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THE TESTING OF FREQUENCY MONITORS FOR THE FEDERAL RADIO COMMISSION*

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Summary—*Rule 144 of the Federal Radio Commission of the United States of America requires broadcast stations to maintain their carrier frequencies within fifty cycles per second of the assigned values. To meet this requirement a new and more accurate frequency checking instrument (known as a frequency monitor) was required by each broadcast station. A type test of the different kinds of frequency monitors manufactured was made by the Bureau of Standards. This paper gives a general description of the monitors tested and of the test procedure. Results of the tests are given for ten monitors approved by the Federal Radio Commission.*

I. Introduction

SINCE June, 1932, broadcast stations have been required by Rule 144 of the Federal Radio Commission to maintain their carrier frequencies within fifty cycles per second of the assigned values. This requires an accuracy of approximately five parts in a hundred thousand. To meet the requirement, new apparatus and checking equipment were necessary. The need has been filled by installation in each station of a device known as a frequency monitor. The Commission has required that the monitor be of a specifically approved type.

It thus became necessary to determine which of the frequency monitors manufactured would be satisfactory for broadcast station use and worthy of the approval of the Federal Radio Commission. To be certain of the qualities of the apparatus, the Commission requested the Bureau of Standards to test a sample of each frequency monitor which any manufacturer wished to submit. A preliminary outline of the tests to be made was prepared at a meeting of representatives of radio manufacturers, the Federal Radio Commission, and the Bureau of Standards.

No specifications were drawn up by the Radio Commission; the design of monitors was left to the choice of the manufacturer. The most important part of the device had to be a standard, or self-contained source of constant frequency. Other equipment to give a comparison of the broadcast transmitter's frequency and the monitor standard was of course necessary. Simplicity and reliability of operation were essential.

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II. Description of Monitors Tested

General information is given here on the type of apparatus included in the majority of monitors tested. It is not the purpose of this paper to describe the individual monitors.

For the frequency standard, or self-contained source of constant frequency, a standard capable of maintaining a high degree of accuracy over a long period of time, requiring little attention and having a moderate cost, was necessary. For long-time constancy of frequency, the piezo oscillator provides an almost ideal source of standard frequency, and by observing certain precautions its constancy can be made far in excess of that required. All of the frequency monitors tested use piezo oscillators as the monitor standard.

The frequency of the monitor's piezo oscillator is in most cases of a value not far from the broadcast transmitter's assigned frequency. The difference between the piezo-oscillator frequency and the transmitter's frequency then produces a beat note of audio frequency. The audio frequency is obtained with a detector and amplified to sufficient power to operate indicating or measuring equipment. The detector is supplied with a plate-current meter so that its operation is known and undue distortion is not introduced. The coupling circuits supplying voltage to the detector are so designed that there is no danger of their resonating at or near the second or third harmonic of the radio frequency being monitored. If such resonance occurred, it would cause the resulting wave form to be distorted or, in extreme cases, the audio frequency would be double or triple the actual radio-frequency difference. An audio-frequency amplifier having fairly constant amplification over the frequency range of the frequency difference measuring instrument is used. The amplifier has an output voltmeter and some means of controlling its gain.

To avoid a more or less indefinite warming-up period, during which the monitor's frequency would be inaccurate, the monitors are designed for continuous operation, giving a continuous indication of the radio transmitter's frequency, and enabling the radio station operator to tell at a glance whether the transmitter is within the assigned limits. The frequency-indicating instrument is calibrated in cycles per second, and shows whether the radio transmitter's frequency is high or low. This instrument is operated by the audio-frequency power from the detector-amplifier within the monitor. Its audio-frequency range determines the radio frequency to which the monitor piezo oscillator is adjusted. For example, an audio-frequency meter with a range of 900 to 1100 cycles having its scale marked in cycles, high and low from its 1000-cycle indication, would be used with a monitor piezo oscillator having a frequency 1000 cycles different from the transmitter's assigned frequency. The heterodyne note between the monitor piezo oscillator and the radio transmitter's frequency would then vary between 950 and 1050 cycles as the transmitter's frequency drifted within its allowable limits. It is, of course, assumed that the monitor's frequency remained constant. With certain types of frequency indicators the monitor piezo-oscillator frequency is adjusted to the transmitter's assigned frequency. With this arrangement the heterodyne note in cycles is the amount in cycles that the transmitter is off the assigned frequency. Such an audio-frequency meter has a range of from a few to 75 or 100 cycles. Meters of this type have been previously described in detail.[1] Audio-frequency meters having ranges of 450 to 550 and 900 to 1100 cycles are usually of the type used for power work. They are advantageous in that they are sturdy and have been used as frequency indicators for many years. When used on a monitor they show at a glance whether the transmitter frequency is high or low.

A monitor can be designed to operate with a standard of almost any frequency, but if the frequency of the standard is not an even multiple of the frequency to be monitored the instrument would be complicated and impractical. However, by choosing a standard frequency of 10 kilocycles, monitors are built which are universal in application. Such monitors may be used to check the frequency of any broadcast station in the United States. In one of the monitors tested, the 10-kilocycle output was obtained from a 100-kilocycle piezo oscillator by means of a multivibrator. The desired harmonic of the 10-kilocycle output is amplified sufficiently to give a beat note at the broadcast transmitter's fundamental frequency. It has the advantage of adaptability and ease with which its piezo oscillator can be checked against standard frequency transmissions. On the other hand, it is not as simple as the other types.

III. Test Procedure

Type tests were made of fifteen monitors, ten of which were subsequently approved by the Federal Radio Commission. Each monitor tested had been adjusted by the manufacturer to indicate correctly the frequency of a 1500-kilocycle radio transmitter. Thus all monitors were tested under the same conditions and considerable convenience in testing resulted. Another reason for the 1500-kilocycle adjustment

[1] N. P. Case, "A precise and rapid method of measuring frequencies from 5 to 200 cycles per second," *B.S.J.R.*, vol. 5, p. 237; August, (1930); Proc. I.R.E., vol. 18, p. 1586; September, (1930).
F. Guarnaschelli and F. Vecchiacchi, "Direct-reading frequency meter," Proc. I.R.E., vol. 19, p. 659; April, (1931).

was to have as the test monitor the one most difficult to build. The accuracy requirement was more severe at 1500 kilocycles than at any other broadcast frequency.

The methods used in testing the monitors were basically similar to those used by the Bureau in testing piezo oscillators,[2] except that the test was extended over a greater period of time and was considerably more detailed. Test conditions simulated those in a radio station in that a powerful 1500-kilocycle generator was operated near the monitor. The 1500-kilocycle generator was directly controlled by one of the piezo oscillators of the primary standard of frequency.

When a frequency monitor was received for test, it was examined carefully to see that it had not been damaged in shipment. The monitor was then set up in a temperature-controlled room, connected to a power supply, and left running continuously until the tests were completed.

The tests made upon the monitors were as follows:

(1) Measurement of constancy of monitor's piezo-oscillator frequency and deviation indicator.

(2) Measurement of frequency change caused by tilting, tipping, and jarring monitor.

(3) Measurement of frequency range of frequency adjusting device.

(4) Determination of the effect of changing the piezo-oscillator tube.

(5) Measurement of the frequency change with supply voltage change.

(6) Calibration of the frequency deviation indicator.

(7) Tests of frequency indicating instruments for sensitivity and effects of starting and stopping.

(8) Determination of the effect of coupling on frequency.

(9) Measurement of frequency change caused by room temperature change between 15 and 35 degrees centigrade.

(10) Examination of quartz plate and mounting.

IV. Results

The results which follow are averages for the ten piezo oscillators which received the approval of the Federal Radio Commission. The average time required for all tests of a monitor was 40 days.

1. *Constancy of Oscillator and Frequency Deviation Indicator.*

[2] E. L. Hall, "Method and apparatus used in testing piezo oscillators for broadcasting stations," *B.S.J.R.*, vol. 4, p. 115, (1930); Proc. I.R.E., vol. 18, p. 490, March, (1930).

Twenty-four hours or more after turning the monitor on the tests were started. To determine the constancy of frequency of the unit as a whole and any frequency drift caused by an aging of the parts of a gradual change in the piezo-oscillator temperature or from other causes the piezo-oscillator frequency was measured every other day over a period of about thirty days. The room temperature was maintained at 25 degrees centigrade during that time. The method of measuring the piezo-oscillator frequency was to measure the audio-frequency heterodyne note between it and a radio-frequency generator controlled by the Bureau's primary frequency standard at a frequency of 1,500,000.0 cycles. The heterodyne note was obtained with an ordinary broadcast receiver, tuned to 1500 kilocycles, located in the vicinity of the monitor and the 1500-kilocycle generator. With a monitor that was well shielded a small pick-up coil was placed near the monitor and connected to the antenna circuit of the broadcast receiver; this expedient increased the volume of the audio-frequency note obtained. A very low audio frequency, below forty cycles, would not pass through the amplifier of the radio receiver. For such a case, an additional radio-frequency voltage having a frequency of about 1501 kilocycles was introduced into the radio receiver which caused the low frequency to pass through superimposed upon the higher audio-frequency note. The audio-frequency beat note obtained was measured on a direct-reading frequency meter or it was determined by matching it with a frequency from a calibrated audio-frequency oscillator.[3]

During the average time required for all tests of a monitor, forty days, the average frequency drift of the monitor's piezo oscillator was 13 cycles. The frequency deviation indicator indicated an average drift of 14 cycles. The minimum drift was 6 cycles and the maximum, 30 cycles. These results are cycles deviation in 1500 kilocycles.

2. *Effect of Tilting, Tipping, and Jarring.* Tilting or tipping a monitor usually causes the quartz plate to be differently located in its holder when the monitor is set back into position. Such a change can cause the quartz plate to oscillate at a considerably different frequency. In this test the monitors were tipped and jarred sufficiently to move the quartz plate in its holder. Of course such is not the case when the quartz plate and its electrodes are clamped into one position. One monitor had such a quartz plate mounting and showed no frequency change when tipped. For the remaining nine monitors approved, tilting or tipping a monitor caused an average frequency change of 6 cycles. The minimum change was 1 cycle, the maximum 14 cycles.

[3] E. G. Lapham, "An improved audio-frequency generator," *B.S.J.R.*, vol. 7, p. 691; (1931); Proc. I.R.E., vol. 20, p. 272; February, (1932).

3. *Frequency Range of Frequency Adjusting Device.* The radio station operator requires some simple means of adjusting the frequency of the radio station's frequency monitor to take care of the frequency drift in the piezo oscillator. A manufacturer can make a considerable saving in cost of the monitor if small frequency adjustments can be made without changing the size of the quartz plate. There are two convenient methods of making small frequency changes in a piezo oscillator. One is to change the capacitance across the quartz plate electrodes. The other is to change the inductance or capacitance at some other point in the piezo oscillator. Four of the monitors had a small variable air condenser in parallel with the quartz plate holder. Five had a small variable air condenser in the plate circuit of the piezo oscillator. One had no external means of frequency adjustment. The average range of the frequency adjusting devices was 159 cycles at 1500 kilocycles. The maximum was 675 cycles, and the minimum 28 cycles.

4. *Effect of Changing the Oscillator Tube.* Four vacuum tubes of the same type were tested in the piezo oscillator of each monitor. The average maximum frequency change was 6 cycles, while frequency changes from zero to 15 cycles were noted.

5. *Frequency Change with Supply Voltage Change.* The power supply voltage was changed plus and minus 15 per cent and the piezo-oscillator frequency measured. The average plate voltage change was 55 volts which caused an average frequency change of 1.5 cycles. With the individual monitors, the effect was from zero to 4 cycles.

6. *Calibration of Frequency Deviation Indicator.* Seven of the monitors approved had frequency deviation indicators of the type used in power frequency work. They operated from 450 to 550 cycles and their scales read from -50 to $+50$ cycles. One monitor had a specially designed meter that operated from 900 to 1000 cycles. Its scale read from -100 to $+100$ cycles. One monitor was equipped with a mechanical relay. Its meter range was a few to 75 cycles. Another monitor had a vacuum tube relay type of frequency meter with a scale reading from 0 to 100 cycles.

The frequency indicators were tested at three temperatures, 15, 25, and 35 degrees centigrade. The average error noted in the readings was -2 cycles at 15 degrees centigrade and $+1$ cycle at 25 and 35 degrees centigrade. The maximum error was -11 cycles at 15 and 25 degrees centigrade and -10 cycles at 35 degrees centigrade. The temperature change of 20 degrees centigrade caused a change in the frequency meter readings an average amount of 2 cycles and a maximum amount of 5 cycles for readings near the center of the scale.

7. *Tests of Indicating Instruments.* The frequency indicating instruments were tested for sensitivity, and were checked to see that they gave the same indication after starting and stopping the monitor several times.

8. *Effect of Coupling on Frequency.* If two oscillators are operating at nearly the same frequency, one may appreciably change the frequency of the other or there is a tendency to synchronize when sufficiently coupled. All but one monitor were carefully designed to eliminate such effects. A large change in coupling to the generator operating at 1500 kilocycles caused that monitor to change frequency an average of 5 cycles.

9. *Effect of Variation in Room Temperature between 15 and 35 Degrees Centigrade.* Of the ten monitors approved by the Federal Radio Commission, three had double temperature control on the quartz plate of the piezo oscillator. The three showed a change in frequency of 0.1, 0.45, and 0.68 cycle per degree change in room temperature. The other seven monitors each had a single temperature control. The average change in frequency was 0.59 cycle per degree centigrade change in room temperature, the maximum was 1.3 cycles, the minimum 0.10 cycle per degree centigrade room temperature change.

10. *Examination of Quartz Plate and Mounting.* The mounting tested, or a similar one supplied for the purpose, was disassembled and examined. Seven of the monitors used plate holders with an adjustable air gap. In two, the top electrode rested on the quartz plate. One had a clamped quartz plate.

V. Conclusion

The principal results of the tests of the ten monitors are summarized in the following table.

	Frequency change in cycles at 1500 kilocycles		
	Maximum	Minimum	Average
Drift in 40 days, continuous operation	30	6	14
Tipping or tilting unit	14	0	6
Changing the oscillator tube	15	0	6
Supply voltage change	4	0	1
Error in frequency indicator	11	1	2
20 degrees centigrade room temperature change	26	2	12
Total	100	9	41

No one monitor had the maximum variation of 100 cycles, likewise no one monitor had a constancy in all respects as good as that shown under the minimum column. Frequency changes shown were not at all in the same direction. The average monitor showed a constancy somewhat better than 41 cycles, during the period of the tests.

In actual service the frequency of the piezo oscillator of the monitor must be periodically checked and adjusted.

All the monitors which were approved by the Federal Radio Commission were thoroughly satisfactory for the exacting service which they have to render. They represent a great advance over the frequency meters and the piezo oscillators without temperature control which were previously used as frequency-checking equipment. A standard with an accuracy of the order of 5 parts in 100,000 was required. For ordinary operation and care, the units tested and approved by the Commission were at least 5 times as accurate, i.e., reliable to 1 part in 100,000.