency is sufficiently free from fluctuations of amplitude or phase, it is generally found advantageous to make the comparison at some harmonic such as 10,000 or 100,000 cycles per second. For example, consider the use of method A1. The two frequencies are applied to the two pairs of plates of a cathode-ray tube and their frequency difference is determined by timing the shift of the pattern on the screen through one or more complete cycles. A high accuracy of comparison, better than a part in a million, for example, may be secured by timing for 15 minutes when the comparison is made at 1000 cycles per second, but may be secured by timing for only 9 seconds when the comparison is made at 100,000 cycles per second.

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The greater/fluctuations of the received standard frequency, the lower must be the harmonic at which the observations are made and the longer the time required for the determination. Fortunately, such longer time of observation tends to eliminate any error in the result due to the fluctuation. The better the accuracy required, the longer must be the time of observation.

It may be desirable to multiply either the incoming standard frequency, the local frequency, or both. Frequencies can be multiplied quite simply by means of tuned harmonic amplifiers. Another means is the use of frequency doublers utilizing two tubes connected with their grids in a push-pull arrangement and their plates in parallel. It is convenient to have the incoming 1000-cycle frequency control a multivibrator and step up in frequency from that.

The use of the cathode-ray oscillograph has a number of advantages. It simplifies the differentiating of amplitude variations and interfering noise from phase changes. Also, if a linear sweep circuit controlled by the local frequency is used, one can tell readily whether the local frequency is higher or lower than the standard modulation frequency. If the oscillograph beam is swept from left to right and the standing wave moves to the left the local frequency is low; if the standing wave moves to the right the local frequency is high.

In method A2, use is made of any type of high-speed recording oscillograph that may be available. A requirement is that the time displacement be sufficient to separate the individual cycles so that the record can be readily analyzed. In this method the two frequencies are recorded simultaneously on the same film, which permits a direct comparison by means of measurements of the photographic or other trace. If the speed of the recorder will not give sufficient time displacement of the 1000 c/s, the received signal can be stepped down to a desired value by means of a multivibrator.

In method A3, the frequency difference between the standard and the local frequency is measured by combining the two, amplifying the beat frequency, and rectifying by means of a detector (e.g., copper oxide rectifier or diode detector). A double diode triode tube is convenient for both the amplifying and rectifying. A d-c meter can be used as a visual indicator, and a relay can be used to operate a counter. The direct voltage output can also be recorded on a graphic recorder. If the rate at which the recorder paper moves is controlled by a synchronous motor, or some type of time marker is used, a very satisfactory measure of the frequency differences can be made. This method is limited to quite small frequency differences. If audio frequencies are compared directly rather than by their harmonics, the method requires the operation of the equipment for a considerable time.

When it is desired to check a local frequency which is lower than 1000 c/s (e.g., 60 c/s), the procedure is to multiply the local frequency up to a frequency which can be compared directly with the standard modulation frequency or some harmonic of it. In the case of 60 c/s it would be multiplied by 5, divided by 3, and in turn multiplied by 10 in one or two steps, which would give an output of 1000 c/s, The received standard 1000-cycle frequency would conceivably be divided by the proper steps and compared directly against 60 c/s, but this would result in a lower accuracy of comparison or would require a longer time to make a measurement.

In method A4, the beats can be counted by the aid of either aural or visual indication. A combination of the two means is often very convenient. Very great accuracy can be obtained by using harmonics such as to make frequencies of the order of 100,000 cycles per second. Broadcast radio frequencies can be checked by having the standard 1000 c/s control a 10-kc multivibrator or oscillator and using harmonics of its output in the manner described in Part 2.

The accurate control of a source of frequency (B in above list) involves the use of an automatic means of keeping a local source of frequency in agreement with the received standard audio frequency or a harmonic or subharmonic. Where the local source of frequency is a mechanical device, such as a tuning fork or synchronous motor-generator, its inertia is useful in carrying along through periods of rapid fluctuation of amplitude or phase of the received frequency. Any local source can usually be so designed as to operate through considerable fading or phase shifts of the received frequency.

If the local source is a 1000-cycle tuning-fork it can be driven directly from the received 1000-cycle frequency. In this application it is necessary that the adjustment of the fork be such that its natural frequency is in agreement with the driving frequency within rather narrow limits. In one particular installation it was found that the fork had to be in agreement with the received frequency within a few parts in 10,000. These limits depend in any particular case on such factors as the driving voltage and the mass of the fork.

The standard audio frequency can similarly be used to control a multivibrator at the fundamental or a multiple or submultiple frequency. The multivibrator frequency can be multiplied by means of tuned harmonic amplifiers to higher frequencies as desired. It is also possible to multiply the standard audio frequency by means of harmonic amplifiers to radio frequencies and control a radio-frequency oscillator.

A simple means of producing a time rate standard (method C) from the received standard audio frequency is to use a simple a-c generator of any desired frequency mounted on the same shaft with a synchronous motor driven by an amplified alternating voltage from the received frequency. Such a generator can operate an electric clock. Thus may be provided a standard of time rate for short periods, as well as of frequency, of an accuracy not generally available hitherto to laboratories from any service.

Part 4. Standard Time Intervals

The standard intervals of one second provided on Tuesdays and Fridays of each week are accurate, as stated in the Appendix, to better than 0.000 01 second, as sent out from the transmitter. Taken over a longer period of time this figure may be divided by the number of seconds duration of the time interval considered, up to a limit of one part in five million. That is, under ideal receiving and measuring conditions one could measure a time interval of 50 seconds or longer to better than a part in five million. However, measurements to 0.000 01 second are difficult and a longer time interval than fifty seconds would ordinarily be required to obtain a certainty of one in five million. The limitation on accuracy from the vagaries of radio wave transmission are as stated in the section on "Standard audio frequency" in the Appendix. The most accurate time intervals are provided, at any place or time, by that one of the three carrier frequencies which has the least fading.

Measurements of a time interval must be started and completed during either the 5000, 10 000 or 20 000-kc emission. Thus a time interval longer than 1 1/2 hours can not be measured by these signals. This is partly because the transmitter equipment may be readjusted when changing from one carrier frequency to the next, which would destroy the regular sequence of the second pulses.

For high accuracy the radio receiver should be supplied with well regulated power and be accurately tuned. A carrier intensity meter or tuning indicator, (such as the 6E5 tube), would be desirable for detecting fading. Automatic volume control would be helpful. A piezoelectric filter or an audio-frequency filter having a narrow band width should not be used. Audio-frequency circuits having a very long time constant will give the impression of a weak signal or a low percentage of modulation. An oscillograph would be required to make short time measurements to 0.001 second or less. An oscillograph with a suitable viewing screen would be helpful in determining whether subsequent pulses have the same wave form and whether high accuracy is possible.

With appropriate chronographs or oscillographic recording equipment the seconds pulses can be used to measure short or medium length time intervals. With the foregoing equipment or by visual or aural means the seconds pulses can be used to calibrate most time measuring devices.

The seconds pulses are emitted without regard to the absolute time when they begin or end. They cannot be used to determine solar time as can be done with the time signals transmitted from astronomical observatories such as the U. S. Naval Observatory.

Part 5. Standard of Musical Pitch.

Each day (except Saturday and Sunday) from 4:00 P.M. to 2:00 A.M. Eastern Standard Time, the American standard of musical pitch, 440 cycles per second, is broadcast on a frequency of 5000 kilocycles per second. This pitch is for A above middle C. While this service is intended primarily for musicians, it may also be useful to laboratories as a frequency standard in ways similar to those described in Part 3 for the 1000-cycle emissions.

The station call letters WWV are given every ten minutes, starting on the hour. The radiated power is one kilowatt with 100% modulation.

Musicians, musical instrument manufacturers, and others who may be interested in these emissions may listen to the standard "A" tone with a "short wave" or "all wave" radio receiving set.

The radio carrier frequency used is much higher than the well-known frequencies on which the usual broadcast entertainment programs are given. The broadcast receiving sets sold previous to about 1933 will not receive this high frequency but most of the receiving sets now being sold will do so, as will also "short-wave" or "all-wave" receiving sets.

The "all-wave" receivers have a number of scales usually marked in "megacycles" for the higher frequency scales. The scale should be set for 5 megacycles in order to receive the standard "A" broadcasts. This frequency is the same as 5000 kilocycles per second.

In order to receive these broadcasts, considerable care must be used in the tuning of the radio receiver because a slight adjustment of the receiver at high frequencies changes the tuning by a much larger amount than at lower frequencies. The standard "A" tone from the transmitter will not be as loud as the program usually received from stations in the broadcast band. In fact at certain times during the day or night great difficulty may be experienced in satisfactorily receiving the broadcast, because of "static", electrical noise from electrical machines, and other types of interference present at the receiving location.

To facilitate the reception of the standard "A" tone, the following suggestions are given. Turn on the radio receiver and, after allowing a few minutes for it to warm up, adjust the dial to the setting for 5 megacycles. The volume control should be turned well up. The calibration marked on the dial of the receiver may be in error by one or two divisions. To locate the station, slowly adjust the dial of the receiver from two or three divisions below the desired frequency marking on the dial to the same amount above. If the note of 440 cycles per second is heard, adjust the dial very carefully to give the loudest signal and adjust the volume control to give the desired volume or loudness. If no signal is heard, raise the volume control setting and vary the dial as before.

Every ten minutes the 440-cycle tone will be interrupted in a series of long and short intervals providing the call letters WWV, the identification of the station in International Morse telegraph code. Persons not familiar with the code can identify the station by the musical note and its interruption every ten minutes.

Part 6. Bibliography.

Further information on frequency measurements is given in the articles which are listed below in chronological order. Except where noted, they are not issued by, and are not available from, the National Bureau of Standards. These publications can be consulted in public libraries which maintain files of periodicals or copies may be secured from the publishers at the following addresses:

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Hochfrequenztechnik und Elektroakustik. Akademische Verlagsgesellschaft MBH, Leipzig, Germany.
Journal of the Optical Society of America (formerly Journal Optical Society of America and Review of Scientific Instruments). American Institute of Physics, 175 5th Ave., New York, N.Y.
Marconi Review, Marconi's Wireless Telegraph Co., Ltd., Electra House, Victoria Embankment, London, W.C.2, England.
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Proceedings of the Institute of Radio Engineers. 330 West 42d St., New York, N.Y.
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The Journal of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London W.C.2, England.
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Such papers as are issued by the National Bureau of Standards can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C., at the prices stated. The prices quoted are for delivery in the United States and its possessions, and Canada, Cuba, Mexico, Newfoundland, and the Republic of Panama. For delivery to countries other than those, remittance should be increased by one-third to cover postage. Remittances should be made to the "Superintendent of Documents, Government Printing Office, Washington, D.C."

Serial letters and numbers are used to designate Bureau publications. S, "Scientific Paper", is used for reprints from the "Scientific Papers of the Bureau of Standards" (Sci.Pap.BS), This series was superseded by the "Bureau of Standards Journal of Research" in 1928. RP, "Research Paper", designates reprints of articles appearing in the "Bureau of Standards Journal of Research" (BSJ. Research) and the "Journal of Research of the National Bureau of Standards" (J.Research NBS), the latter being the title of this periodical since July, 1934 (volume 13, number 1).

In each reference below, unless otherwise indicated, the first number (underscored) is the volume of the periodical; the numbers following indicate pages and the year of publication. Names of periodicals abbreviated can be found in full in the list of addresses above.

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Department of Commerce,
Washington, D.C.

Attached: Appendix. Standard Frequency and Other Services Broadcast by National Bureau of Standards.

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*Obtainable from Superintendent of Documents, Government Printing Office, Washington, D.C., at price stated. Designate publication by the letter and number appearing just before price.

APPENDIX

STANDARD FREQUENCY AND OTHER SERVICES BROADCAST BY NATIONAL BUREAU OF STANDARDS.

Beginning June 1, 1937, the National Bureau of Standards will make some changes and extensions in the services broadcast by its radio station WWV, at Beltsville, Md., near Washington, D.C. The services will include: (1) standard radio frequencies, (2) standard audio frequency, (3) standard time intervals in the form of pulses accurately spaced one second apart, (4) the standard of musical pitch, 440 cycles per second, and (5) bulletins of information on the ionosphere and radio transmission conditions.

1. Standard radio frequencies.- This service makes generally available the national standard of frequency, which is of value in scientific or other measurements requiring an accurate frequency, and is useful to radio transmitting stations for adjusting their transmitters to exact frequency, and to the public generally for calibrating frequency standards. This service will be given every Tuesday and Friday, (except nationally legal holidays), as heretofore, but the times, character, and frequencies of the emissions will be somewhat changed. The emissions each Tuesday and Friday will be continuous unmodulated, unkeyed waves (CW) except for a short pulse each second as described under 3 below.

The service will be given successively on three radio carrier frequencies, as follows:

10:00 to 11:30 A.M., EST, 5 000 kilocycles (kc/s).
Noon to 1:30 P.M., EST, 10 000 kilocycles (kc/s).
2:00 to 3:30 P.M., EST, 20 000 kilocycles (kc/s).

The power of the transmitter used is approximately 20 kilowatts. The emissions on 5 000 kc/s are particularly useful at distances within a few hundred miles from Washington, those on 10 000 kc/s are useful for most of the rest of the United States, and those on 20 000 kc/s are useful in the western part of the United States and in other parts of the world.

From any single frequency, using harmonic methods, any frequency may be checked.

During the first four and the last four minutes of the 90-minute emission on each carrier frequency, announcements will be given; they will be made by telegraphic keying and by voice, and will include the station call letters (WWV) and a statement of the frequency and the accuracy. The accuracy of the frequencies is at all times better than a part in five million.

2. Standard audio frequency.- On each Wednesday (except nationally legal holidays), a frequency of 1000 cycles per second will be transmitted as a modulation on the same radio carrier frequencies and at the same times of day as listed above. The radiated power will be approximately 20 kilowatts, with 30% modulation.

Except during announcements, the emissions will consist of the uninterrupted 1000-cycle frequency superposed on the carrier frequency. During the first four and the last four minutes of the 90-minute emission on each carrier frequency, announcements will be given; they will be made by telegraphic keying and by voice, and will include the station call letters (WWV) and a statement of the radio carrier frequency and the audio modulation frequency and the accuracy.

The accuracy of the frequencies (both carrier and modulation) as sent out from the transmitting station is at all times better than a part in five million. Transmission effects in the medium (Doppler effect, etc.) may result in slight fluctuations in the frequency as received at a particular place. As far as the carrier radio frequencies are concerned, such fluctuations practically never exceed a part in five million; furthermore, the presence of the audio modulation frequency does not reduce the accuracy of the carrier radio frequency. Under occasional extreme conditions, momentary fluctuations as great as 1 cycle per second may occur in the audio modulation frequency as received. It is generally possible, however, to use the audio frequency with an accuracy better than a part in a million by employing that one of the three carrier frequencies which has the least fading. It is helpful to use automatic volume control and audio-frequency filters to reduce the effects of fluctuations in amplitude or phase of the received audio frequency.

Any desired frequency may be measured in terms of any one of the standard frequencies, either audio or radio. This may be done by the aid of harmonics and beats, or, in the case of the 1000-cycle standard, also by the operation of a simple motor-generator.

The standard 1000 cycles per second is especially useful in the accurate measurement of audio frequencies and time intervals, calibration of tuning-forks, etc.

3. Standard time intervals.- The CW standard frequency emissions each Tuesday and Friday, described under 1 above, will be modulated (30%) by a short pulse once each second (except during announcements). The pulse lasts about 0.005 second and consists of a 1000-cycle modulation on the carrier frequency; this type of pulse was chosen to facilitate its reception by ordinary

radio receivers. The length of the intervals thus marked between each second and the next is accurate within 0.000 01 second, as sent out from the transmitter. Measurements to this accuracy have not been made of these signals as received, but measurements made at one receiving location showed no error within the limits of precision of the measurement, which was about 0.000 03 second. Vagaries occurring in the transmission medium may cause fluctuations materially greater than this at particular places or times where there is excessive fading.

These standard seconds signals constitute a standard frequency of one cycle per second, and are derived from the Bureau's primary standard of frequency which is in turn based upon the standard time service maintained by the U.S. Naval Observatory. They are of special value in physical measurements, in geodetic, seismological, and similar work, in rapid checking of pendulums and chronometer rates, and wherever short time intervals of great accuracy are needed. They are not capable of giving solar time, as needed in navigation, for example, for which astronomical observations or the Navy's time signals are required.

4. Standard of musical pitch.- The American standard of musical pitch, 440 cycles per second for A above middle C, will be broadcast as a modulation frequency every night except Saturday and Sunday (and except nationally legal holidays). It will be a 440-cycle modulation on a radio carrier frequency of 5000 kc/s. The service will be given daily from 4:00 P.M. to 2:00 A.M., EST. The station call letters (WWV) will be given every ten minutes on the even ten minutes by telegraphic keying, so that musicians using the service may be sure they are listening to the right station. The letters WWV are dots and dashes as follows: .-- .-- ...- The radiated power will be one kilowatt, with 100% modulation. The accuracy of the 440-cycle standard pitch is approximately the same as that of the 1000-cycle tone as described under 2 above, i.e., far beyond any musical requirements.

5. Ionosphere bulletins.- Data on the ionosphere and a summary of high-frequency radio transmission conditions will be broadcast each Wednesday afternoon, the same day on which the 1000-cycle modulated emissions are given. The bulletin will be given by voice on each of three radio carrier frequencies, as follows:

1:30 to 1:33 P.M., EST, 10 000 kc/s
1:40 to 1:43 P.M., EST, 5 000 kc/s
1:50 to 1:53 P.M., EST, 20 000 kc/s

The broadcast includes statements of the normal-incidence critical frequencies and virtual heights of the ionosphere layers, and estimated skip distances for a number of frequencies, all based on observations at Washington the day of the broadcast. Both day and night values are given. The information is an aid in choosing optimum frequencies for long-distance communication.

Further information is given in the Bureau's Letter Circular 499, "The weekly radio broadcasts of the National Bureau of Standards on the ionosphere and radio transmission conditions."

General.- Information on how to receive and utilize these various services is given in pamphlets obtainable on request addressed to the National Bureau of Standards, Washington, D.C.

The Bureau welcomes reports of use and comments upon the services. It is desired that users report to the Bureau their experience in using them, including: description of method of use; statement of relative fading, intensity, interference, etc., on the three carrier frequencies; and suggestions for improvement of any details. Correspondence should be addressed National Bureau of Standards, Washington, D.C.