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MICROPHONIC IMPROVEMENT IN VACUUM TUBES*

By
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Summary—The paper contains a discussion of the causes and effects of microphonic disturbances in small receiving tubes and the nature of these disturbances, and gives methods of testing for microphonic disturbance whereby the sources of the disturbance may be located and corrected, as well as methods of testing tubes as a means of comparison of individual tubes of different types. A new type of tube with low microphonic output but with low filament power for uses where microphonic troubles may be serious is also described and its characteristics are given.

MICROPHONIC effects are usually considered to include all of that class of noises in a vacuum-tube output circuit which are due to external disturbances acting upon the tube in some fashion other than through the electrical circuits. Microphonic output is caused by relative motion between the various elements of the tube with resultant variations in plate current due principally to change of plate resistance of the tube.

In the past the only important occurrence of microphonic difficulties has been in radio receivers where acoustic feedback has occurred between the loud speaker and the small receiving vacuum tubes. The more recent application of vacuum-tube equipment in positions where the tubes are subjected to considerable vibration has resulted in the appearance of new and more serious problems of microphonic response that require investigation.

Vibration of vacuum tubes in receiving sets may be excited by sound waves in the air reaching the bulb or by waves transmitted from speaker to tube through the cabinet, socket, and tube base. The variation in microphonic response between different receiver arrangements has resulted in considerable attention being paid to mounting and shielding to prevent microphonic difficulties. Spring suspension of the socket and covering of the bulbs with caps lined with sound absorbing material have been among the most useful examples of such work. However, such shielding is of limited possibility in sets subjected to severe vibration, as for example, aircraft receivers. In such receivers flexibility of tube mounting is limited by the effect of displacement of the tube itself on radio-frequency circuits before acoustic isolation is attained. Packing with sound absorbing material is likewise limited because of space restrictions. For satisfactory operation under such

* Dewey decimal classification: R130.4. Original manuscript received by the Institute, April 16, 1929. Presented before New York meeting of the Institute, June 4, 1929.
severe service lower microphonic response of the tube itself is required. The possibilities of such improvement are considered in this paper.

**Methods of Microphonic Testing**

The simplest test for microphonics consists of an audio-frequency amplifier of fairly high gain, the tube under test being used in the first stage. If the tube is struck with the finger the output from the amplifier may be heard in a loud speaker. The relative loudness and the time of damping of the sound wave serve as a means of comparison of the tubes. This test depends upon the judgment of the operator and the severity of the blow. Such a test may be used in comparing different lots of vacuum tubes of the same general type, although obviously, different operators will not agree exactly upon the merits of tubes and the test is therefore of no quantitative value.

![Fig. 1](image-url)

The above test may be modified by directing the loud speaker towards the tube. A howl from acoustic feedback may be built up if the tube is close enough to the loud speaker or the socket is sufficiently rigid to transmit vibrations from the speaker. If the initial sound dies out in two or three seconds under this test the feedback will not generally be serious. Although this test may be used in checking uniformity of a vacuum-tube production it still does not give a quantitative measure of microphonic response. The absence of a howl in one circuit is not necessarily an indication that one will not be built up in another circuit. For test purposes the tube mounting and speaker distance must be adjusted to give the best possible percentage cor-
relation with actual receiver performance. This discrepancy between a test circuit and receiver performance is even more pronounced in modern broadcast receivers with built-in speakers. In such combinations the acoustic characteristics of the cabinet and location of the components will determine the possibilities of tube response in the particular equipment. Individual receivers of the same type may vary so considerably that the tubes quiet in one receiver may build up sus-
tained howls in the other. As a consequence, tests of tubes in such a receiver do not show whether the tubes or the receiver itself are abnormal.

For the determination of the effect of forced vibrations a test has been devised in which the tube is strapped to the moving element of a moving coil loud speaker which is excited from a variable frequency oscillator. Microphonic output voltage across the plate circuit load is measured by a tube voltmeter and plotted against frequency. The resultant graph forms a vibration spectrum consisting of peaks at the resonant frequency of the various parts of the tube. Although a few peaks are quite broad the greater number are very sharply defined and easily missed in measurement unless the operator detects them by the sound in head-phones in the voltmeter circuit. Other tests have shown that a number of large peaks indicate a tube which will be poor under operating conditions. This method enables the location of the principal source of disturbance since whenever a large peak occurs one or more of the elements of the tube can be seen to be vibrating quite strongly. A typical vibration frequency record is shown in Fig. 1.
This vibration test is useful but does not give an adequate criterion of the disturbances in the output circuit when the tube is subjected to shock excitation. The number and magnitude of resonance points may be used as a rough measure of possible microphonics, but the difficulty in determining the peaks of the resonance points prevents the use of the readings for quantitative comparisons. For this reason a ballistic impact test has been developed as the best means of obtaining a definite reading to indicate the merit of the tube. The impact is given to the base of the tube and the variation of voltage across the plate circuit load is amplified and recorded on an oscillograph. The oscillographic records show the exact performance of the tube and form an excellent means of studying the problem of microphonic disturbance in tubes. The final form of the apparatus used for this test is indicated by the diagram of Fig. 2 and photograph of Fig. 3. The excitation is supplied by dropping a ball pendulum against the base of the tube which is mounted on a semi-rigid wood chamber. The tube is operated with a plate circuit load of 20,000 ohms impedance and the output disturbance amplified and placed on the oscillograph vibrator. Oscillograms are taken on standard motion picture film carried in a 200-ft. magazine in the film housing. In taking records the oscillograph driving motor is started by the same switch which releases the ball and one foot of film run off. A sixty-cycle timing wave is also placed on the film. Multiple impacts are prevented by attraction of the pendulum to a permanent magnet at one side of the socket.

Oscillograph impact records show the magnitude of initial microphonic response and the duration of the disturbances until the tube is
again quiet. Both are important. Either or both may be the cause of disturbance in radio equipment, the actual voltage in the output circuit being a complex effect depending upon the character of the external disturbance. In addition the records indicate the principal frequency which is set up by such forced excitation of the tube elements. Typical oscillographic impact records are shown in Figs. 4 to

14. Experience has shown that the records are entirely free from any major discrepancies between repeated tests or with impacts in different planes with respect to the tube elements.

Observation of the elements of the tube during the taking of the vibration frequency spectrum permits the determination of the principal sources of microphonic disturbances. Reference to Fig. 1 shows the multiplicity of resonance points within the tube itself. These points are usually sharply tuned. Any one of them may be sufficient to cause variation in plate current with a consequent ripple in the output circuit when the tube is excited at the proper frequency. Likewise any freedom of motion may permit forced vibration when the whole tube is subject to a sudden impact of large magnitude. In this
latter case the amount of microphonic ripple will be limited by the damping of the vibrating part.

In radio broadcast receivers where loudspeaker feedback is the most serious microphonic defect the damping factor of the elements of the tube forms the limitation on microphonic output. If the amount of energy fed back is sufficient to overcome the loss by damping the effect will be to produce a sustained howl. In aircraft receivers on the other hand, where the vibrations of the various parts of the plane are transmitted to the tube, the effect is to force vibrations in the tube which are not of a transient nature and do not depend upon the damping factor in the same way. Stiffness of the electrode structure is important here.

The most common sources of trouble are filament vibration, mount\(^1\) vibration, and grid vibration. The filament gives the most trouble because it is necessarily the freest part build up the largest amplitude. Filament vibration may be serious not only at its own natural period but also at that determined by the fila-

\[\text{Fig. 12}\]

\[\text{Fig. 13}\]

ment and its supports taken together. Mount vibration gives trouble because of the vibration of the assembly of the tube elements at the natural period of the whole, permitting relative vibration of the various parts. Such vibration may also serve to force the filament into vibration at a frequency determined either by the period of the mount or by that of the filament. The grid vibration is important because of its large effect on the plate current. Its movement also may be sufficient

\[^1\] The "mount" is the complete assembly of tube elements in place on the stem.
to force vibration of the bead and consequently of the filament and other parts.

The great effect of the filament on tube noises is well shown by a series of oscillograms which have been taken on a group of tubes with amplification factors of approximately thirty. The tubes tested are indicated in Table I. The oscillograms as given were taken with the same impedance load (20,000 ohms at 60 cycles including a shunt resistor of 35,000 ohms to limit the impedance at higher frequencies)

TABLE I
Structure of Special 30-μ Tubes

<table>
<thead>
<tr>
<th>Oscillograms in Fig.</th>
<th>Filament Voltage</th>
<th>Filament Current (ampere)</th>
<th>Filament Shape</th>
<th>Type</th>
<th>Plate</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.3</td>
<td>0.06</td>
<td>Straight</td>
<td>Thoriated</td>
<td>Cylin.</td>
<td>Typical tube</td>
</tr>
<tr>
<td>5</td>
<td>3.3</td>
<td>0.06</td>
<td>Straight</td>
<td>Thoriated</td>
<td>Cylin.</td>
<td>Extra filament tension</td>
</tr>
<tr>
<td>6</td>
<td>5.0</td>
<td>0.25</td>
<td>V</td>
<td>Thoriated</td>
<td>Flat</td>
<td>Selected tube for special measurement work</td>
</tr>
<tr>
<td>7</td>
<td>5.0</td>
<td>0.25</td>
<td>V</td>
<td>Thoriated</td>
<td>Flat</td>
<td>Tube unsatisfactory as detector</td>
</tr>
<tr>
<td>8-9</td>
<td>1.5</td>
<td>1.0</td>
<td>V</td>
<td>Coated</td>
<td>Flat</td>
<td>Typical tube</td>
</tr>
<tr>
<td>10</td>
<td>2.0</td>
<td>1.0</td>
<td>V</td>
<td>Coated</td>
<td>Flat</td>
<td>Specially reinforced elements</td>
</tr>
<tr>
<td>11-12</td>
<td>4.5</td>
<td>1.1</td>
<td>V</td>
<td>Thoriated</td>
<td>Flat</td>
<td>350-volt heavy duty tube</td>
</tr>
<tr>
<td>13-14</td>
<td>2.5</td>
<td>1.8</td>
<td>Cathode</td>
<td></td>
<td>Cylin.</td>
<td></td>
</tr>
</tbody>
</table>

Note: Cylindrical plates were similar to UX199 with single side rod support. Flat plates were similar to UX201A or UX210 with double side rod.

and the same plate voltage. The difference in degree of disturbance is so great that it is readily shown up without attempting to adjust the amplifier gain to exactly the same for each tube. The oscillograms shown are made with a scale of 240 mv per cm.

These oscillograms show the improve and in time of decay as stiffness is obtained by the use of shorter and heavier filaments. The 60-ma filament tubes (Figs. 4 and 5) show the filament disturbance resulting with the use of this light and low current filament. The five-volt V filament tubes show the extremes possible in this type of tube. High amplitudes such as in Fig. 7 may result from mounting of the filament so it is loose on the center hook. The
best of these tubes are those of Figs. 8 and 9, which have large filaments such as are used for a-c filament operation. This is evident upon comparison with the tubes of Figs. 6 and 7, which are the same structure other than filaments. Small power tubes such as those in Figs. 11 and 12 are inherently freer from microphonic difficulties than the smaller tubes because of their heavier filaments and construction.

One of the best solutions of the microphonic problem would be the use of such heavy filament tubes in receiving circuits, but such an arrangement is impractical because of the power requirements in most radio installations.

Experience has shown that an equipotential cathode tube such as the UY 227 is the least subject to microphonic disturbances of any of the small receiving tubes customarily used for detectors. The low amplitude of disturbance of such tubes is evident from the oscillograms of Figs. 13 and 14. The low microphonic response of the equipotential cathode tubes makes them particularly suitable for laboratory work where high gain amplification is required for measurement purposes.

The change in type of filament used will not change the micro-
phonics of a given style of tube providing the same dimensions and weight of filament is used. In general, a coated wire will be heavier than a tungsten wire of the same filament rating, but the improvement to be obtained by change in the wire material is negligible as compared with that to be obtained by improvement of structure.

As in many other design problems accentuation of one design factor can only be accomplished by some sacrifice of one or more other factors. Thus in a low microphonic tube low cost, gain per stage, and filament power may all be adversely affected in getting the desired freedom from tube noises traceable to mechanical vibration. For the great majority of applications freedom from the effects of vibration to the greatest extent is not justified because of this impairment in the other qualities of the tube.

**A Low Microphonic Tube for Special Applications**

A new vacuum tube which will not respond to external vibration has been developed for use where filament power is limited. This tube
is Radiotron UX864, the construction of which is indicated by the photograph of Fig. 15. Comparison of the oscillograms of Figs. 16 and 17 with the others previously given indicates the improvement obtained. Electrical characteristics and physical dimensions are given in Table II and a plate-voltage plate-current family in Fig. 18.

### TABLE II
#### Radiotron UX864

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament Voltage</td>
<td>1.1 volts</td>
</tr>
<tr>
<td>Filament Current</td>
<td>0.25 amperes</td>
</tr>
<tr>
<td>Plate Voltage</td>
<td>90 volts maximum</td>
</tr>
<tr>
<td>Average Characteristic</td>
<td></td>
</tr>
<tr>
<td>at $E_b = 90$ volts, $E_c = -4.5$ volts, $E_f = 1.1$ volts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5 milliamperes</td>
</tr>
<tr>
<td>Plate Resistance</td>
<td>15500 ohms</td>
</tr>
<tr>
<td>Mutual Conductance</td>
<td>425 micromhoes</td>
</tr>
<tr>
<td>Amplification Factor</td>
<td>6.6</td>
</tr>
<tr>
<td>Plate-Grid Capacitance</td>
<td>5.2 µF</td>
</tr>
<tr>
<td>Maximum Over-all Dimensions</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>4 in.</td>
</tr>
<tr>
<td>Diameter</td>
<td>1 3/16 in.</td>
</tr>
</tbody>
</table>

Fig. 19

*Jointly designed and produced by the General Electric and Westinghouse Companies for the Radio Corporation of America.*
Uniformity tests on microphonic response on a regular production of such tubes require a special apparatus because of the expense of taking individual oscillograms on each tube. An equipment for quantity testing is shown in Fig. 19. The same pendulum and mounting are used as before with the microphonic transient rectified and measured on a microammeter. The maximum deflection is proportional to the quantity of electricity represented in the transient wave. Since both high amplitude and poor damping are generally caused by looseness or weakness of parts a large deflection serves to indicate either or both defects. The amplifier is calibrated by discharging a condenser and subsequent charging through a high resistance grid leak.

The considerable activity in the field of aircraft receiver applications has caused a demand for an especially quiet tube which is being supplied by the UX864. Other applications include receivers and multi-stage tuned audio-frequency amplifiers on small motor driven boats where hull vibration is severe and studio condenser microphone amplifiers where the stand is frequently jarred during a performance. In addition it is being used in various commercial receiver equipments which are subject to either continuous vibration or momentary shocks.