Valve Microphony

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The first part of this article considers in general terms the production of microphony. The various methods of investigating microphony are discussed, and their advantages and disadvantages considered. Illustrations of microphony in various valves are given. The second part considers in more detail microphony in radio and television receivers. Calculations are made of the permissible levels of microphony in the various stages of receivers.

Part 1—Production of Microphony and Methods of Investigation

INTRODUCTION

Many components in electronic equipment do not have a completely rigid structure but consist of parts that can vibrate when the component is subjected to physical excitation. As the parts vibrate, the distance between them may vary and variations in the electrical properties of the component can occur. As a simple example, if the plates of a tuning capacitor vibrate, the distance between the plates may vary and, as a result, there will be a corresponding variation of the capacitance. If the capacitor forms part of the tuned circuit of an oscillator, the frequency of oscillation will vary correspondingly. In other words, the vibration of the capacitor plates with respect to one another gives rise to an interference signal which produces frequency modulation of the oscillator signal. The production of an interference signal as a result of mechanical vibration is known as 'microphony'.

This article considers microphony in valves. The vibration of the electrode structure of the valve can cause variations not only in the inter-electrode capacitances, but also in the anode current and mutual conductance. The vibration may be a result of shocks — for example, equipment in cars or aircraft, and equipment containing push buttons or stiff switches will be subjected to this type of excitation — or the result of continuous excitation from the motors of gramophones and tape recorders, and from the loudspeakers of radio and television receivers. The loudspeaker is often the most troublesome cause of microphony since it is placed close to the valves and can transmit vibrations to the valves both mechanically (through the cabinet and chassis) and acoustically (through the air). Besides causing sound interference, the excitation of the loudspeaker can also affect the valves in the picture channel or timebase circuits of a television receiver and produce interference on the picture. In television receivers, picture microphony is usually more troublesome than sound microphony.

In spite of the very narrow tolerances used in the manufacture of valves, it is impossible to avoid slight differences between valves of the same type. These differences do not have any significant effect on the electrical characteristics of the valve but may affect the microphony considerably. Consequently, certain methods of testing valves can be carried out only on a statistical basis and any modification to a valve to reduce its microphony can be checked only by testing a large number of valves.

FACTORS DETERMINING STRENGTH OF MICROPHONY

A valve subjected to acoustical or mechanical vibration undergoes a varying acceleration. Primarily, it is the magnitude and frequency of this acceleration that determines the strength of the microphony. As an example of the magnitude of the accelerations involved, a typical accelerometer trace is shown in Fig. 1. This trace, of acceleration plotted against excitation frequency, was obtained by replacing one of the valves in a radio receiver by an accelerometer and driving the loudspeaker with a constant 50mW signal of varying frequency. Generally, peak accelerations of between 0·1 to 0·2g (g is the acceleration caused by gravity) can be obtained with loudspeaker powers of 50mW. The magnitude of the acceleration increases with an increase in excitation power, the increase being approximately proportional to the square root of the power.

It has already been mentioned that the vibration may be transmitted from the source to the valve mechanically or acoustically. In the case of mechanical transmission with vibrations reaching the valve through the cabinet and chassis, the magnitude of the acceleration of the valve

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will depend on such factors as the rigidity of the valve in its holder and the rigidity of the valve holder in the chassis. For acoustic transmission, the main factor affecting the acceleration of the valve is the extent to which the vibrations are transmitted through the valve envelope. The factors affecting the magnitude of the acceleration of the electrodes are the acceleration of the valve, the physical properties of the electrodes, the stiffness and rigidity of the electrode structure, and the method of mounting inside the valve.

Further points that have to be considered in connection with the strength of the microphony are the application, the sensitivity, and the operating conditions of the valve. These points are considered in more detail in Part 2 of this article.

INCONSISTENT NATURE OF MICROPHONY

Because of the many factors determining its strength, microphony is very inconsistent. The inevitable slight differences between valves of the same type already mentioned can cause differences in microphony between valves of the same type and valves in the same application. Again, a particular valve may suffer from microphony in one application but not in another, and the position of the valve on the chassis and the method of mounting may affect the microphony considerably. The acceleration on the valve is extremely irregular, as shown by the trace of Fig. 1, since the chassis, cabinet, and other structural members of the equipment have many different resonant frequencies for mechanical and acoustical vibrations, and the whole structure behaves as a combination of mutually coupled resonators. Consequently a small structural change in the equipment can completely alter the frequency spectrum of the acceleration of the valve. For these reasons, it is not possible to calculate accurately the accelerations to which the valve will be subjected, but these can be measured by means of the accelerometers shown in Fig. 2. These laboratory-made accelerometers enable the acceleration on the valve to be measured in three mutually perpendicular directions. The accelerometers are similar in weight and shape to a valve and can be inserted in a valve holder in the equipment under test.

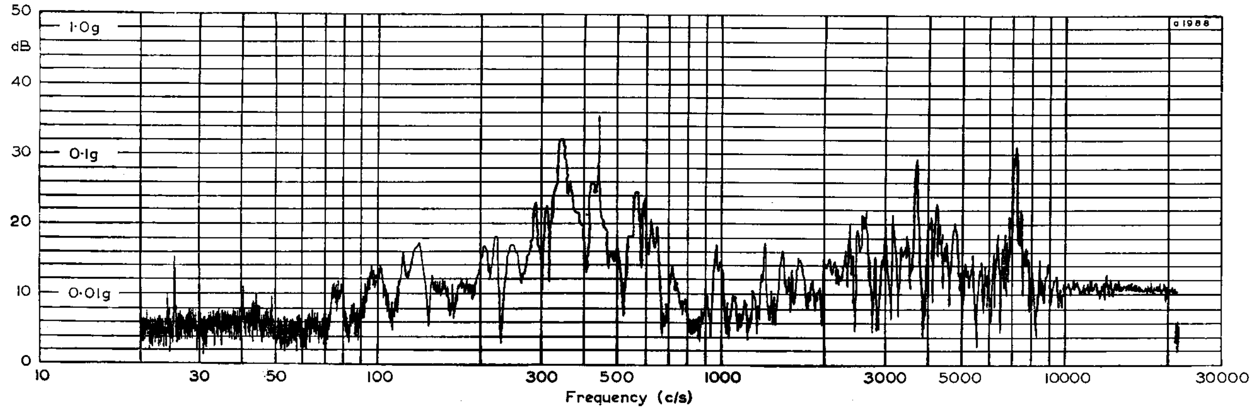


Fig. 1—Pen trace of acceleration plotted against frequency for a valve in a radio receiver subjected to a constant loudspeaker power of 50mW

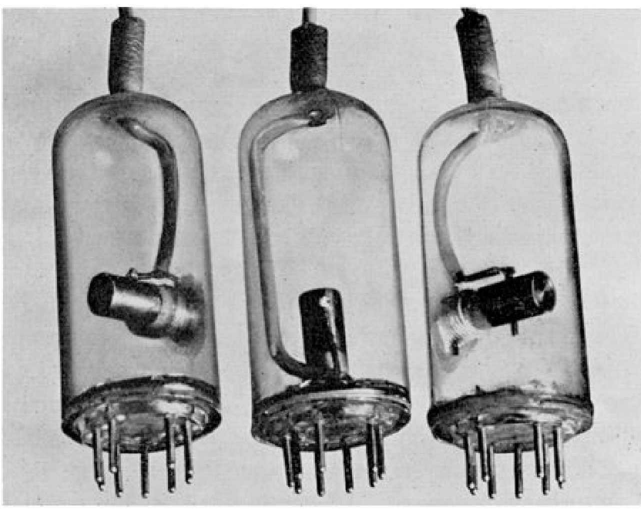


Fig. 2—Accelerometers for measuring the acceleration of a valve in three mutually perpendicular directions

METHODS OF INVESTIGATING MICROPHONY

The methods for investigating microphony can be classified into two groups. The first group uses indirect excitation of the valve such as loudspeaker excitation through the cabinet and chassis. The second group of methods uses direct excitation of the valve itself.

Indirect Excitation Methods

The microphony of an audio amplifier valve may be investigated using the method shown in Fig. 3. The valve is incorporated in an amplifier stage of variable gain and placed near the loudspeaker. The gain of the amplifier

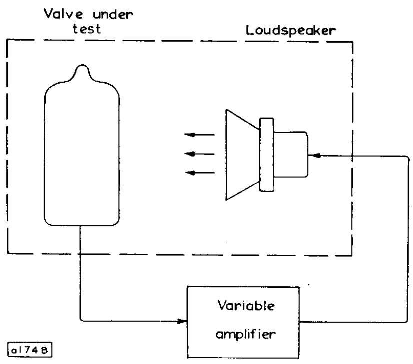


Fig. 3—Method of measuring a.f. microphony by indirect excitation of the valve

is increased until acoustic feedback (or feedback howl) occurs. The gain of the amplifier is then gradually reduced until the howl is just audible. The gain control is left in this position, and the sensitivity of the valve for just-audible howl is determined by injecting a signal of known amplitude into the valve and noting the loudspeaker power. The sensitivity is generally defined as the voltage on the grid of the valve required to produce a loudspeaker power of 50mW. The sensitivity for just-audible feedback howl gives an indication of the maximum amplification of the valve that is permissible.

The performance of an r.f. valve can be tested in a similar way, as is shown in Fig. 4. An unmodulated r.f.

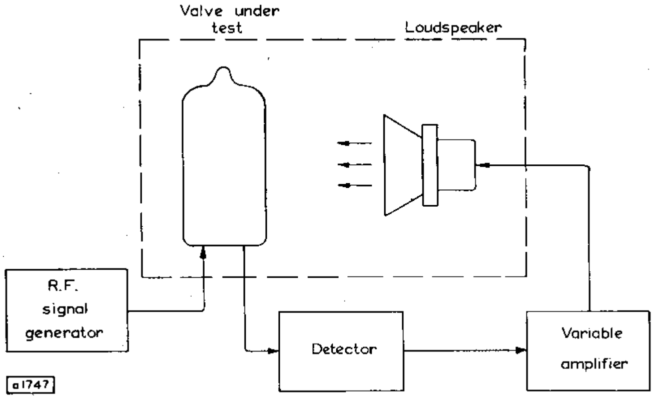


Fig. 4—Method of measuring r.f. microphony by indirect excitation

signal is fed to the control grid of the valve and a detector connected to the output. The output of the detector is fed to the loudspeaker through a variable amplifier. The microphony of the valve causes modulation of the r.f. signal, and the detector delivers an audio-frequency signal which is amplified sufficiently to produce feedback howl. The sensitivity of the valve for just-audible feedback howl can then be determined as before. This sensitivity is defined as the modulation depth required to produce a loudspeaker power of 50mW.

In a similar way, the microphonic tendency of the oscillator valve can be found by determining the sensitivity for just-audible feedback howl. In this case the sensitivity is defined as the frequency deviation required to produce a loudspeaker power of 50mW.

Another method of testing for microphony is shown in Fig. 5. The loudspeaker is excited at a swept frequency

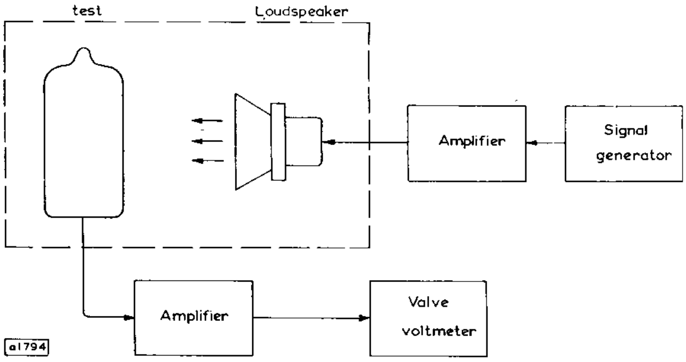


Fig. 5—Method of measuring microphony at a particular frequency by indirect excitation

by an a.f. oscillator and amplifier, and the microphony at the desired frequency is measured by an amplifier and valve voltmeter.

However, as was shown in Fig. 1, even when the loudspeaker power is constant the acceleration on a valve is very irregular and, as a result, it is not easy to investigate the microphony characteristics of the valve itself since there is always the possibility that the cause of the microphony lies outside the valve. To obtain results that refer solely to the valve, methods that excite the valve directly and not through a loudspeaker and chassis must be used.

Direct Excitation Methods

There are three methods for the investigation of microphony using excitation of the valve alone. These use shock excitation, swept-frequency sinusoidal excitation at constant acceleration, and white-noise excitation.

Shock Excitation

An apparatus for shock excitation is shown in Fig. 6. The valve is incorporated in an a.f. amplifier. The pendulum is allowed to strike the valve, giving it an impact of known strength, and the resultant microphonic voltage measured. The method is of use only for comparing

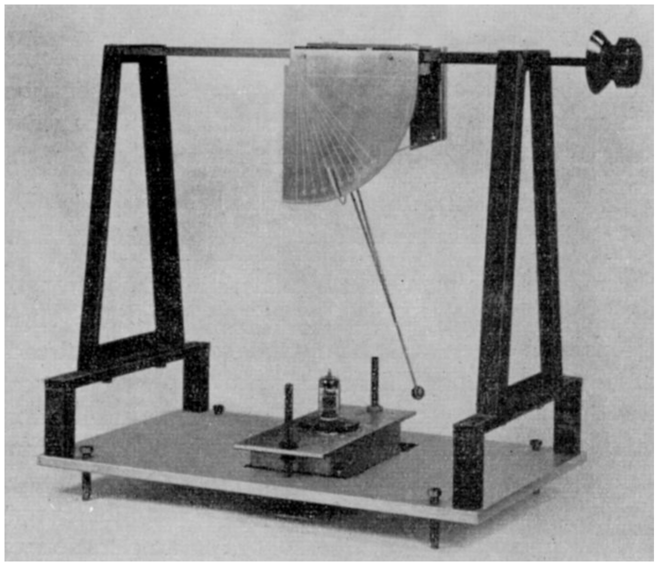
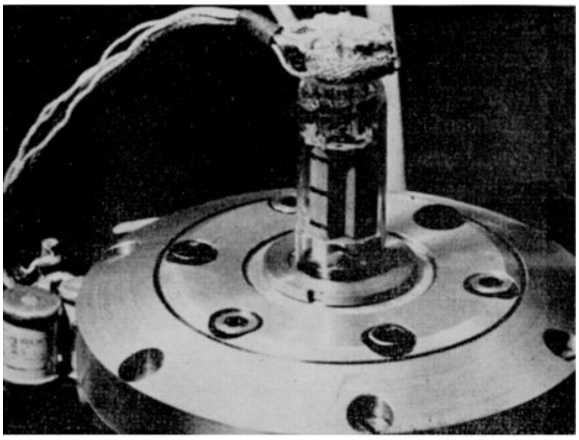


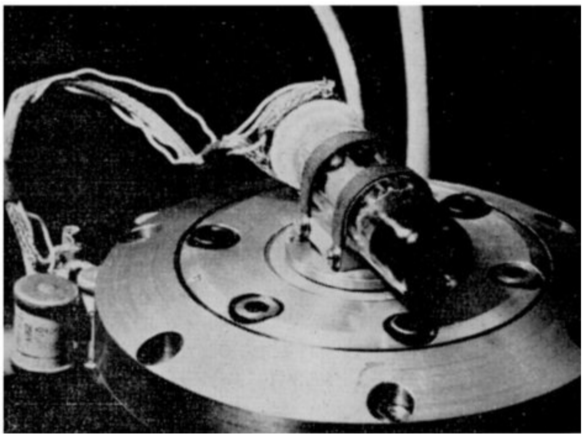
Fig. 6—Apparatus for measuring microphony by shock excitation

valves since all the components of the valve are brought into vibration simultaneously, and it does not provide information on the cause of microphony inside the valve. It does have the advantage, however, of providing a quick, cheap check on valves.

Swept-Frequency Sinusoidal Excitation

The method using swept-frequency sinusoidal excitation is the most useful method for investigating causes of microphony. The valve to be tested is rigidly clamped to a vibrator whose frequency can be varied over a wide range. The resonant frequency of the vibrator is well above the frequency range used for testing valves, the resonant frequency being about 30kc/s and the testing range 30c/s to 20kc/s. An accelerometer is mounted on the vibrator





(a) (b)

Fig. 7—Valve mounted on the vibrator:
(a) with vibration along longitudinal axis of valve (b) with vibration perpendicular to longitudinal axis of valve

to monitor the acceleration on the valve. Photographs of valves mounted on the vibrator are shown in Fig. 7.

Interference voltages resulting from the vibration are measured as the frequency of the vibrator is slowly varied. Typical examples of pen recordings of microphonic voltage plotted against frequency are shown in Figs. 18 to 20. The peaks in the trace correspond to the resonant frequencies of various parts of the electrode structure of the valve. The part of the structure responsible for the microphony is best discovered by examining the valve with a microscope and stroboscope, and a block diagram of the equipment for this is shown in Fig. 8.

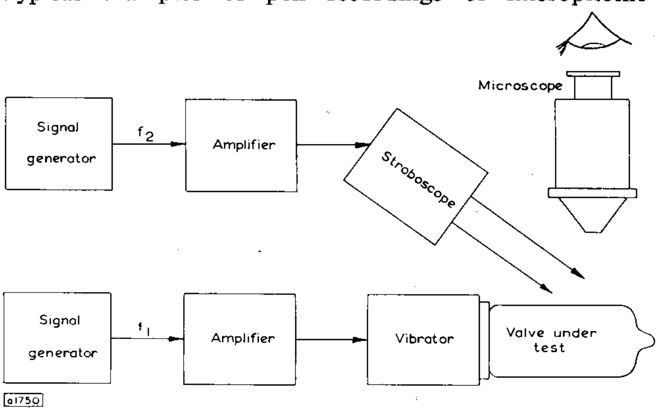


Fig. 8—Block diagram of equipment for examining vibrating valve

Two signal generators are used, one to operate the vibrator and the other to operate the stroboscope. The difference in frequency between the two generators is kept small—a few cycles per second—so that the vibrating parts of the electrode structure appear to be moving very slowly when viewed through the microscope. It is difficult in practice to couple the frequency controls of two signal generators to give a small frequency difference over a wide range and in Fig. 9 a block diagram is shown of the practical version of the equipment. In this case one signal generator is used, feeding the vibrator directly through an amplifier and the stroboscope through a frequency-shift network. This network introduces a constant frequency difference of a few cycles per second between the frequency of the signal generator and that of the signal fed to the pulse generator and stroboscope. The output voltage from the valve is taken to one pair of deflection plates of the oscilloscope and the other pair of plates is supplied with a voltage proportional to the current driving the vibrator.

As the frequency of the vibrator is varied, so the microphonic output voltage of the valve will vary. With any vibrating system, if the frequency of the driving force is lower than the resonant frequency of the system, the deflection will be in phase with the force. If the frequency

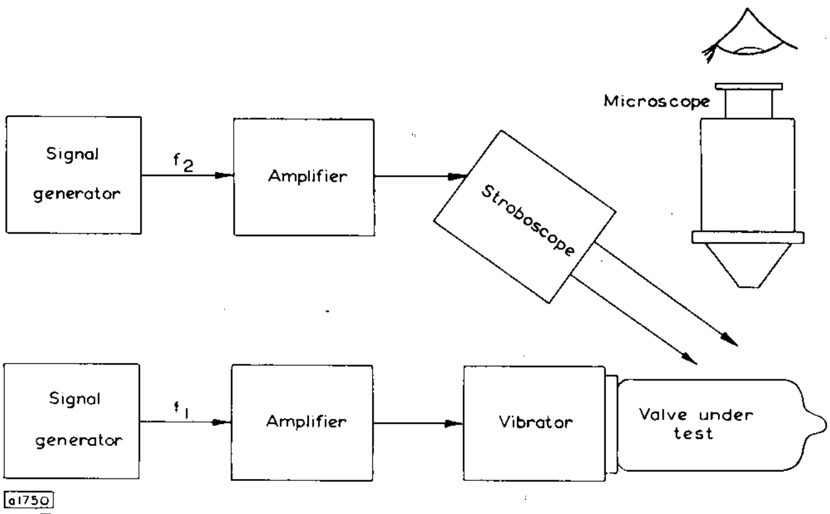


Fig. 9—Block diagram of practical version of equipment shown in Fig. 8

of the force is higher than the resonant frequency, the deflection and force are 180° out of phase. The transition between these two states takes place in a narrow frequency range about the resonant frequency, and at the resonant frequency itself there is a 90° phase shift between the deflection and the force. The changes of phase will also be shown on the oscilloscope as the phase difference between the current driving the vibrator and the voltage produced by the microphony, displayed as a Lissajous figure. At the resonant frequency of a component both the amplitude of the vibration of that component and the microphonic output voltage will be a maximum. Also, the sudden change of phase will be shown on the oscilloscope. Hence by varying the frequency of the vibrator until the microphonic voltage shows a maximum, and by observing the oscilloscope trace and the valve through the microscope, it is possible to determine whether the vibration of a certain component is responsible for the microphony. A photograph of the equipment in use for testing a valve is shown in Fig. 10.

This method of investigating microphony has the advantages of enabling the responsible component to be located, and immediately showing the effects of modifications. Its main disadvantage is that it is time-consuming.

White-Noise Excitation

The third method for investigating microphony using direct excitation also uses a vibrator. This time the vibrator

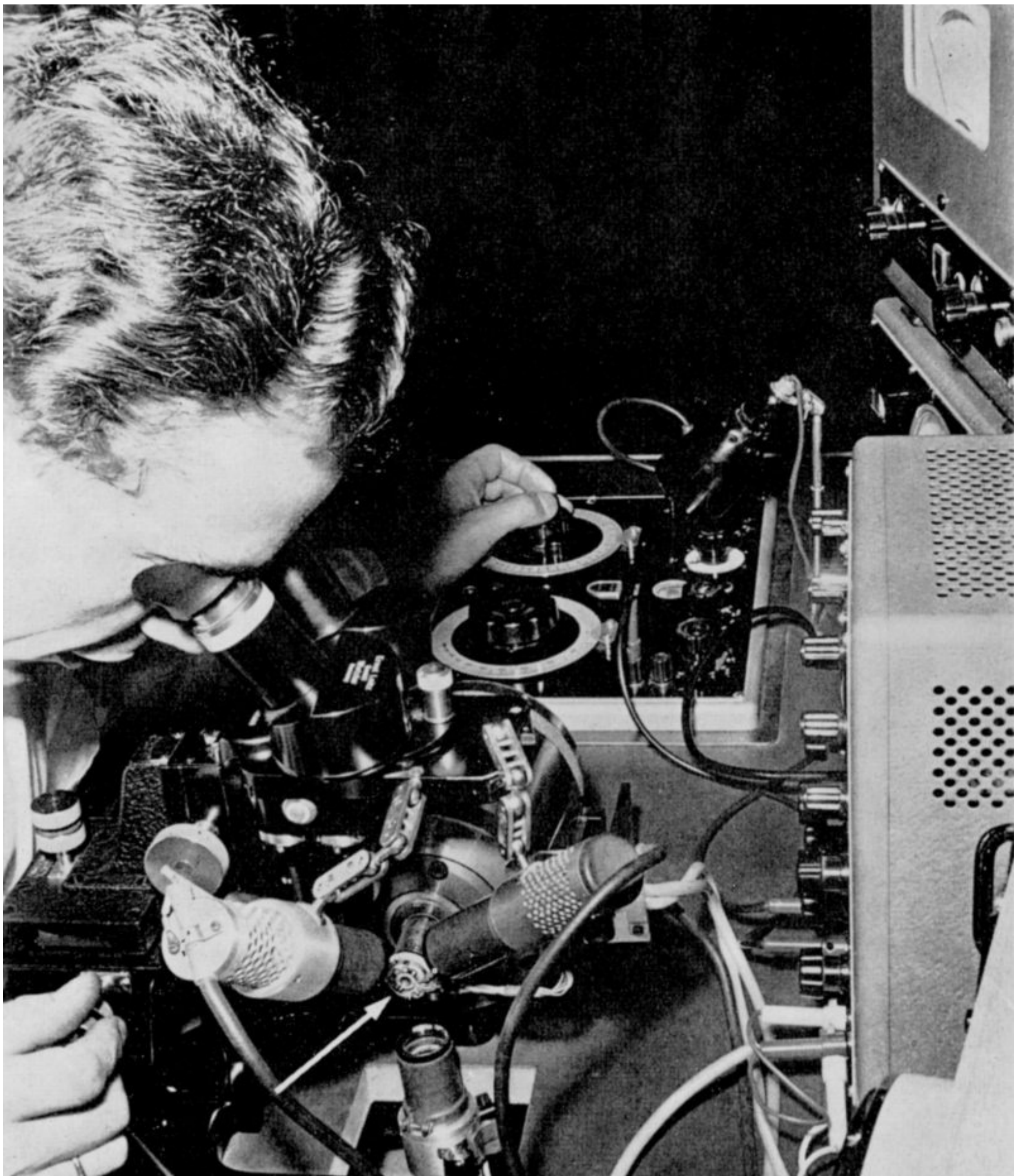


Fig. 10—Photograph of vibrator equipment in use. The arrow points to the valve under test

is not driven at one frequency but by a white-noise signal containing all frequencies. All the parts of the electrode structure of the valve will be driven into resonance simultaneously. Measurement of the r.m.s. value of the interference signal may give an indication of the microphony performance of the valve but by using a frequency-selective amplifier which can 'scan' the complete frequency range investigated, a plot of microphonic voltage against frequency can be obtained. This can be displayed on an oscilloscope or produced as a pen trace.

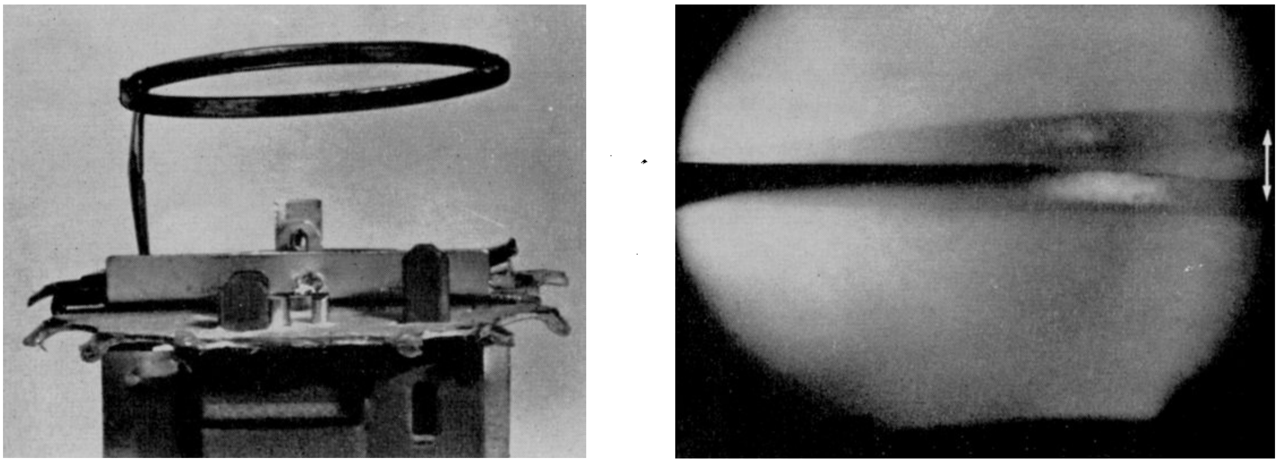
A disadvantage of this method is that the height of the peaks in the display depend on their width. This is because the vertical deflection of the display is proportional to the value of the microphony voltage averaged over the bandwidth of the frequency-selective amplifier. Consequently a peak narrower than the bandwidth of the amplifier will appear shorter than a wider but equally high peak. This has to be remembered when analysing the display.

ILLUSTRATIONS OF MICROPHONY

To end this part of the article, some illustrations of the vibration of electrode structures inside valves will be given. The photographs were taken using the vibrator equipment shown in Fig. 10. A double-exposure technique, each exposure being taken at the extremes of the vibration, enables the amplitude of the vibration to be shown on one photograph.

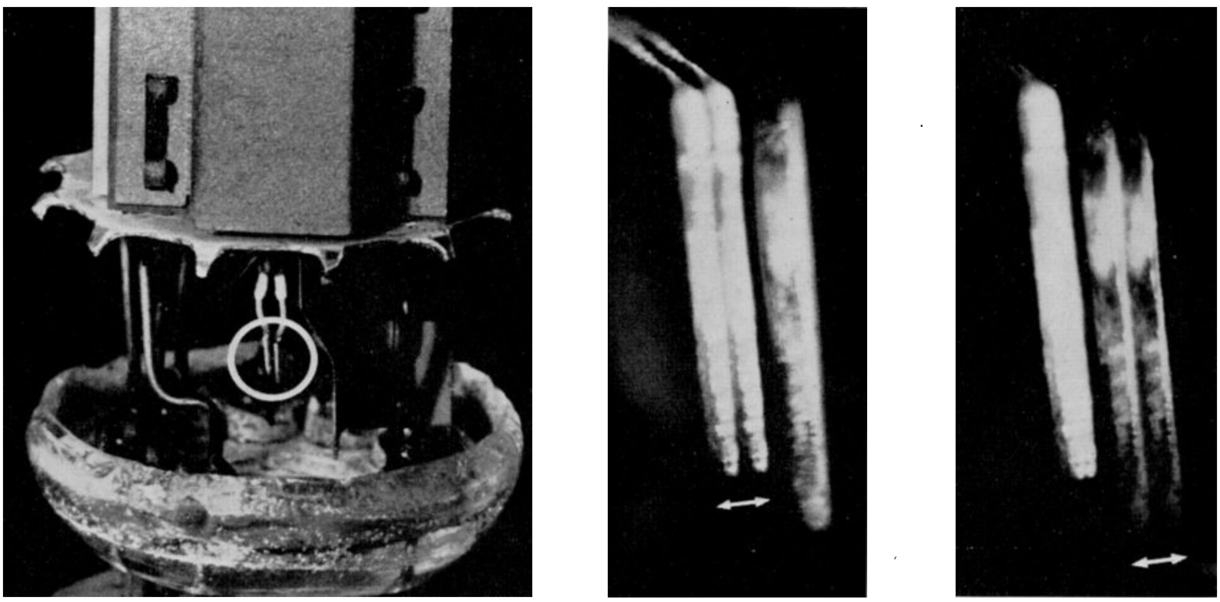
Fig. 11a shows the getter in a valve, fixed at one end only. Fig. 11b shows the vibration of this part at its resonant frequency of 300c/s. Although the getter does not have any electrical effect on the operation of the valve, it may force-excite other electrodes and so adversely affect the operation.

Fig. 12 shows two heater leads of a valve which have different resonant frequencies. Fig. 12a shows the two heater leads, Fig. 12b shows one of the leads vibrating at its resonant frequency of 570c/s, and Fig. 12c shows the other lead vibrating at the resonant frequency of 600c/s.



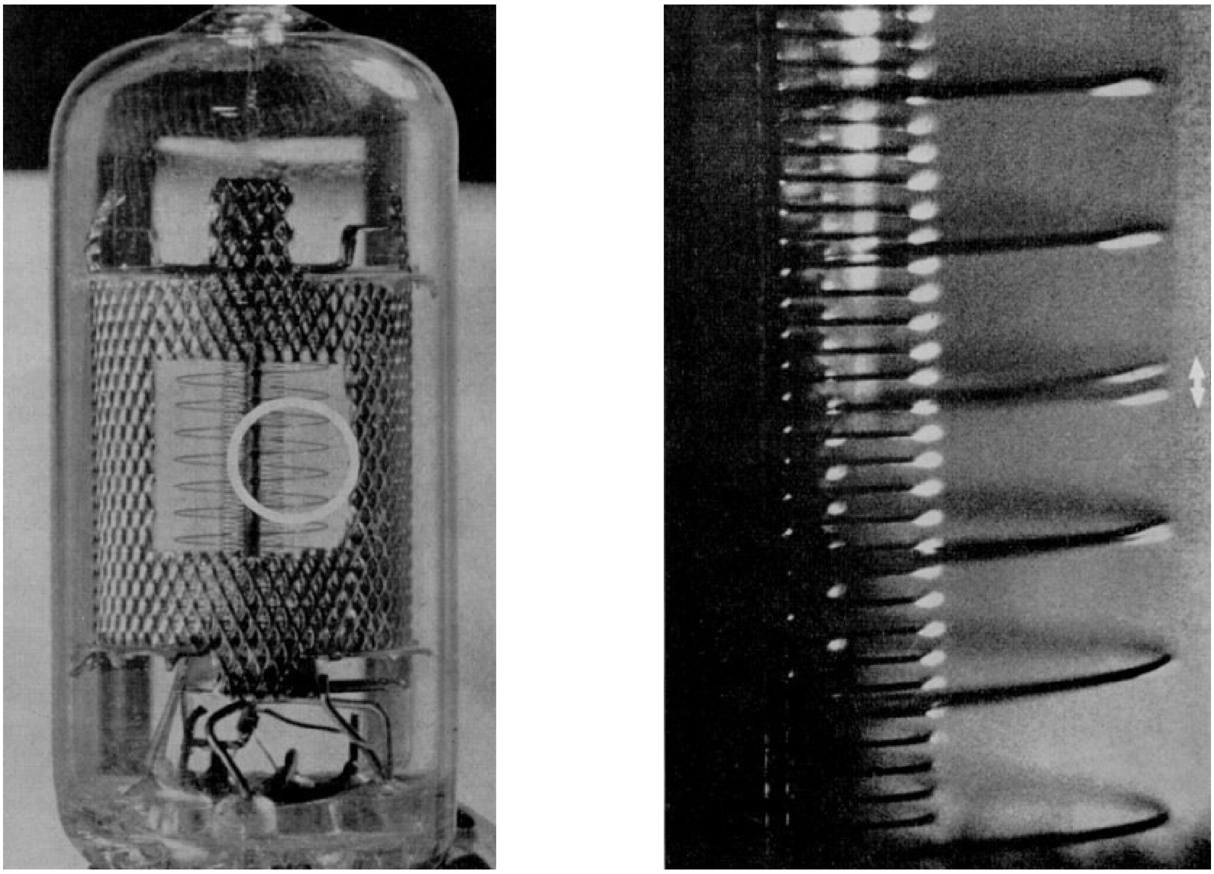
(a) (b)

Fig. 11—(a) Getter of valve fixed at one end only
(b) Getter resonating at 300c/s



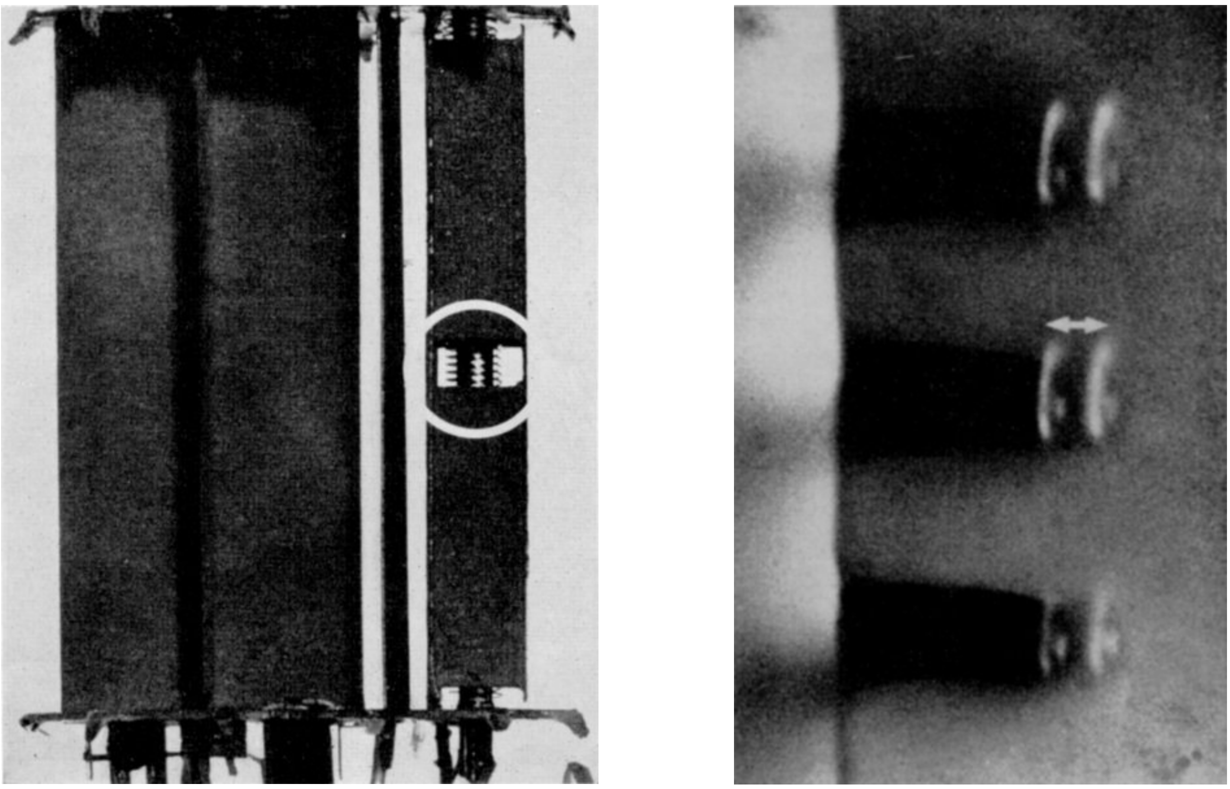
(a) (b) (c)

Fig. 12—(a) Heater leads of valve (in circle)
(b) One heater lead resonating at 570c/s
(c) Other heater lead resonating at 600c/s



(a) (b)

Fig. 13—(a) Suppressor grid of pentode seen through opening cut in anode. The circle marks the part of the grid shown in (b)
(b) One turn of suppressor grid resonating at 2100c/s

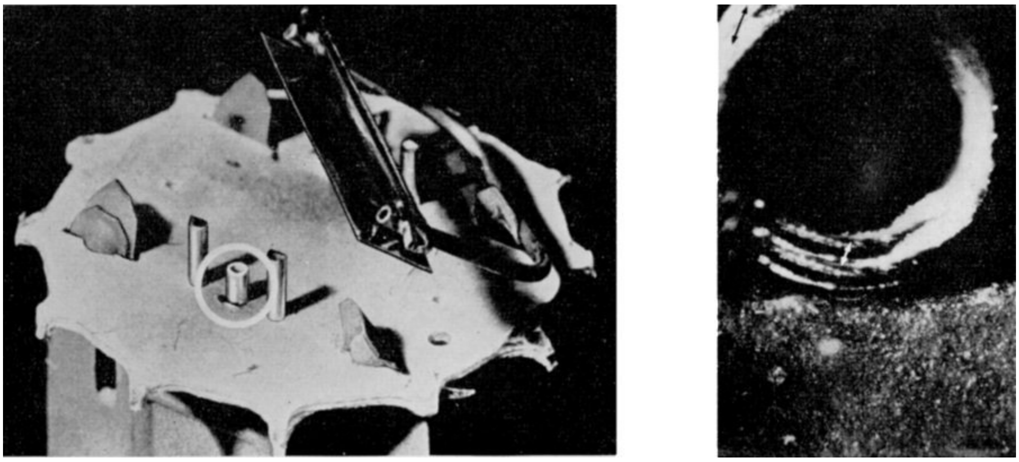


(a) (b)

Fig. 14—(a) Grid of triode section of a triode hexode
(b) Grid resonating at 1900c/s

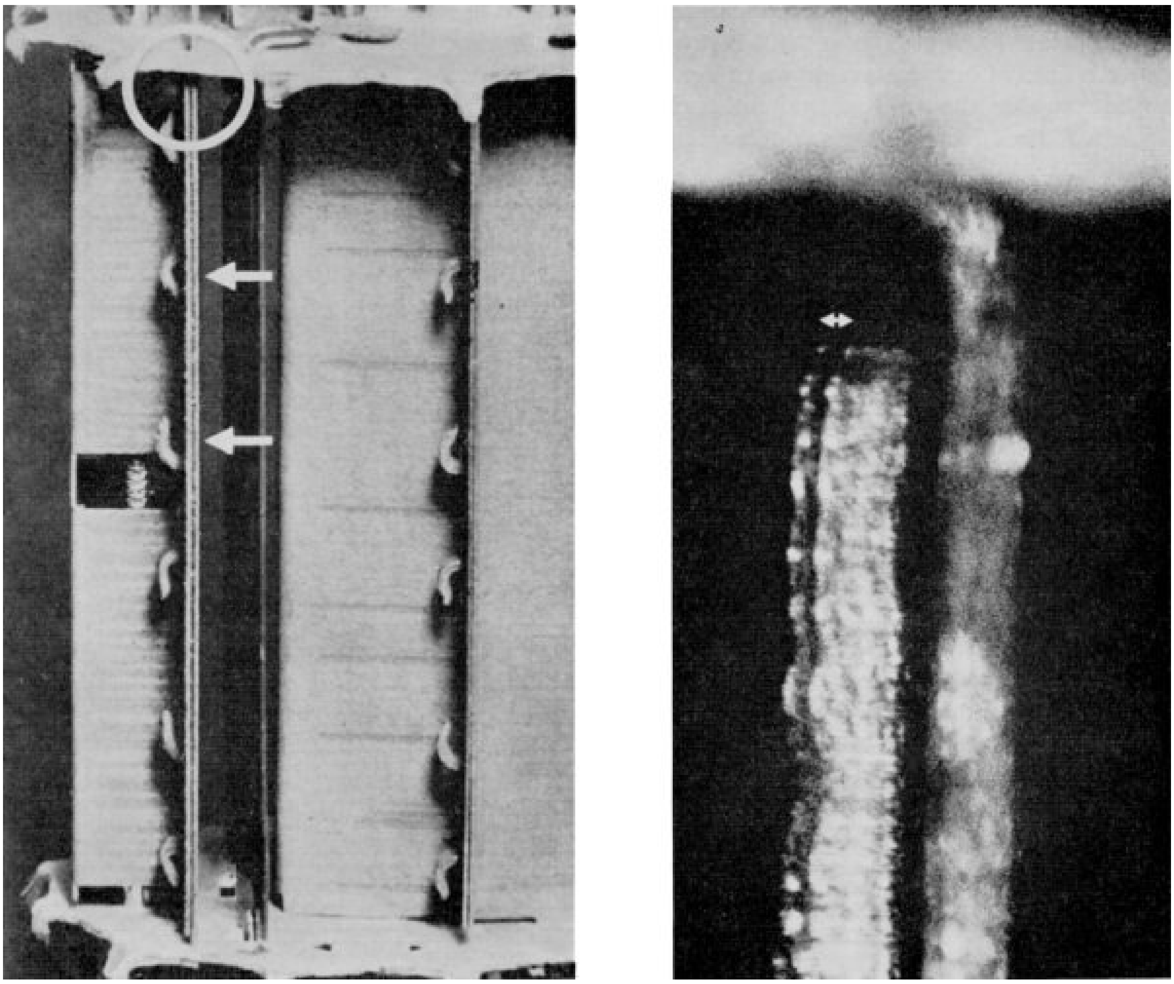
It can be seen that there is little movement of the lead that is not at resonance.

Fig. 13a shows the electrode structure of a pentode valve with the suppressor grid made visible by an opening cut in the anode. In Fig. 13b one of the turns of the grid is at resonance, at 2100c/s, whilst the other turns are at rest. The vibration of the grid of the triode section of a triode-hexode valve is shown in Fig. 14. The resonant frequency this time is 1900c/s. Fig. 15 shows how the slight play between the cathode and the top mica of a valve enables the cathode to vibrate at a frequency of 600c/s. In Fig. 16, insufficiently tight clamping between the two halves of the anode structure has led to movement between them at a frequency of 1300c/s. An example of



(a) (b)

Fig. 15—(a) Top of electrode structure of valve showing (in circle) end of the cathode (b) Cathode resonating at 600c/s

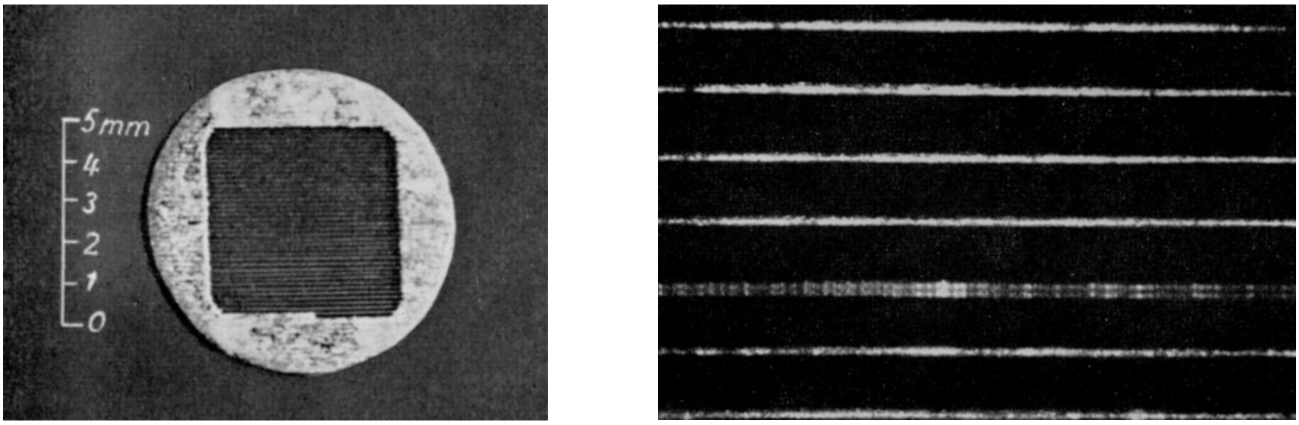


(a) (b)

Fig. 16—(a) Anode structure of valve insufficiently clamped at points marked by arrow
(b) Movement between the parts of the anode at 1300c/s

vibration at higher frequencies is shown in Fig. 17 where one of the wires of a frame grid is resonating at a frequency of 37kc/s.

Pen traces of the output voltage of a valve mounted on the vibrator are very useful for checking the effect of any modifications to the electrode structure of the valve.



(a) (b)

Fig. 17—(a) Frame grid of valve
(b) One wire of frame grid resonating at 37kc/s

lug instead of a single lug on the anode structure of a valve is shown in Fig. 19. The double lug ensures better locking of the anode to the mica and so reduces the microphony. The construction of the anode can also affect the microphony, as shown in Fig. 20. The anode shown in Fig. 20a is greatly inferior to that shown in Fig. 20b, as the two pen traces show.

In Fig. 18a (derived from a pen trace), the getter of the valve is fixed at one point only and the pen trace shows high levels of microphony at low frequencies, including a very high peak at 1300c/s. The modified structure where the getter is fixed at both ends is shown in Fig. 18b, where it can be seen that the low-frequency microphony has been eliminated. The effect of using a double mounting

Although the valve manufacturer tries to make valves as free as possible from microphony, it is not always possible to make the required structural modifications without affecting the electrical characteristics of the valve. For this reason, it is sometimes necessary for a compromise to be made. In general, however, the electrode structure of a valve is made as rigid as possible.

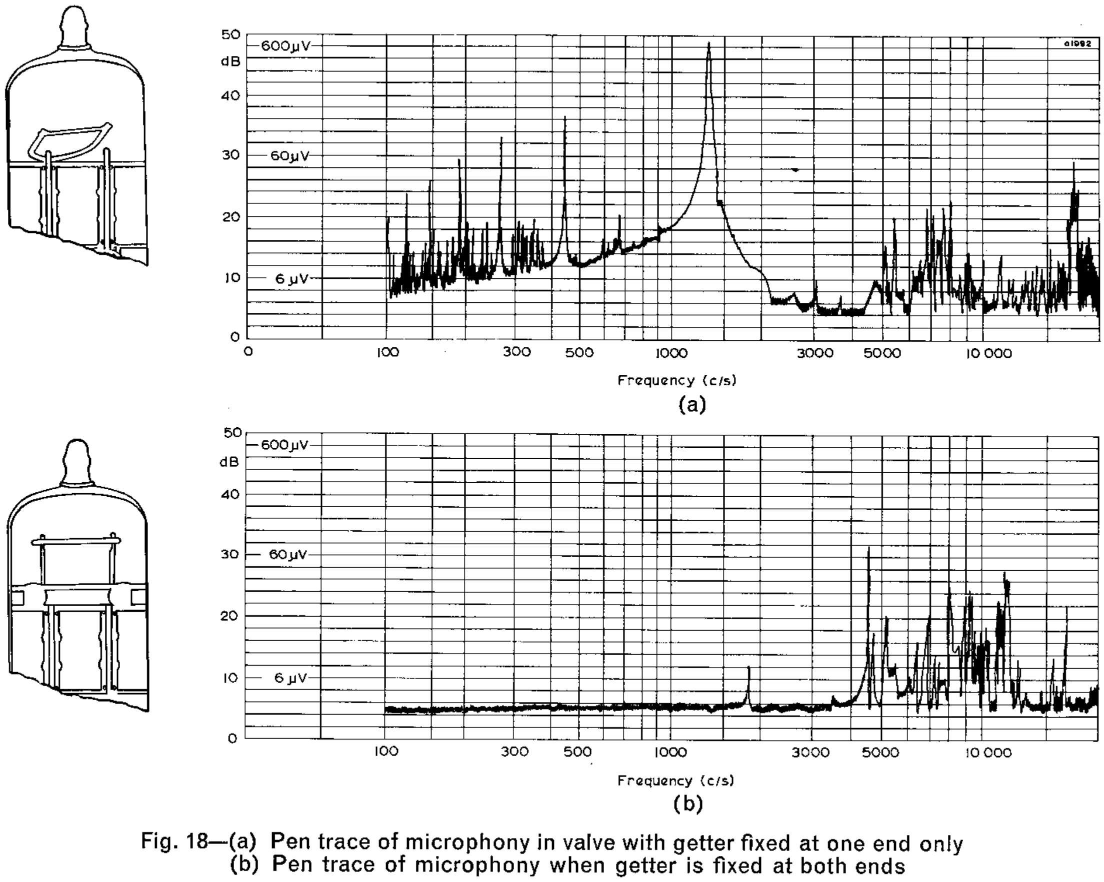


Fig. 18—(a) Pen trace of microphony in valve with getter fixed at one end only
(b) Pen trace of microphony when getter is fixed at both ends