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MONITORING THE STANDARD RADIO-FREQUENCY EMISSIONS

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ABSTRACT

The method and equipment used in monitoring the standard frequency emissions are described in this paper. The emissions are continuously recorded in terms of the primary standard of frequency maintained by the Bureau. By means of selector circuits and frequency multipliers the received signal is heterodyned with the appropriate harmonic of the primary standard. The beat frequency is then recorded on a recording potentiometer by means of a circuit arrangement which produces a potential difference that is proportional to the frequency difference. The records show that the emissions have been in agreement with the primary frequency standard within two parts in one hundred million at practically all times, and the absolute value of the frequency transmitted is rarely in error by as much as one part in ten million.

CONTENTS

I. INTRODUCTION

The radio transmitting station of the National Bureau of Standards is located near Beltsville, Md.,[1] which is about 13 miles northeast of the Bureau's principal radio laboratory. Standard radio frequencies are transmitted regularly from the Beltsville station. Prior to February 1, 1935 [2] an unmodulated wave having a frequency of 5,000.000 kc/s was transmitted each Tuesday from noon to 2 p. m., and from 10 p. m. to midnight, EST. The transmitted frequency is obtained by means of suitable frequency multipliers from a piezo oscillator,[3] located at the transmitting station, which has a fundamental frequency of 200 kc/s. A precise frequency adjustment is provided on this standard so that the transmitted frequency can be readily brought into exact agreement with the primary frequency

[1] BS J. Research **12**, 1 (1934) RP630.

[2] Beginning February 1, 1935, and continuing each Tuesday and Friday thereafter (except legal holidays), three frequencies will be transmitted as follows:

Time (EST)	kc/s
12 noon to 1 p.m.	15,000
1:15 to 2:15 p.m.	10,000
2:30 to 3:30 p.m.	5,000

[3] BS J. Research **11**, 59 (1933) RP576.

standard [4] in the principal radio laboratory, Washington, D. C. Although the standard at the transmitting station normally maintains agreement with the primary frequency standard within the desired limits for a period of 2 hours, which is the duration of a standard frequency emission, frequency comparisons against the primary standard are made continuously during the emissions, so that a readjustment of the frequency could be made if it became necessary and also as a check on the proper operation of the transmitter. Special apparatus was developed which automatically records the frequency difference between the transmitted frequency and the primary standard.

II. METHOD USED IN MAKING FREQUENCY MEASUREMENTS

The method used in making the frequency measurements is indicated schematically in figure 1. Receiver no. 1 is connected to the antenna and to one of the outputs of the auxiliary oscillator. The frequency of the auxiliary oscillator is approximately 1000.120 kc/s. The receiver being tuned to 10,000 kc/s amplifies the second harmonic of the signal received from the transmitter and the tenth harmonic of the frequency of the auxiliary oscillator. The two signals, which are amplified by receiver no. 1, differ by 1,200 cycles per second. The result is that an audiofrequency of 1,200 cycles per second is produced in the output of this receiver. The other receiver, no. 2, is connected to the output of one of the units of the primary standard, no. 6 in figure 1, and output of the auxiliary oscillator. This receiver is likewise tuned to 10,000 kc/s and thus amplifies the one-hundredth harmonic of the primary standard and the tenth harmonic of the auxiliary oscillator. Assuming the frequency of this primary standard to be 100.00004 kc/s, the two frequencies amplified by this receiver differ by 1,196 cycles per second and an audiofrequency of 1,196 is produced in the output of receiver no. 2. The outputs of the two radio receivers are then combined and connected to an audiofrequency amplifier. These two audiofrequencies alternately reinforce and interfere so that the resulting output of the audiofrequency amplifier carries a frequency which is equal to the difference between the two audiofrequencies, or 4 cycles per second in the example cited. If one calculates the frequency difference between the second harmonic of the transmitted signal and the one-hundredth harmonic of the primary standard, it is seen that it is 4 cycles per second. The beat frequency on the output of the audiofrequency amplifier, thus, is the difference between the frequency of the primary standard, no. 6, and the second harmonic of the transmitted signal, and is independent of the frequency of the auxiliary oscillator, the latter serving only to provide a carrier frequency. In order to determine the frequency of the transmitter at any given instant it is necessary to measure this beat frequency. For this purpose a special form of beat recorder was developed. The frequency of the transmitter can then be calculated if it is known whether the transmitter is higher or lower than the corresponding harmonic of the primary standard. The direction of the difference is determined by making a check against another unit of the primary standard which is known to be higher or lower than the one previously used.

[4] Elmer L. Hall, Vincent E. Heaton, and Evan G. Lapham. *The national primary standard of radio frequency*. BS J. Research 14, 85 (1935) RP759.

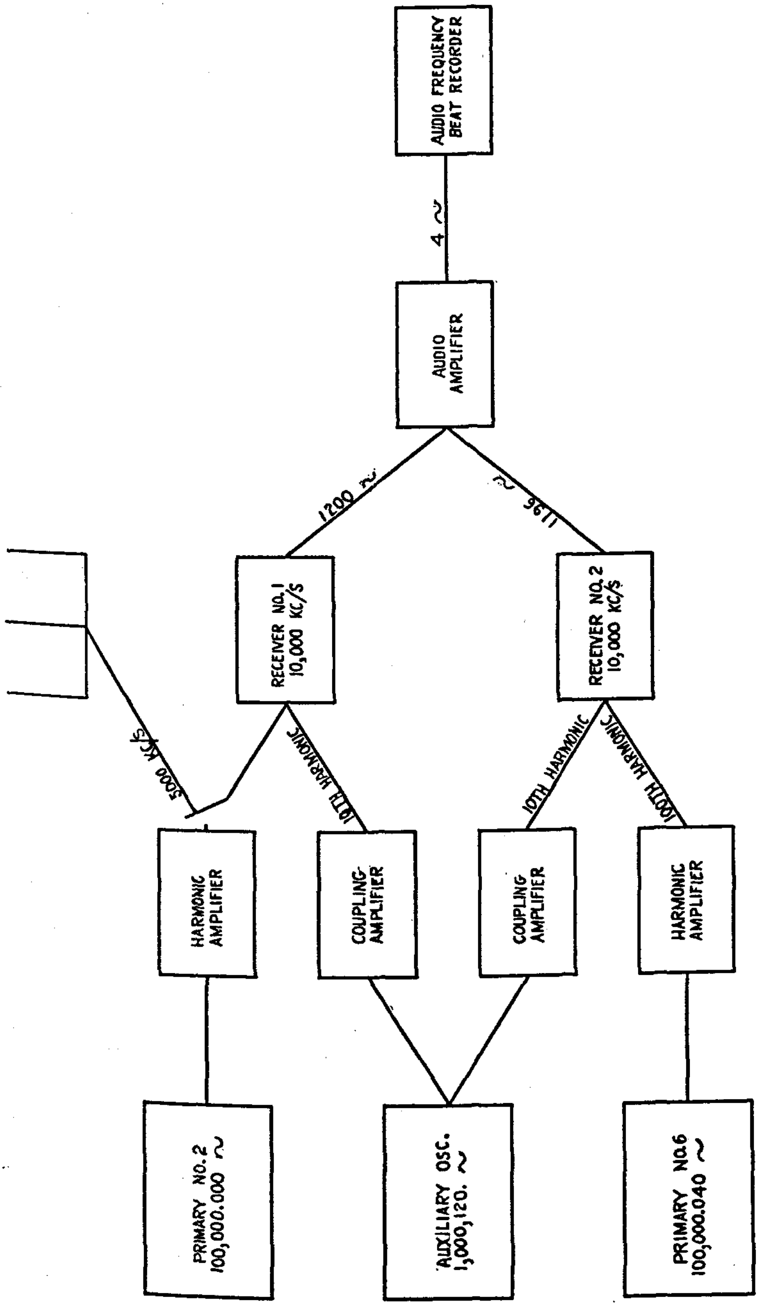

FIGURE 1.—*Schematic diagram of standard frequency monitor.*

III. DESCRIPTION OF EQUIPMENT

The complete monitoring equipment is shown in figures 2 and 3. The various sections are assembled on panels which are mounted on two relay racks. The equipment on each of the panels, except for the rectifiers and filters for the plate voltage supplies, are shielded by metal covers. The shields are fastened to the horizontal subpanels by thumbscrews, and phosphor-bronze springs make low-resistance contacts with the vertical panel along the top of the covers. The connections between circuits which carry radio-frequency voltages are made by means of concentric tube lines. These shielded lines are constructed of ⅝-inch brass tube with ⅛-inch brass rod held centrally within it by means of bakelite insulators. Figure 3 is a view of the back of the unit with the shields removed.

The receivers, indicated by A in figures 2 and 3, are commercial receivers of the regenerative type. Either receiver can be connected to an outside antenna by means of the double-throw switch mounted in the center at the top of the racks. They may be tuned from 2,500 to 25,000 kc/s by means of interchangeable coils, making possible the measurements of frequencies which are multiples of 1,000 between 3,000 and 25,000 kc/s. There is a single stage of radio-frequency amplification, a detector, and two stages of audiofrequency amplification. The receivers were altered slightly in order to incorporate an automatic volume control which would maintain a relatively constant audiofrequency output voltage. The automatic volume control was obtained by shunting a portion of the output voltage through a copper-oxide rectifier and filter and applying this direct-current potential to the grid bias on the radio-frequency amplifier in the customary manner. The power supplies for the receivers are located at B in figures 2 and 3.

The auxiliary oscillator is a temperature-controlled piezo oscillator. It is indicated by C in figures 2 and 3. The frequency of this oscillator is approximately 1000.120 kc/s at 50.8° C. The piezoelectric element is a circular, X-cut quartz plate. The quartz-plate holder consists of two stainless-steel electrodes mounted in a horizontal position, which are spaced by a toroid of pyrex glass. The thickness of the spacer is such that an air gap of approximately 0.004 inch is left between the quartz plate and the upper electrode. The outside diameter of the pyrex spacer is 1¾ inches, the inside diameter 1 inch, and the thickness 0.15 inch, approximately. The pyrex glass spacer also serves to retain the quartz plate between the electrodes. The inner diameter is only very slightly larger than the diameter of the quartz plate and therefore permits very little lateral motion in any direction. The damping produced when the quartz plate makes contact with the spacer was minimized by grinding the inner surface of the spacer slightly conical from each face in such a way that the two conical surfaces intersect midway between the faces. The quartz plate thus makes contact with the spacer at only one point. The oscillator and amplifier circuit arrangements are conventional in every way and therefore require no explanation. Two separate coupling amplifiers are provided for connection to the two receivers. The coupling capacitors are variable 15-$\mu\mu$f condensers. The frequency of this piezo oscillator is constant to about 1 part in 300,000. The power supply for the piezo oscillator is shown at E in figures 2 and 3. A UX874

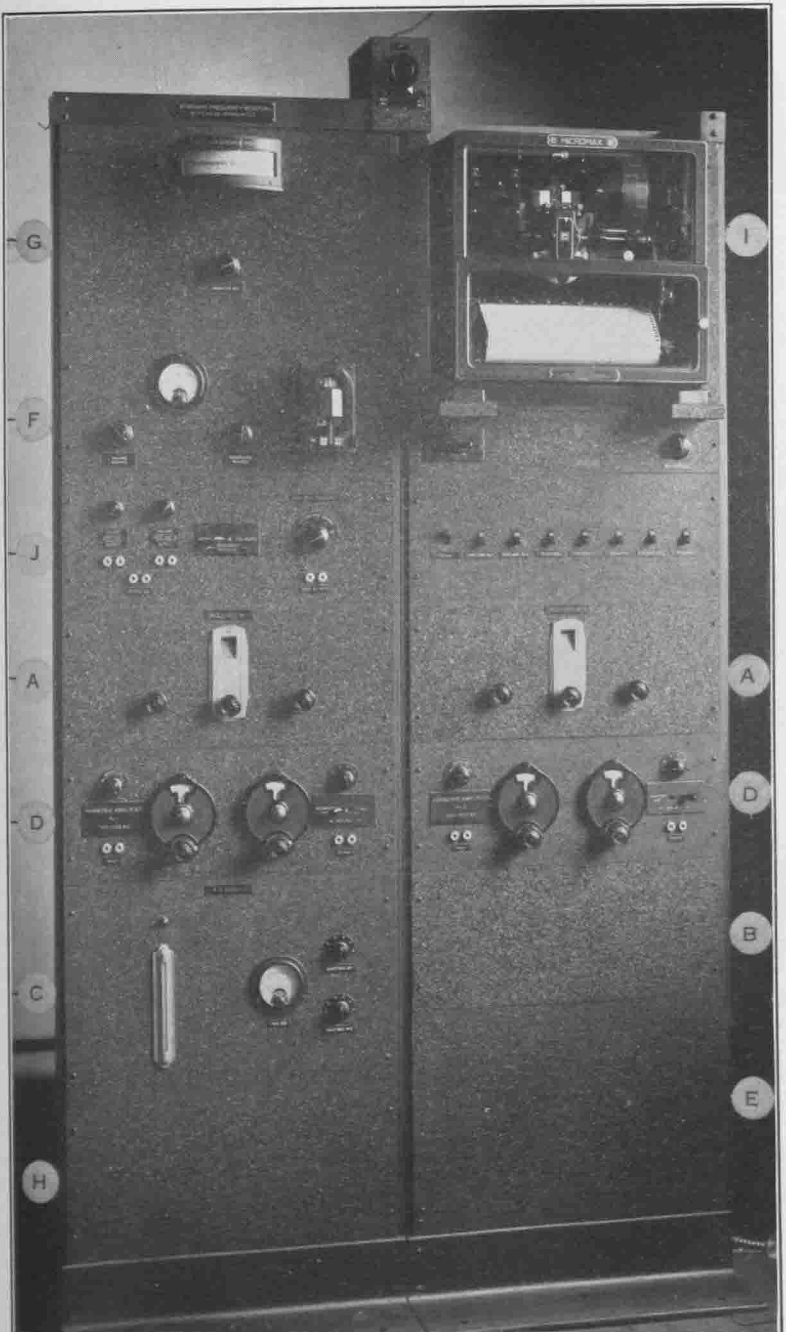

FIGURE 2.—*Front view of the standard frequency monitor.*

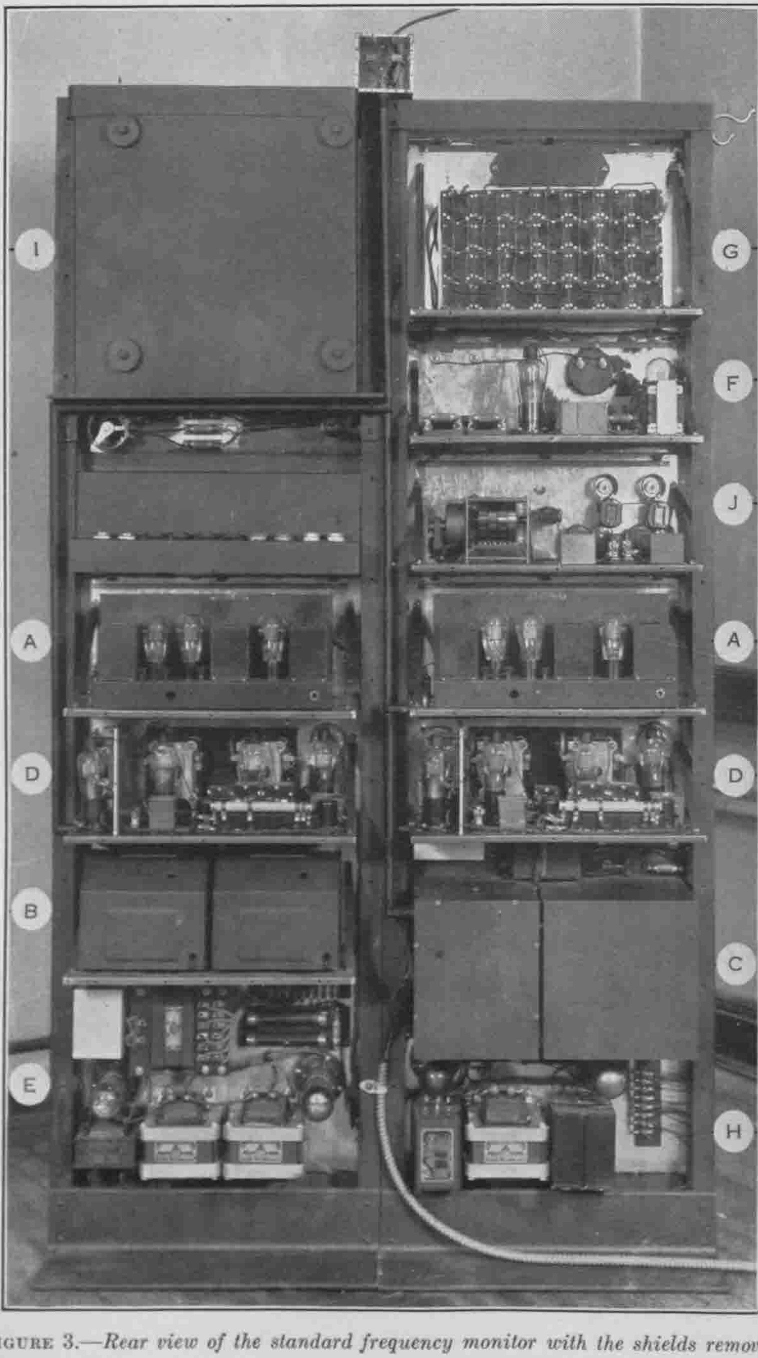

FIGURE 3.—*Rear view of the standard frequency monitor with the shields removed.*

voltage-regulator tube is used to supply the plate voltage for the oscillator tube.

The plate and filament voltages for the harmonic amplifiers are also supplied by the rectifier and filament transformer on the panel at E. The two harmonic amplifiers are shown at D. These units consist of an impedance-coupled input amplifier, two tuned amplifier stages, and an impedance-coupled output amplifier. In one of these units the first tuned amplifier is tuned to 200 kc/s and the second to 1,000 kc/s. This harmonic amplifier has an output of 1,000 kc/s with an input of 100 or 200 kc/s. The other harmonic amplifier has the tuned amplifiers adjusted to 500 and 1,000 kc/s, respectively, and gives an output of 1,000 kc/s with an input of 100 or 500 kc/s. The type 224 tube is used in these amplifiers.

Considerable difficulty was encountered in preventing the input voltage to one of the harmonic amplifiers from feeding into the other. The interaction between these two units was eliminated by having separate voltage dividers and 60-mh radio-frequency chokes in both the positive and negative leads of the plate voltage supply. The output of the harmonic amplifiers can either be connected to the receiver or to the jacks on the front panel, if used for other purposes, by means of the two-way switch on the right of each panel. When the switch is in the position to connect the output to the jacks, the receiver on the panel above can be connected to the antenna by properly setting the antenna switch previously mentioned. If the output of the harmonic amplifier is connected to the receiver the antenna connection is grounded. A 15-$\mu\mu$f variable condenser is provided to control the voltage input to the receiver.

The equipment used in measuring the beat frequency between the transmitted signal and the primary frequency is shown at F, G, H, I, and J, figures 2 and 3. The circuit arrangement is shown in figure 4. The voltage divider and voltage-regulator tube are mounted with the power pack for this unit on the panel H. The remainder of the circuits are on the panels F and G. The outputs of the two receivers are connected to the audiofrequency amplifier. The output of this amplifier is rectified by means of two half-wave copper-oxide rectifiers, Q, of the type used in rectifier type alternating-current meters, connected in a familiar voltage doubling arrangement. By rectifying the audiofrequency output a unidirectional potential is produced, which is the envelop of the two audiofrequency notes. This direct-current potential is connected as shown, to the grids of two type UY235 tubes. The plate impedance for these tubes is a 10,000-ohm voltage divider and the variable contact is used to balance the currents in the two tubes. The screen grid and plate are connected together as shown. A sensitive, polarized relay is connected across the plate resistor in series with a zero-center milliammeter which serves as a beat indicator. When the audiofrequency voltage reaches a maximum the resulting direct-current potential charges the 1-μf condenser, L, positively through the 2-megohm grid resistor, making this grid less negative, which accordingly increases the plate current in this tube. At the same time the 1-μf condenser, M, is charged negatively and the current in this tube is decreased. The result is that a difference of potential is produced across the plate resistor, a current flows through the coil of the polarized relay and the reed moves in one direction. When the audiofrequency voltage decreases to a minimum the 1-μf condensers discharge through the 2-megohm grid resistors, which reverses the change in bias on the tubes, the potential difference across the plate impedance is in the opposite sense, and the relay reed moves in the opposite direction. The combination of coupling condenser and grid resistor which is used must be one which has a charging time somewhat greater than one-fourth the period of the modulation frequency. The comparatively slow rate of charge and discharge of the 1μf condenser through the 2-megohm resistor serves to prevent noise of short duration from interfering with the operation of the relay. The particular values used in this case make the relay operate over a range from 0.2 cycle per second to approximately 25 c/s. When the relay makes contact in one position, a 0.1-μf condenser is charged to 90 v, and when it makes contact in the other position the condenser is discharged completely into a condenser having a capacity of approximately 112 μf. The 112-μf condenser discharges slowly through a 50,000-ohm resistor connected in series with a microammeter. After the relay has operated at a given frequency for a short time the voltage in the 112-μf condenser reaches an average value which is proportional, approximately, to the frequency operating the relay. The current through the microammeter is consequently approximately proportional to the frequency, and the instrument can be calibrated to read frequency directly. The record of the frequency variations is obtained by connecting a recording potentiometer across a portion of the 50,000-ohm resistor which is in series with the microammeter. The Leeds & Northrup recording potentiometer, I, in figures 2 and 3, has been found to operate very satisfactorily for this purpose. The principal requirement is that the galvanometer have a high sensitivity and a low natural frequency. By adjusting the voltage across the slide wire the recorder is likewise made direct reading. The 90-v supply which charges the 0.1-μf condenser also supplies the voltage for the potentiometer, which makes the recorder moderately independent of voltage fluctuations. The frequency-indicating meter reads from 0 to 9 c/s with the smallest division 0.1 c/s or one part in one hundred million at 10,000 kc/s. The recorder covers the range from 0 to 5 cycles per second, with the smallest division 0.05 c/s or one-half part in one hundred million at 10,000 kc/s.

In order to be able to readily calibrate the frequency-indicating meter and recorder it was necessary to have a source of known frequency with which to operate the beat-frequency measuring equipment. This was provided by constructing a device which would interrupt a 1,000-cycle voltage at a known rate. The 1,000-cycle voltage was used in this case as it was available in the laboratory, but practically any audiofrequency, such as a small 60-cycle voltage from the power line, would be satisfactory. The interrupting device, J, in figures 2 and 3, consisted of a 5-w telechron motor which was geared to turn a shaft at the rate of 12 revolutions per minute. Four separate insulating disks were mounted on this shaft. One of the disks had two metal segments equally spaced on the cylindrical surface. The space between segments was equal to the length of the segments. Two phosphor-bronze springs pressed against this disk in such a way that they were connected together at the times that the metal segment was passing under them. The 1,000-cycle voltage was connected so that it was in series with these sliding contacts. One revolution of

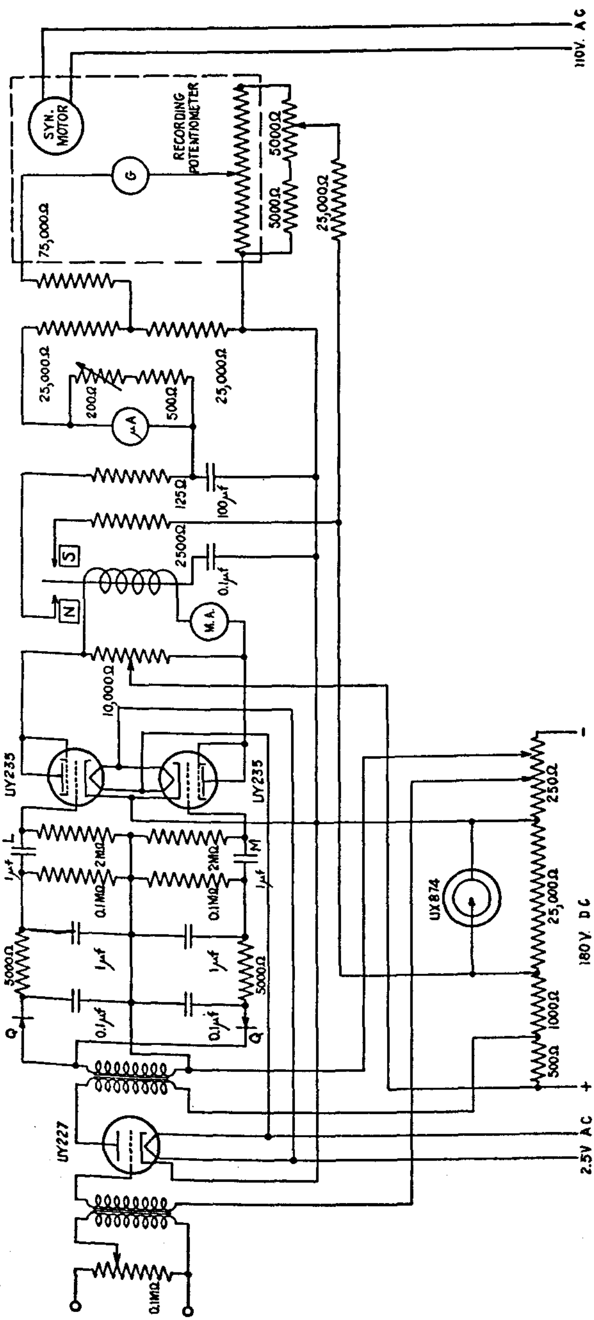

FIGURE 4.—*Circuit arrangement of the beat indicator and recorder*

this disk completed 2 cycles. With the disk rotating at the rate of 12 revolutions per minute the resulting frequency is 24 cycles per minute or 0.4 cycle per second. The other three disks had 5, 10, and 15 segments, respectively, and provided a beat frequency of 1, 2, or 3 c/s. A switch was provided so that any of these frequencies could be used for calibrating purposes.

IV. RESULTS

The emissions on 5,000 kc/s were originally measured on the fundamental frequency. The received signal, however, was subject to considerable fading during the daytime emissions. The signal received during the night emissions was much more dependable for measurement purposes, although there were times when fading intefered with the measurements during this emission. Fading of the received signal makes the frequency record very unreliable. If the signal fades out completely, the recorder operates as though the frequency difference was zero. If the fading has a period of the same order as the beat frequency being recorded, the intensity variations tend to operate the relay at the frequency of the fading and this obscures the actual beat frequency. If the fading is due to a movement of an ionized layer in the ionosphere a frequency change due to the Doppler effect is to be expected and has actually been observed at the receiving point. Such changes are very rapid and of short duration, so that the recorder responds only partially to such changes. The result is that fading tends to broaden the record obtained and limits the accuracy with which the transmitted frequency can be compared with the primary frequency standard. A representative record obtained on 5,000 kc/s during a daytime transmission is shown in curve A, figure 5. The blank spaces which occur at 10-minute intervals are the periods during which the transmitter is keyed for identification purposes. During this period the recorder does not measure the frequency but drops to some other point which depends on the average keying speed. The beat frequency recorded was actually 2 to 3 cycles per second, but in reproducing this record the coordinates were shifted so that they indicate directly the deviation in cycles per second from 5,000 kc/s. The variations in the transmitted frequency would appear from this record to be ± 0.5 cycle per second. Such variations in the transmitted frequency undoubtedly do not occur, however, as a record (curve B) of the frequency variations 10 hours later when no noticeable fading was present, and the frequency was obtained from the same frequency standard, indicates that the maximum variations are ± 0.1 cycle per second. The frequency variations indicated by the latter record may be due to variations either in the standard controlling the transmitter or in the reference oscillator, to the small amount of fading which may still be present in the signal but which is not noticeable as a variation in amplitude because of the action of the automatic volume control, or to hunting in the recording potentiometer. The latter variation is of the order of 0.02 cycle per second. The unreliable nature of the record obtained on 5,000 kc/s when fading was present made it necessary to make the frequency measurements in terms of the primary standard on another frequency.

It was found that the second harmonic of the transmitted frequency, 10,000 kc/s, was sufficiently strong at the laboratory in Washington, D. C., to be measured and recorded dependably. The signal received on the second harmonic, moreover, was free from fading, and records indicate frequency variations of the order of those in curve B, figure 5, both during day and night emissions.

The use of the standard frequency emissions where the received signal is subject to fading must be limited to the periods when the received signal is fairly steady if instantaneous measurements of a high order of accuracy are to be obtained.

In order to show the magnitude of the deviations of the emissions from agreement with the primary standard, the highest and the lowest frequencies indicated on the record for each of the emissions during the first 10 months of 1934 were tabulated, and are presented in curves A, figures 6 and 7. The dates of the emissions are plotted as abscissas.

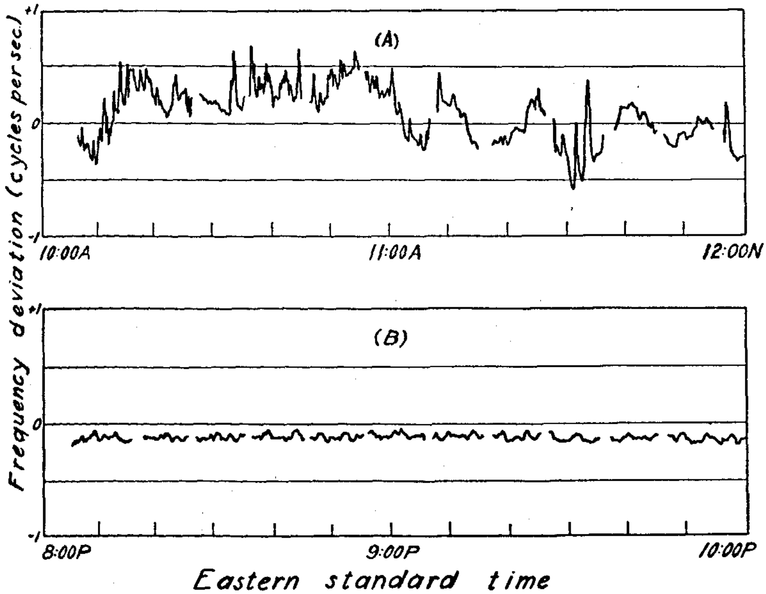

FIGURE 5.—*Sample record of standard frequency emission on 5,000* kc/s

The deviations from agreement with the frequency of the primary standard as indicated by the data available at the time of the emission are plotted as ordinates. The points directly to the left of a vertical line are for the daytime emission on that particular date, and the points directly to the right of the line are for the evening emission. The upper points indicate the highest value that the transmitted frequency attained during the 2-hour period and the lower points the lowest value transmitted. The curves show that, during the 10-months period, the disagreement was at no time as great as one part in 10 million. On all but a very few occasions the emissions were in agreement with the primary standard within about two parts in a hundred million. The average variation of the emission frequency from the primary standard was one-half part in a hundred million.

The absolute accuracy of the emissions depends on the determination of the absolute frequency of the primary standard. The determination of the frequency of the primary standard is made by comparing the time indicated by a synchronous-motor clock controlled by one of the standards with standard time. The time signals received by radio from the Naval Observatory are used for this purpose. Since the time signals are somewhat in error, corrections are sent out by the Naval Observatory. These corrections were formerly received

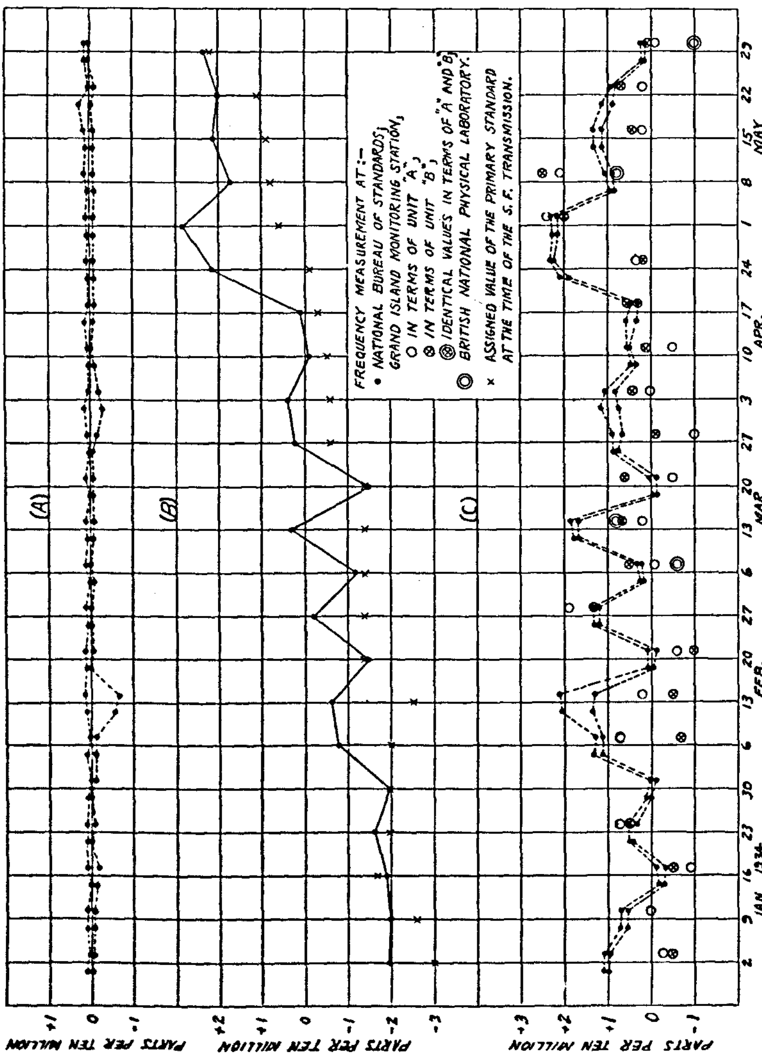

FIGURE 6.—*Graphical representation of the accuracy of the emissions, January to May 1934.*

(A) deviations of emissions from assigned value of primary standard; (B) assigned and corrected values of a unit of primary standard in parts in ten million above or below 100 kc/s; (C) deviation of emissions from corrected value of primary standard.

a month or more late, although recently the delay in the receipt of the corrections has been reduced to about 1 week. The frequencies as calculated in terms of the uncorrected time signals show variations of the order of four parts in 10 million. For the standard frequency emissions it is necessary to extrapolate a curve through these points. After the corrections are received the variations in the frequency as indicated by the time checks are narrowed down to approximately one part in 10 million. For this reason the value of the primary standard assigned at the time of the emission differs from the final corrected value. Curves B, figures 6 and 7, give the frequency, on the date of the emission, of one of the units of the primary standard which was checked against standard time during this period. The solid line

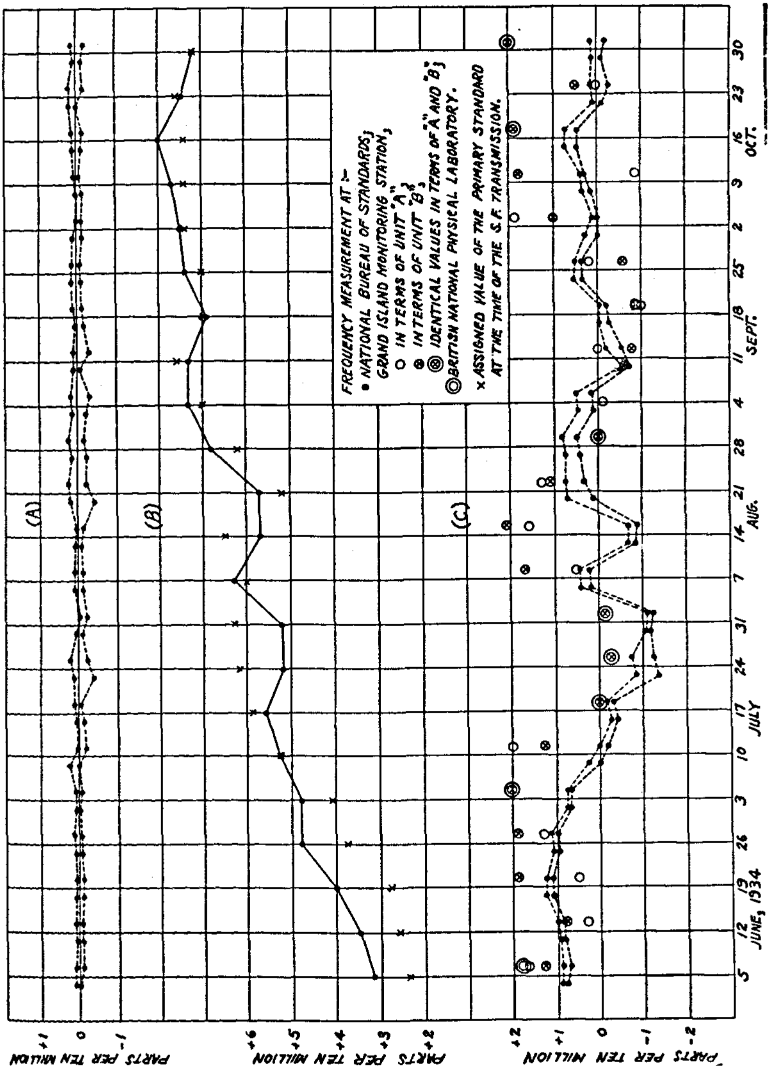

FIGURE 7.—*Graphical representation of the accuracy of the emissions, June to October 1934.*

(A) deviations of emissions from assigned value of primary standard; (B) assigned and corrected values of a unit of primary standard in parts in ten million above or below 100 kc/s; (C) deviations of emissions from corrected value of primary standard.

indicates the corrected values and the crosses the frequencies which were assigned at the time of the emissions. This error in the frequency of the primary standard decreases the absolute accuracy of the standard frequency emissions by a corresponding amount, as shown in curves C, figures 6 and 7, which give the transmitted frequency as determined in terms of the corrected values of the primary standard.

It is seen that the absolute value of the transmitted frequency was rarely in error by as much as one part in 10 million.

An interesting check on the measurements made at the National Bureau of Standards is shown in curves C, figures 6 and 7. Frequency comparisons are given which have been reported by the British National Physical Laboratory in terms of their national primary standard, and also measurements by the Federal Communications Commission in terms of the standards at the monitoring station at Grand Island, Nebr. These measurements show agreement within two parts in 10 million at all times, and many are in agreement within one part in 10 million. These measurements indicate not only the very close agreement between these independently operated standards, but also the very high accuracy of the frequency comparisons which can be made by means of standard frequency emissions.

V. ADDITIONAL USES OF APPARATUS

The equipment which is described has also a useful application in comparing different frequency standards. If the standards have fundamental frequencies of either 100 or 200 kc/s they can be connected to the two harmonic amplifiers and a record of the frequency difference obtained. Very minute variations can be detected in this way. The frequency of one unit in terms of the other can also be very accurately determined in this manner. Such frequency comparisons can be made at any harmonic frequency desired which is within the range of the receivers and is an integral multiple of 1,000 kc/s.

WASHINGTON, December 7, 1934.