Part 2—Microphony in Radio and Television Receivers

INTRODUCTION

The first part of this article considered the production of microphony in general terms. This part of the article considers microphony in valves for radio and television receivers. The production of microphony in these valves is described in more detail, and calculations made of the permissible levels of microphony in the various stages of radio and television receivers.

Although microphony can occur with valves in any application, it is only in entertainment applications that it is possible to define readily the requirements of each stage and so express these requirements in terms of the minimum permissible signal level or maximum interference level. For this reason, the article does not deal with industrial or professional applications of valves.

PRODUCTION OF MICROPHONY

Microphony is defined as the electrical output from a valve caused by a mechanical input. It has already been described how the valves in a radio or television receiver can be subjected to varying accelerations through mechanical or acoustical excitations. These excitations can be produced by the operation of the loudspeaker or by an outside mechanical force. The changes in acceleration produce relative motion between the electrodes of the valves and hence, among other effects, cause variations in anode current, mutual conductance, and inter-electrode capacitances.

The variations in anode current affect mainly the operation of audio and video valves, producing an interference voltage across the load resistance. Variations in mutual conductance affect mainly the r.f. and i.f. valves in a.m. receivers, causing corresponding variations in the amplification. Alternatively, the effect may be regarded as a modulation of the carrier amplitude to a modulation depth of $m = \Delta g_m/g_m$, where Δg_m is the change in mutual conductance g_m. Variations in inter-electrode capacitances affect the operation of oscillator valves, by varying the total capacitance in the tuned circuit and hence modulating the oscillator frequency. This modulation can cause interference in receivers, mainly in f.m. receivers but also, in certain circumstances, in a.m. receivers. The possibility of interference occurring in a.m. receivers depends on the relative position of the carrier frequency with respect to the i.f. response characteristic, and the relative variation of the frequency with respect to the bandwidth of the response characteristic. Interference occurs when the frequency variations are large in comparison with the bandwidth of the i.f. response characteristic, or if the carrier frequency is located on the sloping side of the response characteristic. The carrier frequency may be on the slope accidentally, as in the case of a radio which is off tune, or intentionally, as in the case of the vision carrier of a television receiver. A further but less important result of these variations in inter-electrode capacitances is variations in the impedance of the tuned circuits which will modulate the carrier amplitude and cause interference in an a.m. receiver.

Microphony caused by variations in anode current is called current or a.f. microphony, that caused by variations in mutual conductance is called slope or r.f. microphony, and that caused by variations in inter-electrode capacitance is called capacitive or oscillator microphony. Microphony can also be classified by the output device which reveals the interference. This method leads to such classifications as sound microphony, picture microphony, oscilloscope microphony, and so on.

PREVENTION OR REDUCTION OF MICROPHONY

There are three methods which can be used to prevent or to reduce the effects of microphony. These methods are: the use of anti-microphonic valves, the reduction of the vibration on the valve, and the use of suitable electrical sensitivity, circuitry, and operating conditions to make the equipment less sensitive to microphony.

Anti-Microphonic Valves

Anti-microphonic valves are specially manufactured so that when the valve is subjected to vibration, the relative motion of the electrodes is as small as possible. The electrode structure of the valve is firmly fixed and the natural frequencies of the electrodes are made as high as is practicable. These conditions are achieved by using short, thick, rigid electrodes, arranging the electrodes symmetrically, using double micas and locking straps, and using high tensions in the grids of frame-grid valves. Most modern valves are designed to be anti-microphonic.

Reduction in Vibration

There are many methods by which the vibration reaching a valve may be reduced. The main ones are:

(i) removing or reducing the exciting force;
(ii) positioning the valve on a 'quiet' part of the chassis;
(iii) isolating the valve from the vibration, by means of resilient mountings or acoustic screening, etc.;
(iv) damping, by introducing frictional forces to limit the vibration at resonant frequencies;
(v) increasing the natural frequency of vibration of the chassis or the cabinet, by local strengthening.

Use of Suitable Electrical Sensitivity, Circuitry, and Operating Conditions

In general, the electrical sensitivity of a circuit should be made such that the signal-to-microphony ratio, referred to the output terminals of the receiver (the loudspeaker for sound or the cathode of the picture tube for video), is as high as the design considerations allow. As will be shown later, microphony depends to some extent on the electrical sensitivity* of the circuits used and on the operating conditions of the valve (Refs. 1 and 2). As far as the operating conditions are concerned, it is advisable to choose the working point well away from the knee of the I_a/V_g characteristic. The picture and sound microphony of the oscillator section of a frequency-changer valve can be reduced by reducing the extent to which the valve inter-electrode capacitances form part of the oscillator-circuit capacitances, and by increasing the ratio of oscillator capacitance to oscillator frequency.

EXAMPLE

As an example of microphony calculations, the a.f. and r.f. microphony as functions of operating voltage and the relative variation in inter-electrode spacing will be calculated.

For simplicity, a single planar valve system is considered (Fig. 1) with the following assumptions:

(i) the electrodes move uniformly throughout their length in a direction perpendicular to the plane of the electrodes;

(ii) microphony other than that at the fundamental frequency of vibration is negligible;

(iii) the valve operates outside the 'island effect' region.

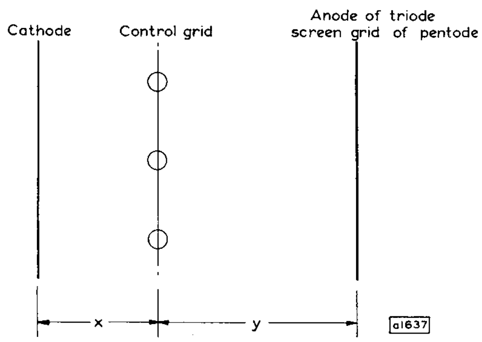


Fig. 1—Single planar valve system

The approximate value of anode current is given by the equations:

$$I_a = \frac{k_1}{x^2}\left(V_g + \frac{V_a}{\mu}\right)^{3/2},$$

$$= \frac{k_1}{x^2}\left(V_g + k_2\frac{V_a}{y}\right)^{3/2}, \qquad \ldots(1)$$

where I_a is the anode current of a triode, V_g is the grid voltage, μ is the amplication factor $[dV_a/dV_g]_{I_a}$, x and y are the electrode spacings as shown in Fig. 1, and k_1 and k_2 are constants. The equations also apply to a pentode if I_a is taken as the space current and the anode of the triode is replaced by the screen grid of the pentode. The amplification factor is then $[dV_{g2}/dV_{g1}]_{I_{g2}}$.

Fundamental values of a.f. and r.f. microphony can be calculated as shown below. The fundamental value of a.f. microphony is defined by the equation:

$$\Delta V_g = \frac{\Delta I_a}{g_m}, \qquad \ldots(2)$$

where ΔI_a is the change in anode current caused by the vibration and ΔV_g is the equivalent microphonic change in grid voltage corresponding to ΔI_a.

I_a may be expressed as a MacLaurin's series and an expression for ΔI_a derived. Neglecting the second and higher order terms and substituting this expression for ΔI_a in Eq.(2) gives:

$$\Delta V_g = \frac{1}{g_m}\left(\frac{\partial I_a}{\partial x}.\Delta x + \frac{\partial I_a}{\partial y}.\Delta y\right). \qquad \ldots(3)$$

From:

$$g_m = \left[\frac{dI_a}{dV_g}\right]_{V_a},$$

and Eq.(1), it follows that:

$$g_m = \frac{3}{2}\frac{k_1}{x^2}\left(V_g + k_2\frac{V_a}{y}\right)^{1/2}. \qquad \ldots(4)$$

If the expression for g_m of Eq.(4) is substituted in Eq.(3), and the partial differentiation of I_a in terms of Eq.(1) performed, Eq.(3) becomes:

$$\Delta V_g = \left\{\frac{3}{2}\frac{k_1}{x^2}\left(V_g + k_2\frac{V_a}{y}\right)^{1/2}\right\}^{-1}\left\{-\frac{2k_1}{x^3}\left(V_g + k_2\frac{V_a}{y}\right)^{3/2}\Delta x - \frac{3}{2}\frac{k_1 k_2}{x^2 y^2}V_a\left(V_g + k_2\frac{V_a}{y}\right)^{1/2}\Delta y\right\}.$$

This simplifies to:

$$\Delta V_g = -\frac{4}{3}\left(V_g + k_2\frac{V_a}{y}\right)\frac{\Delta x}{x} - k_2\frac{V_a}{y}\frac{\Delta y}{y}. \qquad \ldots(5)$$

Similarly the equation for the fundamental value of r.f. microphony:

$$m = \frac{\Delta g_m}{g_m},$$

may be developed as above to yield:

$$m = -2\frac{\Delta x}{x} - \tfrac{1}{2}\left(V_g + k_2\frac{V_a}{y}\right)^{-1}.k_2\frac{V_a}{y}\frac{\Delta y}{y}. \qquad \ldots(6)$$

From Eqs.(5) and (6) it can be seen:

(i) For cathode motion $\Delta y = 0$, and with increasing negative grid bias the a.f. microphony decreases, Eq.(5), but the r.f. microphony remains constant, Eq.(6).

(ii) For anode motion $\Delta x = 0$, and with increasing negative grid bias the a.f. microphony remains constant but the r.f. microphony increases.

(iii) For grid motion $\Delta x = -\Delta y$, and ΔV_g and m can be reduced to zero at:

$$V_g = -\frac{V_a}{\mu}\left(1 - \frac{3}{4}\frac{x}{y}\right) \text{ for } \Delta V_g = 0,$$

and

$$V_g = -\frac{V_a}{\mu}\left(1 - \frac{1}{4}\frac{x}{y}\right) \text{ for } m = 0.$$

In a double planar valve system, the effective values of ΔV_g and m will be reduced by cancellation between one side of the valve and the other. In a valve with perfect

*Electrical sensitivity with respect to sound microphony is defined as:

$P_o^{1/2}/v_i$, $P_o^{1/2}/m_i$, or $P_o^{1/2}/f_d$.

P_o is the loudspeaker output power in watts; v_i is the input voltage to the a.f. valve, m_i is the modulation depth, and f_d the frequency deviation in kc/s, to produce a loudspeaker power P_o.

symmetry, fundamental a.f. and r.f. microphony will be zero but microphony at harmonics may exist. This is not shown in the above equations as only fundamental microphony has been considered. In practice, because of the island effect, both ΔV_g and m may increase with increasing negative grid bias.

SOUND MICROPHONY

The main types of sound microphony are 'feedback howl' (or howlback) and 'clang'.

Feedback Howl

Feedback howl occurs when the initial microphony of a valve is amplified, converted by the loudspeaker into vibrations that are fed to the valve with such a phase relationship and amplitude as to sustain the vibration of the electrodes that produced the initial microphony. It can be seen, therefore, that feedback howl can be prevented, even with a favourable phase relationship, if the microphony from a certain loudspeaker power is made less than the input signal required to produce that same speaker power. The input signal and the microphony should be defined in the same terms – input voltage for an a.f. valve, modulation depth for an i.f. or r.f. valve, and frequency deviation for an oscillator valve.

Since the possibility of feedback howl increases with increasing electrical sensitivity and relative vibration with respect to speaker power, the microphony limits should be expressed in terms of the acceleration caused by a given loudspeaker power and the electrical sensitivity of the valve. The acceleration of a valve in a receiver is proportional to the square root of the loudspeaker output power. In general, the peak acceleration in a receiver is less than 0·2g at 50mW or 1·0g at 1W output power.

If it is assumed that the loudspeaker output power for a television receiver does not exceed 5W and for a radio receiver 12W, and also that these output powers are realised only if the modulation depth with an a.m. receiver is greater than 30% and if the frequency deviation of an f.m. receiver is greater than 15kc/s, the requirements for the prevention of feedback howl can be expressed as below.

A.F. Valves

From the equation for electrical sensitivity, the requirement for the prevention of feedback howl is:

$$\frac{P_o^{1/2}}{v_i} = \frac{(0 \cdot 05)^{1/2}}{v_i'}, \qquad \ldots(7)$$

where v_i is the input voltage for a loudspeaker power of P_o, and v_i' is the input voltage for 0·05W. Eq.(7) can be rearranged as:

$$v_i = v_i' \left(\frac{P_o}{0 \cdot 05}\right)^{1/2}. \qquad \ldots(8)$$

Amplifiers using a.f. valves should therefore be designed, unless otherwise stated in published data, so that the vibration on the valve from a loudspeaker power of 50mW does not exceed the normal value of 0·2g, and the minimum permissible input voltage is defined by Eq.8.

R.F. and I.F. Valves

The requirements for the prevention of feedback howl in television and radio receivers respectively are:

$$\frac{P_o^{1/2}}{m} = \frac{5^{1/2}}{0 \cdot 3} \text{ and } \frac{P_o^{1/2}}{m} = \frac{12^{1/2}}{0 \cdot 3},$$

that is:

$$m = 0 \cdot 3\left(\frac{P_o}{5}\right)^{1/2} \text{ and } m = 0 \cdot 3\left(\frac{P_o}{12}\right)^{1/2}. \qquad \ldots(9)$$

Amplitude-modulation receivers incorporating r.f. and i.f. valves should therefore be designed so that the vibration on the valve does not exceed the normal value, and that at maximum sensitivity a speaker power P_o cannot be produced by signals having a modulation depth less than that defined in Eq.(9).

Oscillator Valves

The requirements for the prevention of feedback howl from the oscillator valve in f.m. receivers are:

$$\frac{P_o^{1/2}}{f_d} = \frac{5^{1/2}}{15} \text{ and } \frac{P_o^{1/2}}{f_d} = \frac{12^{1/2}}{15},$$

for television and radio receivers respectively; that is:

$$f_d = 15\left(\frac{P_o}{5}\right)^{1/2} \text{ and } f_d = 15\left(\frac{P_o}{12}\right)^{1/2}. \qquad \ldots(10)$$

Frequency-modulation receivers should therefore be designed so that the vibration on the oscillator valve does not exceed the normal value, and that at full sensitivity a speaker power P_o cannot be produced by signals with a frequency deviation less than that defined by Eq.(10).

Clang

Clang is microphony caused by shock excitation; for example, by the operation of a motor or a switch, or by tapping the chassis or cabinet of a receiver. The effect of this type of microphony on the ear depends on several factors. The most important are: the amplitude, frequency and duration of the clang; the comparison of the clang with the mechanical noise coming directly from the shock source; and the comparison of the clang with the useful signal.

These factors lead to the following limitations for clang microphony:

(i) clang should not produce a more objectionable impression than the mechanical noise coming directly from the shock source;

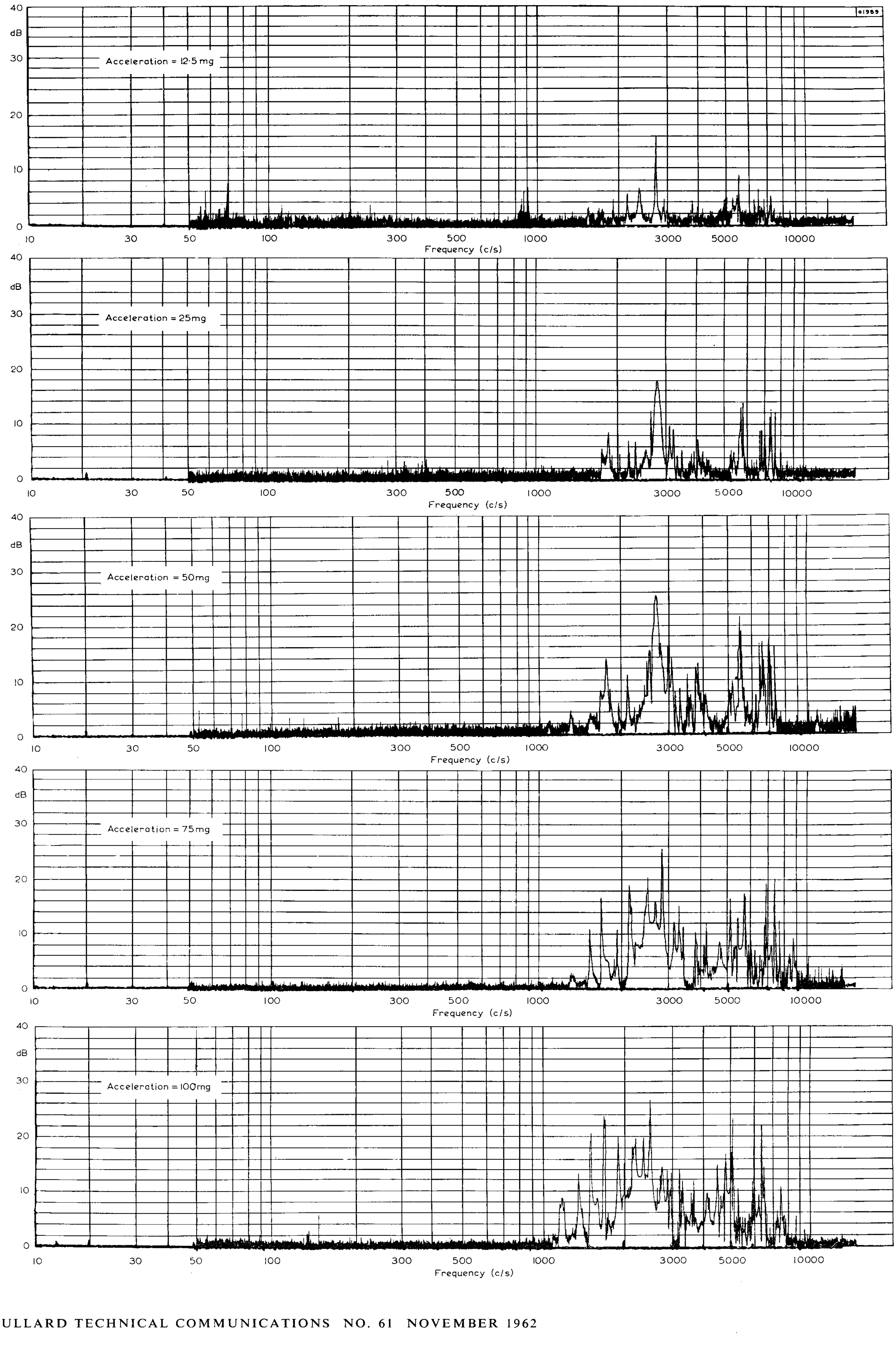
(ii) The signal-to-clang ratio should be greater than 34dB for continuous excitation (for example, caused by a motor), or greater than 24dB for intermittent excitation (for example, caused by a switch).

Example

As a second example of microphony calculations, the determination of the maximum permissible acceleration for an EF86 in a tape recorder is shown. The valve is assumed to be a pre-amplifier with a voltage from the replay head of 0·5mV for a loudspeaker power of 50mW.

If a safety factor of 2 is used, the maximum permissible

Fig. 2 (right)—Pen traces of microphony of an EF86 plotted against frequency for different peak acceleration levels. 0dB corresponds to an equivalent microphonic grid voltage of 6·67μV


40
dB
30
20
10
0
Acceleration = 12·5 mg
10
30
50
100
300
500
1000
3000
5000
10000
Frequency (c/s)
Acceleration = 25mg
Frequency (c/s)
Acceleration = 50mg
Frequency (c/s)
Acceleration = 75mg
Frequency (c/s)
Acceleration = 100mg
Frequency (c/s)

equivalent microphonic grid voltage for a loudspeaker output power of 50mW is 0·5/2 or 0·25mV. This means that the acceleration of the valve caused by vibrations from the loudspeaker at 50mW should be less than the acceleration which would produce an equivalent grid voltage of 0·25mV. The value of acceleration can be obtained from pen traces of microphony plotted against frequency for various accelerations.

Fig. 2 shows such traces for the EF86 at peak accelerations of 12·5, 25, 50, 75 and 100mg. The acceleration is applied to the valve in such a direction that the components of the acceleration along the three main axes of the valve are equal. Tests were carried out on 75 valves from a large manufacturing batch and from the readings the cumulative distribution characteristics of the maximum observed microphony for frequencies above 1kc/s were drawn, as shown in Fig. 3. From Fig. 3 it can be seen that for 99% of the valves the maximum permissible value of acceleration (giving an equivalent grid voltage of 0·25mV) for the example is approximately 20mg.

Similarly curves can be plotted for accelerations at excitation frequencies below 1kc/s and permissible accelerations for these frequencies determined. In practice, however, no microphony trouble occurs with the EF86 at frequencies below 1kc/s.

PICTURE MICROPHONY

The two main types of picture microphony are intensity modulation of the electron beam in the picture tube, and the horizontal or vertical displacement of the picture on the screen.

Intensity Modulation of Electron Beam in Picture Tube

This type of microphony is characterised by alternate bright and dark bars across the picture. It is the result of current variations in the video output valve, variations in the mutual conductance of the r.f. or i.f. valves, or variations in the inter-electrode capacitance of the oscillator valve. The way in which these variations cause interference has already been explained on page 12.

The magnitude of the tolerable interference voltage at the cathode of the picture tube caused by the microphony may be determined by consideration of eye-sensitivity. A curve of the tolerable interference voltage for constant excitation at a given frequency, measured at the cathode of the picture tube, plotted against the frequency of the interference is shown by curve A in Fig. 4. However, when the frequency of interference (which is not necessarily equal to the excitation frequency) deviates by an amount f from the line timebase frequency, or a multiple of this frequency, the interference will appear on the screen of the picture tube at a frequency f. In addition, for speech and music excitation the possibility of excitation decreases with increasing excitation frequency, and hence the

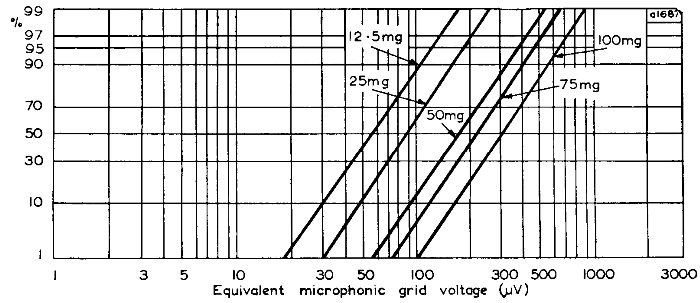


Fig. 3—Cumulative distribution characteristics of EF86 valves

magnitude of the tolerable interference voltage increases. In this case, the tolerable interference voltage caused by speech and music excitation v_m is approximately equal to $v_{tol}(f_{exc})^{1/2}$, where v_{tol} is given by curve A of Fig. 4 and f_{exc} is the excitation frequency in kc/s. Therefore for a line timebase frequency of 10kc/s, the interference voltage will vary with the interference frequency as shown in curve B of Fig. 4.

The microphony requirements for the video, r.f., i.f. and oscillator valves for a particular range of microphony frequencies can be determined as shown below.

Video Valves

The maximum permissible equivalent microphonic grid voltage is v_m/A_v, where v_m is the tolerable interference voltage given in curve B of Fig. 4 and A_v is the voltage gain of the stage. For example, for microphony at a frequency below 1kc/s the maximum permissible microphonic grid voltage is $0{\cdot}2/A_v$.

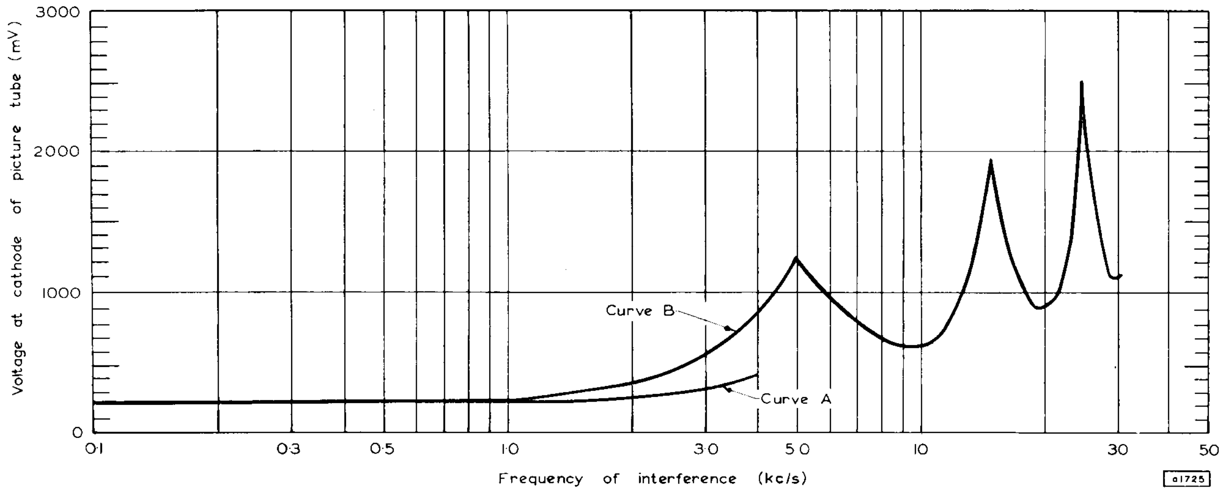


Fig. 4—Curves of tolerable microphonic interference voltage plotted against frequency. Curve A represents the interference voltage determined by eye-sensitivity and curve B the tolerable interference voltage for a timebase frequency of 10kc/s

R.F. and I.F. Valves

It is assumed that the peak-to-peak video signal at the cathode of the picture tube is 70V, representing 65% of the peak-to-peak carrier voltage. For linear amplification and detection, the permissible relative variation in slope or microphonic modulation depth is:

$$m = v_m \times \frac{2\sqrt{2}}{70/0{\cdot}65}.$$

For microphonic frequencies below 1kc/s:

$$m = 0{\cdot}2 \times \frac{2\sqrt{2}}{70/0{\cdot}65},$$
$$\simeq 0{\cdot}5\%.$$

Oscillator Valves

The video i.f. carrier is located in the middle of the sloping side of the video i.f. response characteristic. The width of this sloping side is approximately 1500kc/s so that a frequency deviation of ±750kc/s will correspond to 100% modulation depth. The permissible modulation depth of 0·5% calculated above corresponds to a frequency deviation of ±3·75kc/s.

The relationship between the frequency variation Δf_o and the inter-electrode capacitance variation Δc_o caused by vibration of the oscillator valve is given by:

$$\frac{\Delta f_o}{\Delta c_o} = \frac{f_o}{2c_o}, \qquad \ldots(11)$$

where f_o is the oscillator frequency and c_o the effective oscillator capacitance. Eq.(11) can be obtained by differentiating f_o with respect to c_o in the equation:

$$f_o = \frac{1}{2\pi(L_o c_o)^{1/2}}.$$

For a frequency deviation of ±3·75kc/s, the corresponding variation in oscillator capacitance is given by Eq.(11) as:

$$\Delta c_o = \pm\frac{2c_o}{f_o} \times 3{\cdot}75 \times 10^3. \qquad \ldots(12)$$

A typical value for c_o is 10pF, and for channel 13 f_o is 250Mc/s. Hence:

$$\Delta c_o = 0{\cdot}3\text{mpF}.$$

Displacement of Picture on the Screen

Microphony in timebase valves can cause displacement of the picture on the screen of the picture tube. The microphony limits are therefore set by the amount of displacement of a line that is tolerable.

For vertical displacement, the amount is one line space for excitation frequencies up to 1kc/s. The corresponding peak-to-peak current and voltage variation caused by microphony in the field timebase valves is therefore (100/n)% of the peak-to-peak value required for full vertical scan, where n is the number of lines. For excitation frequencies above 1kc/s, the permissible microphony varies with the interference frequency in a way similar to the intensity modulation effects discussed on page 16.

The tolerable horizontal displacement of a line is 0·2% of the width of the picture and this sets the microphony limit for the line timebase valves. In practice, this corresponds to a horizontal displacement of 1mm on a 19 inch tube.

Example

For a third example, the maximum permissible variation of inter-electrode capacitance will be determined for a Colpitts oscillator forming the oscillator section of the frequency changer in a television receiver. Only interference frequencies up to 1kc/s will be considered. The oscillator frequency is 250Mc/s, and the oscillator capacitance is 10pF. As calculated previously the maximum permissible value of Δc_o is 0·3mpF.

The capacitance c_o is formed from several capacitances and may be expressed as:

$$c_o = C + c_{a-g} + \frac{c_{g-k}c_{a-k}}{c_{g-k}+c_{a-k}}, \qquad \ldots(13)$$

where C is the stray capacitance of the circuit; c_{a-g} is the anode-to-grid capacitance, c_{g-k} is the grid-to-cathode capacitance, and c_{a-k} is the anode-to-cathode capacitance of the valve.

If C is constant, the incremental oscillator capacitance caused by changes in the various inter-electrode capacitances can be determined by partial differentiation of c_o. This yields:

$$\Delta c_o = \frac{\partial c_o}{\partial c_{a-g}}\Delta c_{a-g} + \frac{\partial c_o}{\partial c_{g-k}}\Delta c_{g-k} + \frac{\partial c_o}{\partial c_{a-k}}\Delta c_{a-k} \qquad \ldots(14)$$

If Eq.(13) is differentiated in turn with respect to c_{a-g}, c_{g-k}, and c_{a-k} the following three expressions are obtained:

$$\frac{\partial c_o}{\partial c_{a-g}} = 1,$$
$$\frac{\partial c_o}{\partial c_{g-k}} = \left(\frac{c_{a-k}}{c_{g-k}+c_{a-k}}\right)^2,$$
$$\frac{\partial c_o}{\partial c_{a-k}} = \left(\frac{c_{g-k}}{c_{g-k}+c_{a-k}}\right)^2.$$

Substituting these expressions in Eq.(14) gives:

$$\Delta c_o = \Delta c_{a-g} + \left(\frac{c_{a-k}}{c_{g-k}+c_{a-k}}\right)^2\Delta c_{g-k} + \left(\frac{c_{g-k}}{c_{g-k}+c_{a-k}}\right)^2\Delta c_{a-k}.$$

If $c_{g-k} = c_{a-k}$, this expression reduces to:

$$\Delta c_o = \Delta c_{a-g} + \frac{\Delta c_{g-k}}{4} + \frac{\Delta c_{a-k}}{4}. \qquad \ldots(15)$$

If it is assumed that the inter-electrode capacitances vary one at a time only, the maximum permissible variations in the individual inter-electrode capacitances from Eq.(15) are:

$$\Delta c_{a-g} = 0{\cdot}3\text{mpF},$$
$$\Delta c_{g-k} = \Delta c_{a-k} = 4 \times 0{\cdot}3 = 1{\cdot}3\text{mpF}.$$

REFERENCES

1. COHEN, V. W. and BLOOM, A., 'Microphonism in a Subminiature Triode', **Proc. I.R.E.**, Vol. 36, No. 8, August 1948, pp. 1039 to 1048.
2. GROSS, G. H., 'A Practical Design Theory for Minimization of Vibration Noise in Grid-Controlled Vacuum Tubes', **Convention Record of the I.R.E.**, Vol. 5, 1957, Part 3, pp. 103 to 113.