A METHOD OF MEASURING VERY SHORT RADIO WAVE LENGTHS AND THEIR USE IN FREQUENCY STANDARDIZATION*

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I. Importance of Wave Frequency Standardization

The rapid increase in the number of radio transmitting stations thruout the country and the subsequent increase in the interference produced by these stations has led to the assignment of new frequencies to these stations by the Department of Commerce.[1] In this new allocation the frequencies assigned to the various transmitting stations are closer together than before. These wave frequencies, in the case of the radio broadcasting stations, are 10 kilocycles apart, and the separation is even less in other classes of service. It is obvious that the effectiveness of these frequency assignments is dependent on the accuracy with which each station is adjusted to its allotted frequency, and the care with which these frequencies are maintained.

Radio inspectors and station operators will be able to maintain the stations closely on the assigned frequencies as a result of recent work by the Bureau of Standards in improving the accuracy of its frequency standards and making these standards more generally available.[2] Several independent methods of establishing the standard of frequency were used and satisfactory agreement between them obtained. It is the purpose of this paper to describe in detail one of the methods of frequency standardization. In this method the basis of the frequency

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[1] See "Report of Second National Radio Conference" in "Radio Service Bulletin," April, 1923.

[2] A brief general description of this work may be found in an article by J. H. Dellinger which appeared in "Radio Broadcast," July, 1923, page 241.

determination was the direct measurement of the wave lengths of very short waves.

II. Principle of Method Employed

The method was based on the direct measurement, in linear measure, of the wave length of very short standing waves on a pair of parallel wires. The waves thus used as a basis had a frequency[3] of 33,000 to 19,000 kilocycles, or wave lengths from 9 to 16 meters. The production and measurement of these waves is described in III below. Frequencies of lower values, that is, in the usual radio range, are measured in terms of these ultra-radio frequencies thru a process in which accurate frequency ratios are determined from harmonics of an electron tube generator. This process makes use of the harmonics in a low-frequency (relatively long wave) generating set, which when combined with the ultra-frequency (short wave) generating set produces a beat note in a receiving set tuned to the ultra-frequency (short wave) generating set. For example, suppose a generating set *B* (see Figure 1) to be operating at a frequency of 30,000 kilocycles (10 meters), this wave length being accurately measured and maintained by a method to be described below. Another

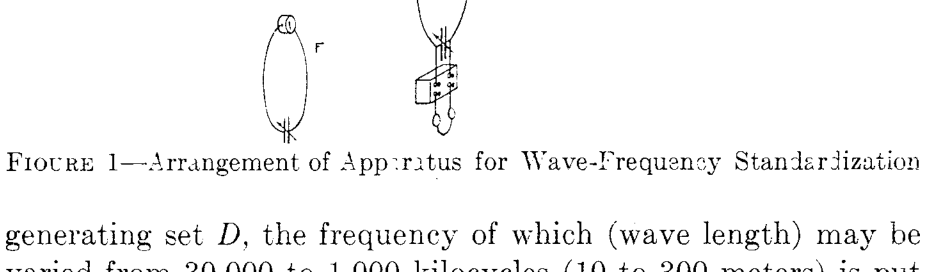

Figure 1—Arrangement of Apparatus for Wave-Frequency Standardization

generating set *D*, the frequency of which (wave length) may be varied from 30,000 to 1,000 kilocycles (10 to 300 meters) is put in operation near the first set *B*. A receiving set *C* placed near both generating sets is tuned to 30,000 kilocycles (10 meters). The wave length of *D* is adjusted until it is about equal to that of *B* by measuring it just as *B* was measured. When it is so

[3] Wave length in meters is converted to frequency in kilocycles by dividing 299,820 by the wave length. For most purposes the approximate ratio, 300,000, is sufficiently accurate.

adjusted the difference in frequency between *D* and *B* produces a beat note which is heard in the receiving set *C*. This note disappears when the exact adjustment is obtained, that is, when the two frequencies are indentical. This process is known as the zero beat note method. The frequency of *D* is then gradually decreased until a second beat note is heard in *C*, and this is likewise made to disappear by exact adjustment. This beat note indicates that *D* has been adjusted to 15,000 kilocycles (20 meters), and that its second harmonic 30,000 kilocycles (10 meters), is producing a beat note with *B* which is heard at *C*. The wavemeter *E* is then adjusted to resonance with *D*, thus establishing the 15,000 kilocycle (20 meter) point on it. The frequency of *D* is further decreased until another beat note is heard in *C*. This means that *D* has been decreased to 10,000 kilocycles (30 meters), its third harmonic which is 30,000 kilocycles (10 meters) combining with *B* giving the beat note heard in *C*. The wavemeter *E* is then adjusted to resonance with *D* and establishes the 10,000-kilocycle (30 meter) point on the wavemeter. Thus by continually decreasing the frequency of *D*, the 4th, 5th, 6th, etc., up to the 30th harmonic may easily be utilized and the wavemeter *E* calibrated down to 1,000 kilocycles (300 meters). By changing the frequency of generating set *B* to 20,000 kilocycles (15 meters), the wavemeter *E* may be calibrated by a similar process down to a frequency of 300 kilocycles (1,000 meters), and so on. The method outlined above requires the following:

A. The development of apparatus for the generation of very high frequencies or short waves.

B. An accurate means for measuring waves of this order of length.

C. Means for utilizing the short-wave generating set thus standardized for determining the frequency of the low-frequency generating set which in turn is used for the calibration of the standard wavemeter.

III. Apparatus Used

A. Ultra Radio-frequency Generating Set

For the purpose of making these measurements an ultra radio-frequency generating set was necessary.[4] The one as constructed is shown in Figure 2. Figure 3 gives the circuit diagram. Coil *C*

[4] See "Directive Radio Transmission on a Wave Length of 10 Meters," by F. W. Dunmore and F. H. Engel. "Bureau of Standards Scientific Paper," number 469.

*Diameter of number 12 Brown and Sharpe gauge wire = 0.0808 inch = 0.0317 cm.

consists of a single turn 18.5 cm (7.3 in.) in diameter of number 12 Brown and Sharpe gauge copper wire* for plate coupling and a similar turn *D* for grid coupling. The coils *C* and *D* were spaced about 3 cm. (1.18 in.) apart. *J* is a radio-frequency by-pass condenser and may also be used to vary the wave length slightly. The three-electrode tube used was rated at 50 watts. It was a coated filament type. The capacity between the elements of the tube together with the coils *C* and *D* form the oscillatory

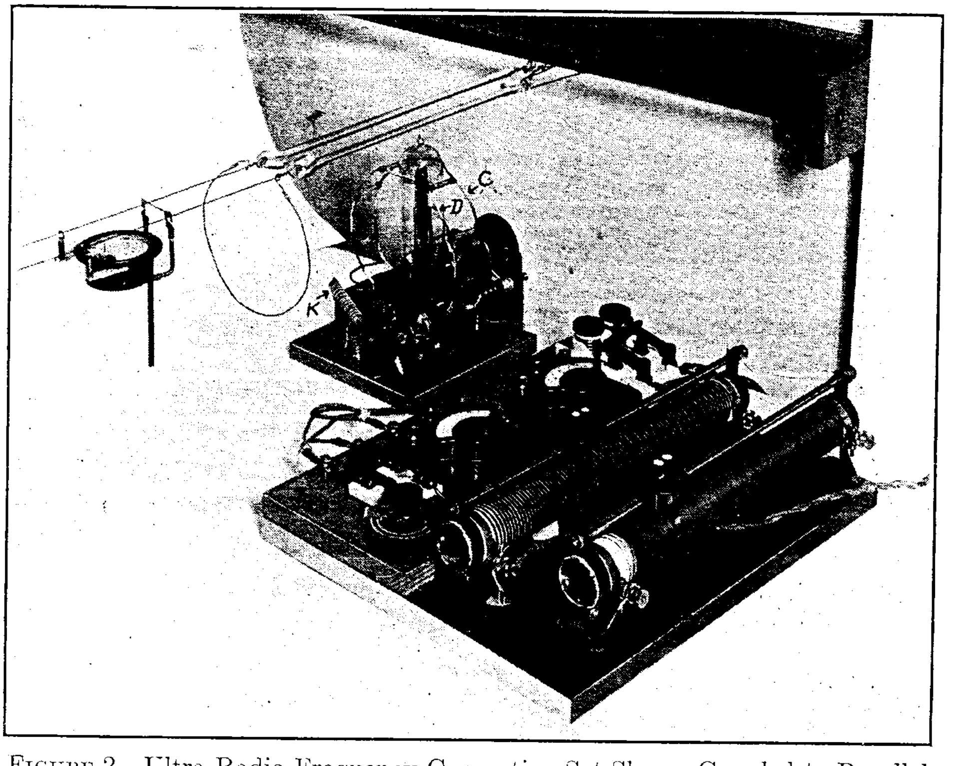

FIGURE 2—Ultra Radio-Frequency Generating Set Shown Coupled to Parallel Wire System

circuit. It is this internal capacity which determines the upper limit of the frequencies obtainable with a given tube. To keep the radio-frequency currents out of the battery circuits, three choke coils were used as shown at *K*. These consisted of thirteen turns of number 20 copper wire* wound ¼ inch (0.64 cm.) apart on a wooden core ½ inch (1.27 cm.) in diameter. These chokes were found necessary to maintain stable operation of the generating set. This generating set produced a frequency of 33,000 kilocycles (wave length of 9 meters). By connecting a variable air condenser across the grid and plate, the frequency could be decreased to 17,640 kilocycles (17 meters).

*Diameter of number 20 wire = 0.032 inch = 0.081 cm.

B. Apparatus for Measuring Short Wave Lengths

The apparatus used for measuring[5] these ultra frequencies is shown in Figure 2.

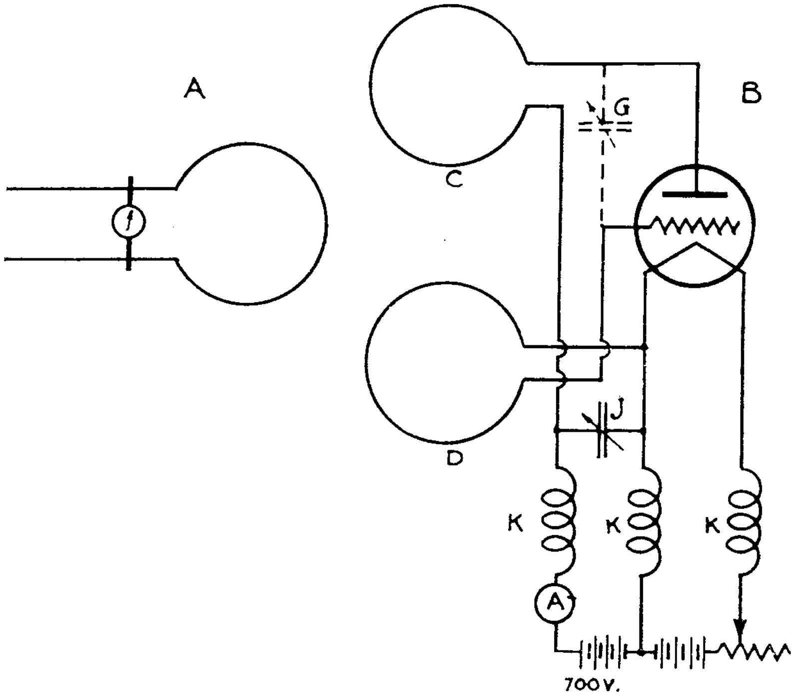

Figure 3—Circuit Diagram of 33,000 to 19,000 Kilocycles (9 to 16 meters) Generating Set

The parallel wire system used is shown terminating in a wire loop. The system consisted of two parallel number 14 bare copper wires† about 45 feet (13.7 m.) long strung between glass insulators as shown. The wires were separated about 4 cm. (1.58 in.) and were held under tension by means of two heavy springs (not shown). The ultra radio-frequency generating set was coupled to the looped end as shown. The apparatus to the right is the control panel, by means of which the output of the generating set is held constant. The wave length is measured by moving the thermo-galvanometer, to be seen suspended from the wires, along the wires until it shows a maximum indication of current. This point is marked on the wires and the galvanometer moved still further along the wires until a second current maximum is indicated. The distance between these two points of current maxima is one-half a wave length. If the parallel wires are sufficiently long, a number of such points may

[5] See "Electric Oscillations in Straight Wires and Solenoids," by J. S. Townsend and J. H. Morrell, "Philosophical Magazine," August, 1921.

†Diameter of number 14 wire = 0.064 inch = 0.0163 cm.

be found. Considerable work was done in order to find the best method of indicating the resonance point. The one finally adopted was the sliding thermo-galvanometer as shown suspended from the wires in Figure 2. It consists of a sensitive thermo-galvanometer (full scale deflection = 115 milliamperes), the terminals of which are connected to the two wires thru sliding contacts shown at the right. The two supports at the left are insulated from the instrument. An interesting point in connection with the use of this instrument at frequencies of 30,000 kc. (10 meters) was that a low resistance shunt across the terminals of the instrument greatly improved the accuracy with which this instrument could be set on the current maxima. The shunt consisted of a piece of number 14 copper wire soldered across the instrument terminals at the sliding contact. This shunt is clearly shown in Figure 2. By the use of this shunt the resistance of the circuit was materially decreased so that the sharpness of resonance was greatly improved. In fact, the point of maximum current was so critical that a movement of the galvanometer 1 millimeter (0.04 inch) either way along the wire at the point of maximum current indication gave a very noticeable decrease in deflection. With such a sensitive indicator it is apparent that the locations of the current maximum may be accurately obtained and the distance between them determined with great precision. A calibrated steel tape was used for measuring distances on the parallel wires. Several measurements of wave lengths of the order of 9 meters have shown variations of only 1 millimeter in 4.5 meters. Thus the indicating instrument may be set on the current maximum to within an accuracy of 1 part in 4,500. Much experimental work was done on the parallel wire method of wave length measurement in order to determine any possible sources of error. Measurements were made under various conditions such as different lengths of wires, different spacing between wires, different size wire, and different methods of indicating current maximum, but none of these changes influenced the accuracy of the measurements. Measurements were also made on an entirely different parallel wire system located on the roof of the radio laboratory. As a check on the method, the results of these measurements were compared with those obtained indoors on much shorter wires, by means of ultra radio-frequency wavemeter shown in Figure 4. This instrument had a range of approximately 35,000 kc. to 32,000 kc. (8.5 to 9.5 meters) and was calibrated by means of the parallel wire system located on the roof and by two different methods of indi-

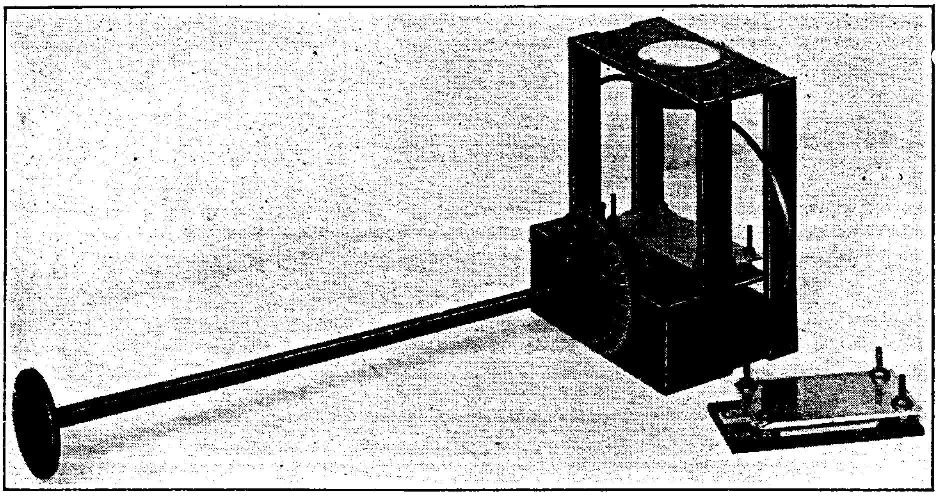

FIGURE 4—Ultra Radio-Frequency Wavemeter

cating the resonance points on the shorter parallel wire system indoors. The results of this calibration are shown in curve form in Figure 5. It will be seen from these three curves, which are practically coincident, that the parallel wire method of wave length measurement as used is reliable. This method of checking the parallel wire measurements of wave length would undoubtedly have revealed any inherent error.

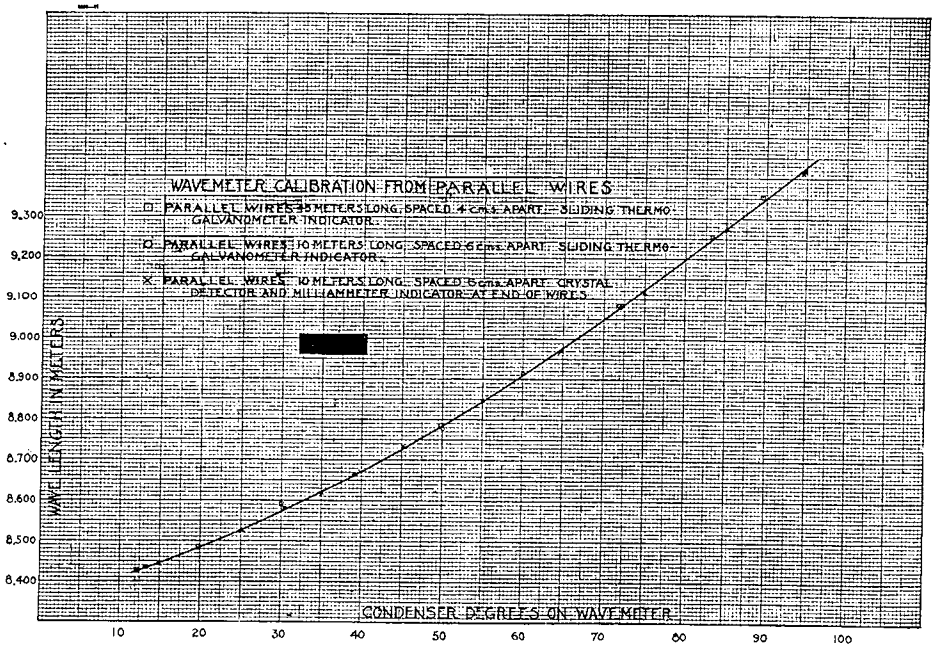

FIGURE 5

C. ULTRA RADIO-FREQUENCY WAVEMETER

For the purpose of investigating the accuracy of the method of wave length measurements on parallel wires and in order to keep a check on the steadiness of the frequency of the ultra radio-frequency generating set when using it to establish wave length standards, an ultra radio-frequency wavemeter as mentioned above was constructed. It is shown in Figure 4. This instrument consisted of a single turn of number 5 Brown and Sharpe gauge copper wire,* the terminals of which were connected to a 50 micromicrofarad 2-plate variable air condenser. A fixed air condenser was connected in parallel with the variable air condenser. It consisted of two fixed plates spaced approximately 3/64 inch (0.12 cm.) apart. The upper plate was 2⅛ inches (5.4 cm.) by 4⅝ (11.7 cm.) inches. The lower plate was 1¾ inches (4.43 cm.) by 4 inches (10.2 cm.). This air condenser was removable so that one of different capacity could be inserted, thereby increasing the range of the wavemeter. Such a 2-plate air condenser is shown in Figure 4 beside the wavemeter. A thermo-galvanometer is inserted in series with the single turn. It is shunted with a piece of number 14 Brown and Sharpe gauge copper wire 1¼ inches (3.16 cm.) long. The wavemeter condenser was provided with a long handle so that the capacity effects of the operator's body were avoided when adjustments were being made.

D. Low Radio-Frequency Generating Set

In stepping up from the wave lengths measured on the parallel wires to the longer wave lengths, ordinarily used for radio communication, a generating set rich in harmonics and variable in frequency from 300 to 16,600 kc. (18 to 1,000 meters) was employed. This is shown in Figure 6. By means of a set of interchangeable coils, the frequency may be varied over the range from 300 to 16,600 kc. (18 to 1,000 meters). A set of single-turn, two-turn, and six-turn coils are shown in the photograph. These may be easily substituted in the plate and grid circuit of the tube. The frequency may also be varied by means of three variable air condensers connected in parallel across the grid and plate of the electron tube generating set. The larger of these condensers has a capacity of 0.001 microfarad, the next 0.0001, and the smallest about 0.00005 microfarad. This latter condenser is provided with a long insulated handle so that the final adjustment for zero beat note may be more easily obtained.

*Diameter of number 5 wire = 0.182 inch = 0.461 cm.

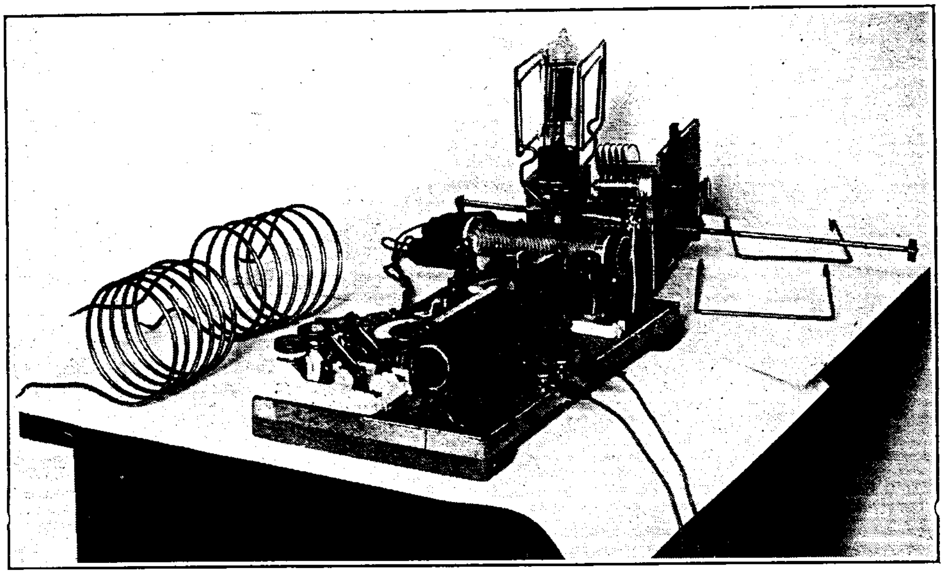

FIGURE 6—Low Radio-Frequency Generating Set

E. ULTRA RADIO-FREQUENCY BEAT-NOTE RECEIVING SET

An ultra radio-frequency receiving set was used for the purpose of determining when the low-frequency generating set was tuned so that one of its harmonics was equal to the frequency of the ultra radio-frequency generating set. This is shown in Figure 7. It was designed to cover a frequency range of approximately 15,000 to 37,000 kc. (8 to 18 meters). The tuning element consists of a single turn of number 12 Brown and Sharpe gauge copper wire* connected to a 0.00025 microfarad variable air condenser, the terminals of which were connected to the input of an electron tube detector with two stages of audio-frequency amplification. This receiving set was located about five feet (1.53 m.) from the two generating sets. By tuning it to the frequency of the ultra radio-frequency generating set, confusion caused by the presence of beat notes from harmonics in the ultra radio frequency generating set, was eliminated.

IV. STANDARD WAVEMETER CALIBRATION

The wavemeter standardized in the course of these measurements was the standard wavemeter of the Bureau of Standards.[6] The following is a detailed description of the procedure employed when calibrating the standard wavemeter using the method and apparatus described above. A comparison of this calibration

*Diameter of number 12 wire = 0.0808 inch = 0.0317 cm

[6] See "Standard Radio Wavemeter, Bureau of Standards Type R70-B," by R. T. Cox, "Journal of the Optical Society of America," volume 6, number 2, page 162.

with two other calibrations obtained by entirely different methods agreed within 0.2 per cent.

The ultra radio-frequency (short-wave) generating set was put into operation and its wave length accurately determined by means of the parallel wire measurements. It was found to be 9.005 meters, which is equivalent to 33,290 kc. During the course of the calibration these parallel wire measurements were repeated from time to time to insure the constancy of the frequency of the generating set *B*. The wavemeter *F* was used as a constant check on the frequency of the generating set *B*, and thus reduced the number of parallel wire measurements considerably.

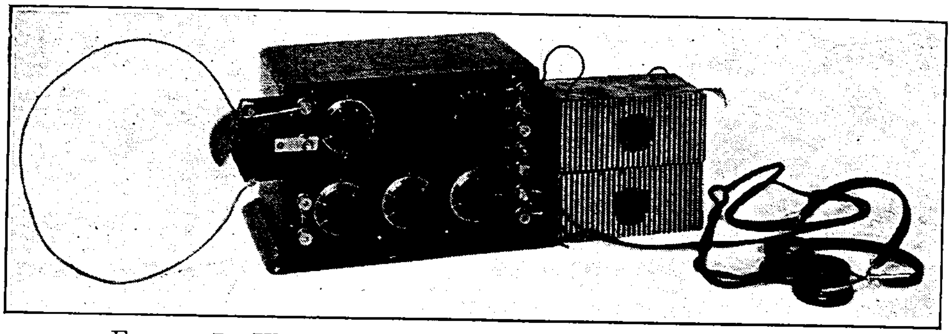

FIGURE 7—Ultra Radio-Frequency Beat-Note Receiving Set

The generating set *D*, Figure 1, was next started and its frequency adjusted to be approximately 16,645 kc. (18.010 meters) by using the parallel system. The operator using the receiving set *C* adjusted the frequency of generating set *D* until a beat note was heard. This beat note is equal to the difference in frequency between the second harmonic of generating set *D* and the fundamental of generating set *B*. Using the vernier condenser on generating set *D*, its frequency may be adjusted until the beat note becomes inaudible, thus indicating that the frequency of the first harmonic of generating set *D* is exactly equal to the fundamental of generating set *B*. From this it follows that the fundamental frequency of the generating set *D* is one-half that of the fundamental of generating set *B*, or $=\frac{33{,}290}{2}$ kc. $=16{,}645$ kc. (18.010 meters).

The wavemeter *F* which was to be calibrated was next tuned to resonance with the fundamental of generating set *D*, the beat note being held at zero. This fixed the 16,645 kc. (18.010 meter) point on the wavemeter.

To obtain the next point on the wavemeter, the frequency of the generating set D was slowly decreased until a second beat note was heard at the receiving set C. This beat note indicated the presence of the third harmonic of the generating set D. No intermediate beat notes were heard because the receiving set was tuned to 33,290 kc. (9.005 meters). By careful adjustment of the generating set D, the zero beat note was obtained as before.

After this adjustment had been made, the fundamental frequency of the generating set D is one-third that of the fundamental of generating set B or $\frac{33,290}{3}$ kc. = 11,096 kc. (27.015 meters). The wavemeter E is again tuned to resonance with the fundamental of the generating set D, thus establishing the 11,096-kc. (27.015-meter) point on the wavemeter.

This process was repeated until the 34th harmonic of generating set D was reached, giving a calibration of wavemeter E up to 979.2 kc. (306.17 meters). By changing the fundamental of generating set B to 18,367 kc. (16.324 meters) the wavemeter E was calibrated by the same process to a frequency of about 352.7 kc. (850 meters).

This process can be extended to calibrate a wavemeter of much greater range by decreasing the frequency of generating set B.

Conclusion

The direct measurement of very short wave lengths by means of standing waves on parallel wires was found to be convenient, practical and accurate. The method of setting a radio-frequency generating set on a given frequency by means of the zero beat method was found to be an extremely simple and reliable one.

This in combination with the parallel wire method of precision wave length measurement gives a combination with which wave frequency standards may be accurately determined.

Radio Laboratory,
Bureau of Standards,
Department of Commerce,
Washington, D. C.
June 27, 1923.

SUMMARY: The paper describes one method of establishing frequency standards employed by the Bureau of Standards which is based on the direct measurement, in linear measure, of the wave length of very short standing waves on a pair of parallel wires. The wave lengths measured were from 9 to 16 meters, the currents having frequencies from 33,000 to 19,000 kilocycles per second. The apparatus for generating these ultra radio-frequency cur-

rents is described, as well as the details of the method used in measuring the wave length of the waves which they produce on the parallel wires.

A method is described for calibrating a wavemeter at frequencies from 30,000 kilocycles to 352 kilocycles (10 to 850 meters). This method makes use of the harmonics in a second radio-frequency generating set, one of which, when combined with the output from the ultra radio-frequency generating set, produces a beat note in a receiving set tuned to the ultra radio-frequency. The zero beat note method is used to obtain an exact setting. Knowing the frequency of the ultra radio-frequency generating set by direct measurement on the parallel wires, and the order of the different harmonics being used in the second radio-frequency generating set, the frequency of the latter may be determined over the range from 30,000 kilocycles to 352 kilocycles (10 to 850 meters).