

FIG. 1
Standard wavemeter of the Bureau of Standards

Reducing the Guesswork in Tuning¹

How the Bureau of Standards Will Measure the Wavelengths of Broadcasting Stations with an Accuracy of 99.9%, Making it Possible for Any One to Use His Receiving Set as a Wavemeter

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THE good results already appearing from the recommendations of the Second National Radio Conference could easily be wrecked if the radio broadcasting stations and other stations should not operate accurately on the frequencies to which they are assigned. One of the reasons why interference has been the great draw-back to progress in radio has been that the transmitting stations have used waves which approximated the assigned wavelength or frequency only very roughly indeed. Among its numerous tasks of standardization and research, the Bureau of Standards has devoted itself with some vigor to the task of improving the frequency standards of the country, with the result that there is every prospect that the interference situation will be greatly relieved from now on. The Bureau's work in this direction² has been directed at two objectives:

increasing the accuracy of its standards, and making these standards available to the radio public.

About a year ago the Bureau began a program of work which would materially improve the accuracy of its radio-frequency measurement. Prior to that time the basic wavemeter standards were based entirely on circuits made up of standard capacities and inductances, the values of which were either calculated or measured at low frequencies. These standards were prepared with great care and precautions were taken to avoid errors in the measurements, but there was no certainty that the frequency basis thus established could be relied upon to be correct within less than 1 per cent., particularly for the very high radio frequencies. The work that has been done recently has given a new basis of measurement, resulting from several interesting and quite independent methods of frequency determination, and is much more accurate. The goal set in this work was an accuracy of 99.9 per cent. The reason why this degree of accuracy is important may be seen from a brief consideration of the

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²Among those who are engaged in this important work, under Dr. Dellinger's direction, are Mr. E. L. Hall, the Misses F. Kenyon and G. Hazen, Mr. F. W. Dunmore, Mr. F. H. Engel, and Mr. H. J. Walls.

frequency assignments to broadcasting stations. The waves used by the broadcasting stations are spaced 10 kilocycles apart (3 meters at a wavelength of 300 meters). Thus one station is on 990 kilocycles, another on 1000, and another on 1,010 kilocycles. If one of these is inaccurately adjusted by as much as 0.1 per cent, this would mean a variation of 1 kilocycle from the established value. The next station having a frequency only 10 kilocycles different, this variation of 1 kilocycle is decidedly appreciable in comparison with the 10 kilocycle separation. A variation of the frequency of 1 per cent, for example, would be a variation of 10 kilocycles and could cause one station to be using exactly the wave that had been assigned to another. The whole success of American broadcasting is thus tied up with the placing of broadcasting stations on the correct frequencies to an accuracy approaching 99.9 per cent. Since receiving sets are now available by which an individual can hear the stations from all over the United States on the same night, the importance of this accuracy is apparent.

The basis of frequency measurement of the Bureau of Standards includes absolute frequency measurements by four entirely independent methods. These are:

A. Measurement or calculation of capacity

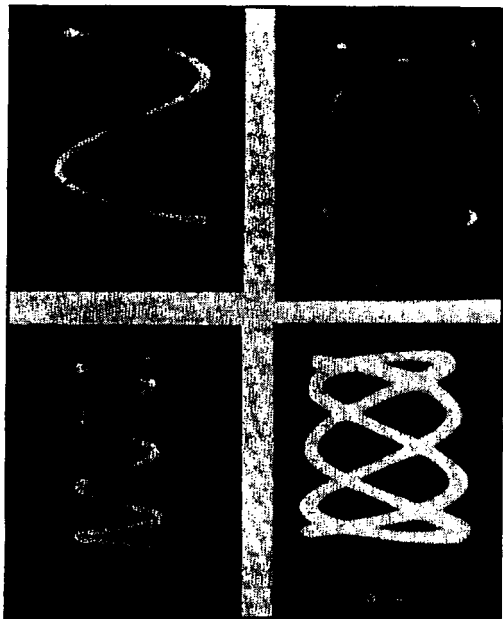


FIG. 2

Lissajous figures giving accurate frequency ratios

and inductance of carefully constructed standard condensers and inductors.

B. Measurement of frequency of the sound from a tuning fork, together with measurement of ratio of such frequency to radio frequencies by use of harmonics from an electron tube generator.

C. Measurement of frequency of the sound of a tuning fork, together with measurement of the ratio of such frequency to radio frequencies by the use of Lissajous figures produced by the direct application of the two frequencies to a cathode-ray oscillograph. This method is free from the assumption of integral ratios involved in the harmonic method (B).

D. Measurement of the actual length of very short waves and calculation of the frequency from this and the known velocity by the relation, $f = v/\lambda$. (λ = wavelength in meters). Ratios of frequencies thus measured, to lower radio frequencies, are obtained by the same general methods for ratio measurements as in B and C.

These four methods are not all that are theoretically possible. Another one that could be used is the accurate measurement of the speed of a radio-frequency alternator. Every method goes back ultimately to the measurement of a time interval.

Method A was the first method to be used by the Bureau of Standards. Where this system is employed, the capacity of specially designed condensers are measured by their charge and discharge at about 1 kilocycle. The inductance of the standard inductors is measured at the same frequency. The design of both capacity and inductance standards is such that there is no appreciable change with frequency. The capacity of coil and leads is measured by the use of harmonics as described on page 100 of the Bureau of Standards Circular 74, entitled "Radio Instruments and Measurements." This standard wavemeter, with its instruments for indicating resonance, is shown in Fig. 1.¹

Method B employs the frequency of a tuning fork as the starting point, measuring the ratio of such frequency to radio frequencies by means of harmonics of the current in an electron tube generator. The use of harmonics for establish-

¹Further information on the standard wavemeter is given in an article now in preparation entitled, "The Standards of Radio Frequency of the Bureau of Standards," by Mr. E. L. Hall, who is in charge of radio standards and testing. The time and place of publication of that article, and others referred to below, will be announced in the Radio Service Bulletin.

ing radio frequency ratios has been described in Circular 74, page 103. The method has been especially developed by Prof. H. Abraham whose apparatus is known as the multivibrator. The multivibrator has not been set up in the Bureau of Standards laboratory, but has been in use in the Naval Radio Research Laboratory located at the Bureau of Standards. Comparisons of this multivibrator and the other methods have been carefully made throughout the range from 18 to 3600 kilocycles.

In method C, the frequency of a tuning fork is carefully measured with a chronograph, and ratios of this to frequencies in the radio range are measured by the use of the cathode-ray oscillograph. This device is a special kind of vacuum tube in which a beam of cathode rays produces a spot of light on a fluorescent screen placed in the end of the tube. When the beam is deflected the spot moves across the fluorescent screen. Provision is made for deflecting the beam in two directions at right angles to each other by two pairs of small condenser plates to which controlled voltages may be applied. When two alternating voltages are applied which have frequencies related by a simple ratio, the spot of light traces out a Lissajous figure on the fluorescent screen. The shape of the Lissajous figure tells the ratio; the examples in Fig. 2 show this. The two pairs of deflecting plates are connected in parallel with the condensers of two independent generators of currents of audio or radio frequency. In the first step of the standardization process, the "low-frequency" generator, Fig. 3, is an electron tube generator of approximately 1 kilocycle, the frequency of which is determined by the tuning fork. The "high-frequency" generator is an electron-tube generator having a frequency anywhere from $1\frac{1}{2}$ to 22 times this, the frequency being varied until successive Lissajous figures appear on the screen. The frequency ratio thus measured is extremely accurate, being in all cases closer than the accuracy of setting of the standard wavemeter, which is tuned to the frequency of the "high-frequency" generator. The method was largely developed by Mr. R. T. Cox. Its use will be described in a separate publication entitled, "Primary Radio Frequency Standardization by Use of the Cathode-Ray Oscillograph," by Misses F. Kenyon and G. Hazen.

In method D, a direct measurement of the wavelength of short waves on wires is made by coupling a short-wave generating set (Fig. 4) to

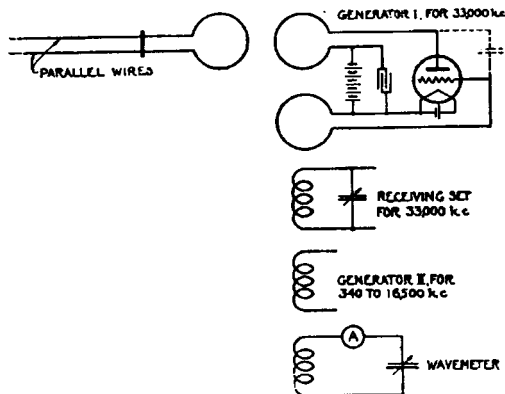


FIG. 3

Showing connections of generators whose frequencies are compared by the cathode-ray oscillograph

a loop of wire connected to one end of two long parallel wires approximately 4 centimeters apart. A short wire at right angles to the parallel wires, and containing a thermo-element is moved along the parallel wires and the positions of successive maxima of current are noted. The distances between these positions are each a half wavelength. They are measured with a steel tape, and agree within a few hundredths of one per cent, for the wavelengths used, 9 and 16 meters. These wavelengths correspond to frequencies of approximately 33,000 and 19,000 kilocycles respectively. These frequencies are not so high as to be beyond practical application in radio telegraphy and telephony. Experiments at the Bureau have shown how to produce them and to use them for communication as well as for measurements.

The method of harmonics has been used to step down from the very high frequencies thus produced and measured to radio frequencies in the whole range down to 340 kilocycles. This is done by placing between generators I and II (Fig. 5) a receiving set tuned to the frequency of generator I which produces the current in the parallel wires. Generator II is an auxiliary, the frequency of which is varied until one of its harmonics approaches the frequency of generator I. The frequency of Generator II is adjusted until the beat note heard in the receiving set becomes zero. The wavemeter is meanwhile tuned to the frequency of the generator II. The frequency for that setting of the wavemeter is then the frequency obtained from the wavelength measured on the parallel wires, divided by the number of the

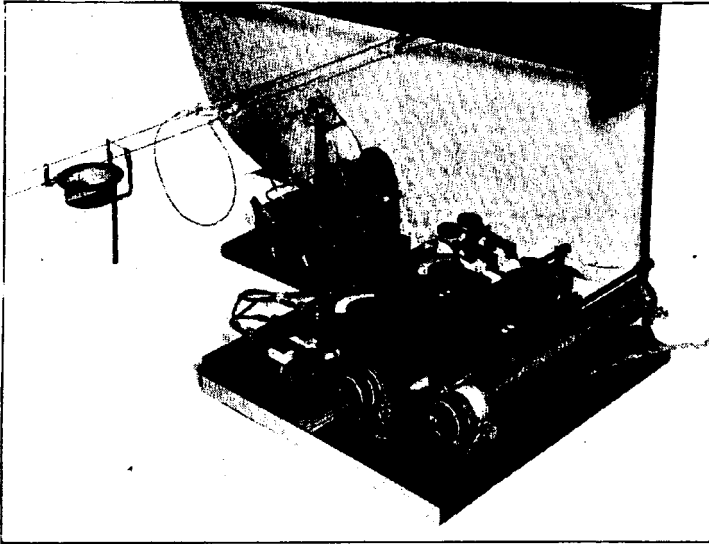


FIG. 4

Generator, detecting instrument, and end of parallel wires used to measure very high frequencies

harmonic. The measurement of these very high frequencies and establishment of the frequency basis by this method is described in a paper prepared by Messrs. F. W. Dunmore and F. H. Engel entitled, "A Method of Measuring Very Short Wave Lengths and Their Use in Frequency Standardization."

The step down from the very high frequencies to some of the more commonly used radio frequencies can also be made by the cathode-ray oscillograph, as described above, obtaining a Lissajous figure directly between the very high frequency and a lower one from an auxiliary generator, the latter frequency being measured by the wavemeter. The method is difficult at such high frequencies, and the work is still in progress.

The results of the independent establishment of the frequency basis by methods A, B, C, and D have been intercompared and the order of agreement is 0.1 per cent. to 0.2 per cent. When the present series of measurements is completed, the Bureau of Standards frequency basis will be certainly accurate well within 0.1 per cent. This frequency basis extends from 3.5 to 33,000 kilocycles.

While an accuracy of 0.1 per cent. is all that has been sought, for present needs, this will clearly not be adequate for the future. It is highly desirable for some purposes to place a heterodyne receiving set on a definite pre-

determined frequency with great accuracy. It would be possible to recognize transmitting stations by the beat note produced in such a heterodyne receiving set. This is important for certain Navy requirements. In order that the beat note may not vary from the pre-determined value by more than, say 100 per second, this means that the station which it is desired to receive should have its frequency adjusted accurately to $\frac{1}{10}$ of a kilocycle which is 0.01 per cent. for a frequency of 1,000 kilocycles. It will be quite possible in the next year or two to attain this accuracy (0.01 per cent.) through further series of careful measurements and particularly by improvements in

the frequency standards and methods of indicating resonance.

The frequency standards have in past years been made available to the country only through the standardization of wavemeters at the Bureau of Standards. This service is now extended through the transmission of standard frequency signals and through measurements at the Bureau of the frequency of various transmitting stations. Only a small amount of direct wavemeter standardization can be done by the Bureau. Because of the Bureau's limited personnel, it has been necessary to restrict tests of wavemeters and other apparatus solely to important standards. The transmission of signals of standard frequency, however, which was begun in March of this year, places the frequency standards in the hands of all who care to use them. These signals are sent out approximately monthly, with special repetitions weekly during May and June, 1923. Starting at 11 P. M., so as not to disturb broadcast programs, some eight or ten standard frequencies are transmitted, the intervals between transmissions on the particular frequencies being approximately 15 minutes. Announcements are given both in radio telephony and in continuous-wave telegraphy, and the standard frequency is transmitted as a series of long dashes and the letters WWV. Methods by which these waves can be received

and wavemeters standardized are very simple. Information on this matter is given in Bureau of Standards Letter Circular No. 92, a limited supply of which is available at the Bureau of Standards, Washington, D. C. The standard frequency signals are transmitted with an electron tube set rated at 1 KW, having a radiation of approximately 150 meter-amperes. The schedules of transmission are announced in the newspapers and in the Radio Service Bulletin. The transmission and utilization of the standard frequency signals are further described by an article in preparation by Mr. H. J. Walls, entitled, "Radio Signals of Standard Frequency."

These signals are received and used throughout the United States east of the Mississippi River. No permanent means have as yet been provided for extending this range to cover the western part of the United States. One method that may be used is the transmission of signals, the frequency of which is kept constant for a certain number of minutes, by a Mid-Western broadcasting station. Measurements of this transmission can then be made by any one, using the same methods as are used for receiving the Bureau of Standards signals of standard frequency. The measurements will simultaneously be made by the Bureau of Standards and the values so measured will be announced by the Bureau.

A final method of supplying frequency standards uses the ether itself as a wavemeter. The transmitting stations operating on definite frequencies are the points on this wavemeter. Broadcasting and other stations will more and more from now on utilize a radio frequency indicator to assure operation on the assigned frequency every time they transmit. Measurements of the actual transmitted frequencies of various stations are made from time to time at the Bureau of Standards. When these measurements for a given station show great

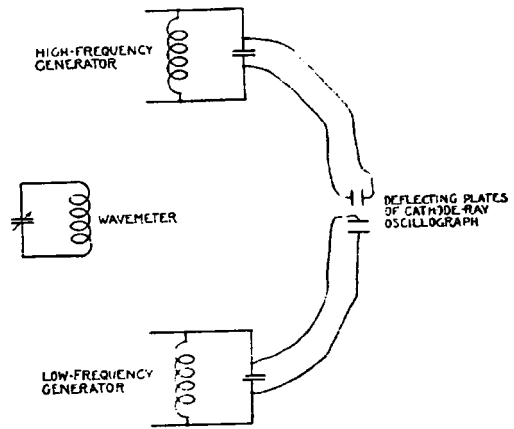


FIG. 5
Arrangement of apparatus for stepping down from very high frequencies

constancy, and the station is known to use a suitable frequency indicator, so that the Bureau is convinced that the station's operating wave can be used as a frequency standard, the Bureau will so announce. These announcements will probably be made in the Radio Service Bulletin. The transmissions from such stations can then be used as known points on the ether wavemeter.

Summarizing, means have been provided whereby accurate frequency adjustment of radio stations is possible. Great improvements have been made in the primary frequency standards and in their availability to the public. This will of itself remove a large portion of existing radio interference and make it possible to realize the benefits of the new frequency allocations recommended by the Second National Radio Conference. It seems quite certain that before long the ether itself will be a standard wavemeter with the frequencies of a number of the transmitting stations as its fixed points.

Next Month! The Ultimate Receiver

Mr. Walter Van B. Roberts, whose articles "A Single-Tube Loop Set in a Brief Case" and "Operating a Loud Speaker on One Tube, Without Batteries" appeared in our May and June issues, respectively, is preparing another article—just as interesting and even more important—for our August number. In building the particular kind of super-heterodyne receiver which he is going to describe, Mr. Roberts has incorporated suggestions from the best technicians of to-day. Although having but two wavelength controls, this receiver is to combine the best there is in the super-heterodyne, the neutrodyne and inverse-duplex methods. With a laboratory model, Mr. Roberts is hearing KFI and KHJ (from Princeton, N. J.) on a loop and five tubes. We know of no receiver that exists which will compare in selectivity, long range and ease of operation with the one which Mr. Roberts will describe in RADIO BROADCAST for August.—THE EDITOR.