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No. 7

THE DESIGN OF A HIGH-QUALITY COMMENTATORS' MICROPHONE INSENSITIVE TO AMBIENT NOISE

by H. D. HARWOOD, B.Sc.

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FOREWORD

THIS is one of a series of Engineering Monographs published by the British Broadcasting Corporation. About six will be produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph will describe work that has been done by the Engineering Division of the BBC and will include, where appropriate, a survey of earlier work on the same subject. From time to time the series will include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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THE DESIGN OF A HIGH-QUALITY COMMENTATORS' MICROPHONE INSENSITIVE TO AMBIENT NOISE

Summary. Broadcast commentaries frequently take place in surroundings so noisy that special precautions are necessary to avoid the transmission of unwanted sounds. Since 1937, this situation has been met in the BBC by the use of special 'lip' microphones which, when held close to the speaker's mouth, give an exceptionally high degree of discrimination against ambient noise. This monograph describes the development of these microphones with particular reference to an improved design produced in 1951.

The design of a lip microphone presents special problems and a number of factors not normally considered has to be taken into account if the transmitted speech is to sound natural. The speech sounds emanating from nose and mouth must be transmitted in their correct proportions, allowance must be made for peculiarities in the spectrum of the voice as heard at short range, while special measures are required to avoid the transmission of unwanted low-frequency pulses caused by the high-velocity air stream which accompanies each explosive consonant.

The human vocal mechanism, considered at close range, is a highly complex sound source and for this reason the measurement of the effective frequency characteristic of a lip microphone is far from straightforward. No one method of objective test is entirely satisfactory but it is possible by the use of several different techniques to arrive at an assessment of performance which agrees well with subjective judgments.

In addition to the usual performance data, the interference effects of wind and of stray alternating magnetic fields are considered.

1. Introduction

In transmitting commentaries from noisy surroundings, special measures are frequently necessary to exclude extraneous sounds; such circumstances arise in the broadcasting of sporting events, where there may be a great deal of crowd noise. An analogous condition often exists at public functions where the commentator may be obliged to speak in a subdued tone. In either case, the ratio of speech to ambient noise reproduced by the listener's loudspeaker is required to be much greater than that existing at the transmitting end of the system. In the early days of broadcasting, it was often necessary to house the commentator in a sound-proof booth, an inconvenient expedient giving rise to poor quality owing to the effects of reverberation in the confined space. In 1937, the position was radically altered by the development, in the BBC Research Department, of a close-talking pressure-gradient ribbon microphone of the so-called noise-cancelling type, which eventually became known as the lip microphone type L.1.* This microphone, when held close to the commentator's mouth, gave sufficient discrimination between the wanted speech and the ambient noise to make the use of the commentator's booth unnecessary and the transmitted quality, while inferior to that of the studio ribbon microphones of the time, was better than that obtained with some of the early types of moving-coil microphone then in use for outside broadcasting.

The principle on which the type L.1 microphone operates has since become generally known and will only be briefly outlined here. The noise-suppression properties of the instrument depend on the fact that on approaching a small sound source, such as the mouth of a speaker, the pressure-gradient rises faster than the pressure; at very close range, therefore, a pressure-gradient microphone gives a higher output than a pressure microphone having an equal plane wave sensitivity. The ratio of speech to ambient noise transmitted is therefore correspondingly increased. The increased response obtained by the use of a pressure-gradient microphone, which does not of course apply to extraneous sounds from relatively distant sources, varies with frequency and increases towards the bass; to give the overall effect of a uniform response to the wanted sound, therefore, the characteristics of the microphone are designed to give appropriate low-frequency attenuation.

The simple explanation given above tacitly assumes that the length of the shortest external path between the front and back of the microphone diaphragm is not only small compared with the wavelength of sound at all frequencies of interest, but is also small compared with the distance

* It should be noted that in present-day usage, the description 'lip microphone' is not confined to instruments of the 'noise-cancelling' type but is applied to any microphone intended to operate at a very short (usually fixed) distance from the speaker's mouth.

from the microphone to the speaker's mouth. In these circumstances, the sound pressures on the two faces of the diaphragm are equal in magnitude and differ only in phase. If, on the other hand, the distance from the microphone to the speaker's mouth were small compared with the front-to-back path length, the sound pressure produced by the speech on the side of the diaphragm remote from the mouth would be negligible compared with that on the near side. In this case, the resultant force on the diaphragm due to the wanted sound would greatly exceed that due to the ambient sound which would still reach both sides of the diaphragm with equal amplitude and nearly equal phase: it was probably the latter circumstance which originally gave rise to the description 'noise-cancelling'.

All pressure-gradient microphones when used for close talking, operate in a régime intermediate between the two extreme conditions just described; a theoretical treatment of the general case has been given by H. E. Ellithorn and A. M. Wiggins[1] For the microphones described in this monograph, however, the front-to-back path can with sufficient accuracy be taken as small compared with the distance from the source of the wanted sound.

The type L.1 microphone (of which no technical description, other than that given in the patent specification[2] has been published) was not the first noise-cancelling microphone; telephone transmitters working on the same principle were patented by Siemens and Halske in November 1936.[3] It is believed, however, to be the first microphone of this kind to give transmitted speech of 'broadcast quality'.

In 1951 an improved lip microphone, type L.2, was designed and the first production models were used in the Coronation broadcasts of 1953.[4] The new version, while incorporating a number of refinements, is similar in its essentials to the original design; and although this monograph deals only with the type L.2, much of the discussion applies to the type L.1 also.

2. Design Considerations

The design of a high-quality pressure-gradient lip microphone involves a number of special considerations, of which the more important are outlined below:

(*a*) As the microphone may be held in the hand for long periods, the weight must be kept to a minimum; moreover, the microphone must be small enough not to obstruct the commentator's view.

(*b*) The sensitivity must be adequate to deal with a whispered commentary.

(*c*) Speech heard at a very short distance from the mouth has certain abnormal characteristics which must as far as possible be compensated if the transmitted signal is to give the effect of a natural voice; in addition, it is desirable that sounds issuing from the nose and from the mouth should be transmitted in the correct proportions.

(*d*) Where a pressure-gradient microphone is used close to the mouth, the effective frequency response varies rapidly with small changes in the working distance; means of exact location of the instrument are therefore necessary.

(*e*) As a commentator's microphone is frequently used out of doors, interference caused by wind must be kept to a minimum; in the case of a ribbon microphone, moreover, there must be no possibility of damage to the somewhat fragile moving element from this cause.

(*f*) Microphones placed close to the mouth are also exposed to the air stream produced by the action of breathing and intensified in the enunciation of explosive consonants; for this reason additional local shielding is required to avoid unwanted breath noises on transmission.

(*g*) Lip microphones used for television commentaries are frequently subjected to large stray alternating magnetic fields from picture monitoring equipment; special measures are therefore necessary to reduce induction interference.

Some of the requirements mentioned conflict with one another; (*e*) and (*f*), for example, are to some extent inconsistent with (*a*) and (*b*). All will be dealt with in more detail later and the effect of varying some of the parameters involved will be discussed.

3. General Description

The general appearance and dimensions of the microphone are shown in Figs. 1, 2, 3, 4. The case is made of perforated metal lined with a very fine metal gauze. The distance from the microphone element to the mouth is fixed by a curved mouth-guard cut away on the underside to avoid obstructing the movement of the lower jaw; the microphone is held with the upper part of the mouth-guard resting lightly against the upper lip.

Screens, *S*, of stainless steel gauze, are provided at the front and top of the microphone to guard against the breath streams from the mouth and nose respectively. A certain amount of moisture from the commentator's breath collects on the front screen; this screen, together with the mouth-guard, are therefore designed to be readily removable for cleaning. To avoid the discomfort which would result in cold weather from direct contact of metal with the face, the mouth-guard is given a coating of plastic material 0·02 in. (0·06 cm.) thick.

The magnet assembly shown in Fig. 4 is mounted in the microphone casing with the length of the ribbon horizontal and with the U-shaped yoke of the magnet towards the speaker's mouth.

Fig. 3 also shows the ribbon-to-line transformer in its Mumetal screening case together with the cable grip, which carries a short reinforcing rubber sleeve. The plastic-covered handle is oval in cross-section with the lesser dimension from front to back, and is attached to the microphone case by a swivel joint to allow the angle of tilt to be adjusted.

For reasons given later a variable equalizer network is provided for use with this microphone. Fig. 1 shows this equalizer, which is accommodated in the microphone carrying case.

The weight of the microphone without connecting cable is 1·0 lb. (0·45 kg.) and the nominal impedance, measured at the output of the equalizer, is 300 ohms.

Fig. 1— Microphone type L.2 with carrying case and variable equalizer

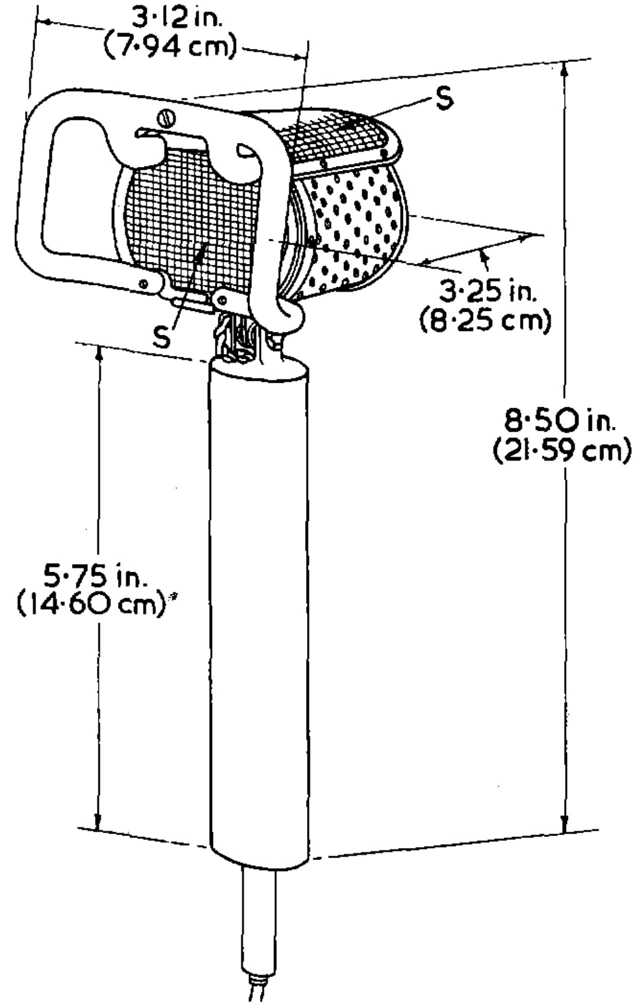

Fig. 2 — Microphone type L.2, external view and dimensions

4. Design Details

4.1 *General*

In the sections which follow, various parts of the microphone design are considered in detail, the effects of varying some of the parameters involved are described and the compromises necessary between conflicting requirements are indicated. Reference should again be made to Fig. 2 which shows the type L.2 microphone complete and to the exploded views of Figs. 3 and 4.

4.2 *Distance of Microphone from Mouth*

From the principles outlined in Section 1, it will be seen that not only the output signal, but the ratio of direct to ambient sound transmitted by a pressure-gradient microphone increases rapidly with diminishing distance from the source of wanted sound.

As the microphone is brought nearer to the mouth, however, breath noises become objectionable. In addition, the speech quality deteriorates; at short range, the mouth may no longer be considered as a point source at a fixed position but rather as a point source, of which the distance from the microphone varies according to the frequency and the particular speech sound being pronounced. The situation is further complicated by the fact that when a pressure-gradient microphone, which has a figure-of-eight polar pattern, is placed close to and facing the mouth, the speaker's nostrils are nearly in the 'dead' plane and certain components of speech—for example, those which are prominent in the sounds 'm' and 'n'—are thus heavily attenuated.

As a result of all these factors, the character of the speech sounds transmitted by a microphone placed within a few inches of the mouth is very different from that picked up at the more usual distance of one or two feet. While the discrepancy can be partially offset by giving the microphone a particular form of frequency characteristic, the transmission of natural, as distinct from merely intelligible, speech becomes impossible at very short distances. As a compromise, the type L.2 microphone is so designed that the plane of the ribbon lies 2⅛ in. (5·4 cm.) behind the central portion of the mouth-guard which makes contact with the face.

4.3 *Ribbon*

4.3.1. *Material and Thickness*

For maximum efficiency of the microphone, the ribbon material should combine low density with high conductivity, and must be able to operate in the humid atmosphere produced by the speaker's breath without risk of corrosion. Pure aluminium fulfils all these requirements.

In an earlier monograph in this series[5] it was pointed out that in the design of ribbon microphones it is sometimes desirable to improve the mechanical damping by using ribbon material of a thickness substantially less than that calculated on the basis of an acoustic impedance match with the surrounding air. Similar considerations apply in the present design, and the ribbon material used in the type L.2 microphone is the same as that employed in the BBC's studio ribbon microphone, i.e. aluminium leaf 2×10^{-5} in. (0·6 micron) thick. The mass of this material, approximately 0·2 mg/cm^2 of ribbon area, is of the order of one-third of the 'optimum' value required to give an acoustic impedance match. The loss in open-circuit sensitivity of the microphone occasioned by the acoustic mismatch, is partly offset by the fact that the ribbon used has a higher electrical resistance than one of 'optimum' thickness, so that the copper loss in the rather long connecting leads to the transformer is smaller; when the microphone is operating into an electrically matched load, the two losses are about equal.

4.3.2 *Width*

The factors which determine the optimum width were also discussed in the earlier monograph already cited, in which it was remarked that damping applied to the ribbon by screens of acoustic resistance material is rendered less effective by air leakage between ribbon and poles and that in these circumstances a relatively wide ribbon is to be preferred. In the design of the type L.2 microphone, acoustic resistance screens are used to reduce the response at fre-

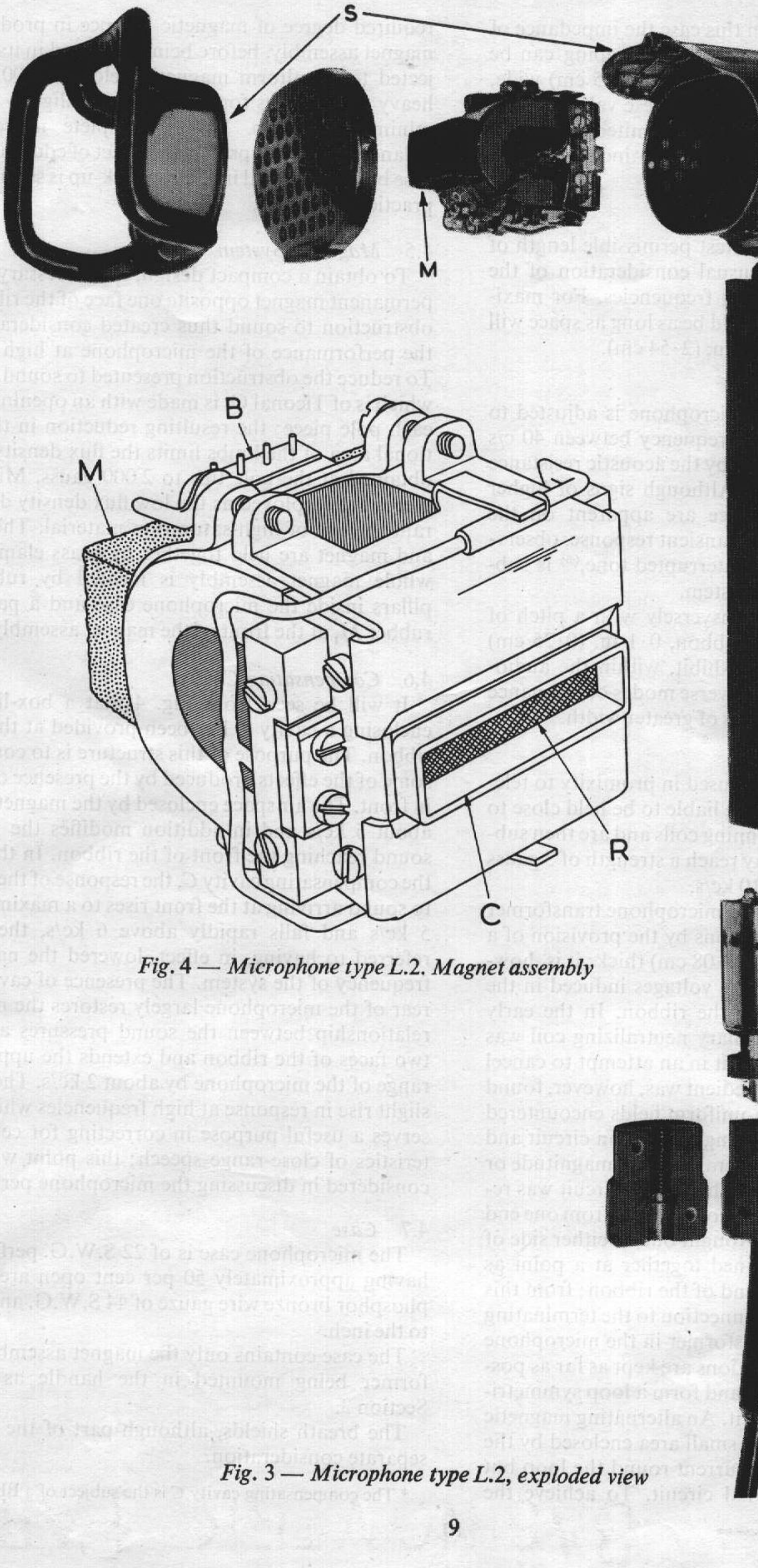

Fig. 4 — Microphone type L.2. Magnet assembly

Fig. 3 — Microphone type L.2, exploded view

quencies below 1 000 c/s but in this case the impedance of these screens is so high that sufficient damping can be obtained with a ribbon of only 0·1 in. (0·25 cm) wide, working in a 0·125 in. (0·32 cm) gap. These values enable the best use to be made of the necessarily limited amount of magnet material employed and avoid an inconveniently low value of ribbon resistance.

4.3.3 *Length*

In a lip microphone, the greatest permissible length of ribbon is not limited by the usual consideration of the directional characteristic at high frequencies. For maximum sensitivity, the ribbon should be as long as space will permit—in the present design, 1 in. (2·54 cm).

4.3.4 *Resonance Modes*

The ribbon in the type L.2 microphone is adjusted to have a fundamental resonance frequency between 40 c/s and 60 c/s but is heavily damped by the acoustic resistance screens previously referred to. Although signs of higher modes of longitudinal resonance are apparent on the frequency response curves, the transient response, observed by driving the ribbon with interrupted tone,[5] is substantially that of an aperiodic system.

The ribbon is corrugated transversely with a pitch of approximately 20 per inch. A ribbon, 0·1 in. (0·25 cm) wide so corrugated, does not exhibit, within the audio-frequency range, any of the transverse modes of resonance sometimes observed with ribbons of greater width.

4.4 *Magnetic Induction*

Commentators' microphones used in promixity to television monitoring equipment are liable to be held close to the power transformers or scanning coils and are then subjected to stray fields which may reach a strength of 3 gauss at 50 c/s and 10 milligauss at 10 kc/s.

The effect of such fields on the microphone transformer is reduced to negligible proportions by the provision of a Mumetal screening case $\frac{1}{32}$ in. (0·08 cm) thick; it is, however, less simple to eliminate the voltages induced in the low-impedance connections to the ribbon. In the early stages of development an auxiliary neutralizing coil was introduced into the ribbon circuit in an attempt to cancel the unwanted voltage. This expedient was, however, found to be ineffective with the non-uniform fields encountered in practice, since the fluxes linking the ribbon circuit and neutralizing coil were not in general equal in magnitude or parallel in direction. Eventually the ribbon circuit was re-arranged as shown in Fig. 4. The connections from one end of the ribbon are duplicated, brought out on either side of the magnet assembly, and joined together at a point as close as possible to the other end of the ribbon; from this point twisted pairs carry the connection to the terminating block *B* and thence to the transformer in the microphone handle. The duplicated connections are kept as far as possible in the plane of the ribbon and form a loop symmetrically disposed on either side of it. An alternating magnetic field which is uniform over the small area enclosed by the loop will induce a circulating current round the loop but none in the ribbon or external circuit. To achieve the required degree of magnetic balance in production, each magnet assembly, before being mounted in its case, is subjected to a uniform magnetic field at 1 000 c/s and the heavy gauge wires forming the loop slightly bent to give minimum pick-up. In the complete microphone, the balance is slightly upset by the effect of eddy currents in the case but the residual induction pick-up is still negligible for practical purposes.

4.5 *Magnetic System*

To obtain a compact design, it is necessary to place the permanent magnet opposite one face of the ribbon and the obstruction to sound thus created considerably modifies the performance of the microphone at high frequencies. To reduce the obstruction presented to sound, the magnet, which is of Ticonal G, is made with an opening adjacent to each pole piece; the resulting reduction in the cross sectional area of the limbs limits the flux density that can be obtained at the pole tips to 2 000 gauss. Mild steel pole pieces are employed as the low flux density does not warrant the use of high-saturation material. The pole pieces and magnet are held together by brass clamps while the whole magnet assembly is located by rubber-covered pillars inside the microphone case and a pad of sponge rubber *M*, at the front of the magnet assembly.

4.6 *Compensating Cavity*

It will be seen from Fig. 4 that a box-like structure enclosing a cavity *C* has been provided at the rear of the ribbon. The purpose of this structure is to compensate for some of the effects produced by the presence of the magnet in front. The air space enclosed by the magnet resonates at about 5 kc/s and in addition modifies the phase of the sound reaching the front of the ribbon. In the absence of the compensating cavity *C*, the response of the microphone to sound arriving at the front rises to a maximum at about 5 kc/s and falls rapidly above 6 kc/s, the phase shift referred to having, in effect, lowered the natural cut-off frequency of the system. The presence of cavity *C** at the rear of the microphone largely restores the normal phase relationship between the sound pressures acting on the two faces of the ribbon and extends the upper-frequency range of the microphone by about 2 kc/s. There remains a slight rise in response at high frequencies which, however, serves a useful purpose in correcting for certain characteristics of close-range speech; this point will be further considered in discussing the microphone performance.

4.7 *Case*

The microphone case is of 22 S.W.G. perforated brass, having approximately 50 per cent open area, lined with phosphor bronze wire gauze of 44 S.W.G. and 250 meshes to the inch.

The case contains only the magnet assembly, the transformer being mounted in the handle as indicated in Section 3.

The breath shields, although part of the case, require separate consideration.

* The compensating cavity *C* is the subject of a BBC patent.[6]

4.8 *Breath Shields*

The breath noises transmitted by a lip microphone are caused partly by the air stream from the mouth or nose acting directly on the moving element and partly by the sounds produced as the stream impinges on the microphone casing or on any other barrier that may be interposed. The first type of noise consists mainly of low-frequency components, while the spectrum of the second type extends over the whole audio-frequency band.

The most prominent breath noises are usually those due to the momentarily high velocity of the air stream accompanying the explosive consonants. Pressure-gradient microphones, which give an output proportional to the particle velocity in a sound wave, are particularly liable to produce unwanted noises if the flow of air is allowed to reach the moving element.

The difficulty of separating the wanted from the unwanted components of the air velocity may be illustrated by the following rough calculation:

At a distance of $2\frac{1}{8}$ in. (5·4 cm) in front of the mouth—the position occupied by the ribbon of the type L.2 microphone—the sound pressure produced by speech is some 20 dynes/cm^2. The corresponding particle velocity is a function of frequency; the highest possible value, estimated by assuming all the speech energy to be concentrated at a frequency of 100 c/s, is about 50 cm/sec. In contrast with this figure, the velocity of the pulse of breath expelled in enunciating the consonant 'p' is estimated to be of the order of 1 000 cm/sec.

It is impossible to remove breath noise from the transmitted signal by reducing the low-frequency response of the microphone or associated equipment unless the process is carried to the point at which the speech quality is seriously impaired. The yoke of the permanent magnet, interposed between the ribbon and the speaker's mouth, provides a certain amount of protection against the breath stream, but any attempt to improve the shielding by making the acoustic impedance at the front of the case very high or by introducing additional solid obstacles in this region, not only casues degradation in the frequency response of the microphone, but lowers its sensitivity to speech without affecting the sensitivity to ambient noise.

In the present design, however, advantage is taken of the fact that the air streams from the mouth and nose are much more directional than the speech sounds which accompany them, so that only local shielding is required. The gauze screens *S* in Figs. 2 and 3 are set at a short distance from the microphone case so that air can escape freely from the intervening space. The provision of this shunt path enables the desired attenuation of the air stream to be achieved with screens having a relatively low acoustic impedance and deterioration in the microphone characteristics is thereby avoided. The front screen is of 40 S.W.G. wire gauze, 90 meshes to the inch (35 per cm) and is spaced $\frac{1}{8}$ in. (0·32 cm) from the microphone case; the top screen is of similar material, strengthened by a backing of coarser gauze, 20 S.W.G., 4 meshes to the inch (1·6 per cm) and is spaced $\frac{3}{16}$ in. (0·48 cm) from the case. It is estimated that these screens* reduce breath noises of all types by some 10 dB.

4.9 *Equalization*

It has already been noted that to give the effect of a uniform response to sound pressure, a pressure-gradient microphone placed in close proximity to a small source of sound must be designed to have a plane-wave response which falls at low frequencies. The necessary equalization can, of course, be achieved by low-frequency attenuation in the associated electrical circuits. In the case of a ribbon microphone, of which the moving element is normally mass-controlled, the required result can, however, be conveniently obtained by the addition of acoustic resistance of a value such that the ribbon is resistance-controlled over the lower part of the audio-frequency range.

In practice, it has been found advantageous to be able to alter the equalization according to the type of commentary, which may vary, according to the occasion, from a confidential undertone to a shout. Quiet speech, when reproduced at normal broadcast listening level, sounds bass-heavy and therefore requires low-frequency attenuation. Loud speech, when reproduced at a lower level than the original, sounds thin or emasculated and a more satisfactory reproduction can be obtained by accentuating the low-frequency components of the sound. For this reason, the equalization in the type L.2 microphone is effected partly by the addition of acoustic resistance elements as already described and partly by an electrical network giving variable low-frequency attenuation.

The acoustic resistance is introduced in the form of two screens, each consisting of a layer of silk bolting cloth stretched over a brass frame, placed one in front of and one behind the ribbon. One of these screens, marked *R*, can be seen in Fig. 4. Bolting cloth is particularly suitable for the construction of acoustic resistances, as the mesh is standardized and is more uniform than that of ordinary fabrics. The screens *R* perform an important secondary function as wind shields, and for this reason the greater part of the required equalization is carried out acoustically; the value of acoustic resistance used is such that the microphone may be exposed to winds of 40 m.p.h. (64 km/h.) without damage to the ribbon.

The electrical equalizer previously referred to is of the constant output impedance type and is controlled by a three-position switch. In the first position, referred to as 'maximum bass', the microphone, which is designed to give a slightly rising low-frequency response to sound from the commentator, is connected directly to the output terminals; the second and third positions, designated respectively 'medium bass' and 'minimum bass', give a progressive low-frequency attenuation, the amount of which was arrived at by subjective comparison between the lip microphone and a studio microphone at the normal speaking distance of a few feet.

*The design of the breath shields is the subject of a BBC patent.[4]

Fig. 5 — Artificial head used to measure the response of lip microphones

5. Performance

5.1 *Frequency Response Characteristic*

5.1.1 *Methods of Measurement*

Because the human mouth, nose, and head do not function as a simple source of sound, it is difficult to define the frequency response of a lip microphone under working conditions. If, for example, the effective frequency response were defined as that of some hypothetical pressure microphone which in free air and at a distance of, say, three feet from the speaker's mouth, would produce an identical electrical signal, it is clear from what has been said in section 4.2.4. that the resulting function would depend upon the particular speech sound being enunciated.

In practice, however, it is found that by considering the results obtained from several types of measurement, an assessment of performance can be made which is in good agreement with subjective judgments.

The test methods employed during the development of the type L.2 microphone included the following:

(*a*) The plane-wave axial frequency characteristic was measured by comparison with a calibrated pressure microphone; tests at frequencies above 150 c/s were carried out in a lagged room and at lower frequencies in a travelling-wave duct.

An approximation to the frequency response of the microphone under working conditions was then obtained by calculations from the plane-wave characteristics, assuming the sound to come from a point source at a fixed distance.

(*b*) In an attempt to make some allowance for the diffraction round the speaker's head, and for the difference in the angle of incidence of sounds coming from the mouth and nose, an artificial head having two sound sources appropriately located was constructed. This head, which is shown in Fig. 5, is provided with a moving-coil driver unit of the type commonly used in horn loudspeakers; the unit is connected to the mouth or nose aperture as required by tubes into which a certain amount of acoustic absorbent material is introduced to avoid standing wave effects. The sound field produced by the head was first measured in a lagged room, using the mouth and nose sources individually; because of the insensitivity of the type L.2 microphone to ambient sound, it was possible to carry out the remainder of the test in a live room.

The 'effective' response characteristic of the microphone measured with the artificial head, differs from that obtained by calculation from the plane-wave response at low frequencies, at which the obstruction of the sound outlet by the microphone causes a local rise in pressure, and also in the range above 5 kc/s, in which there are signs of back-and-forth reflection between microphone and head. The effect of the microphone on the sound field immediately in front of a source depends on the acoustic impedance of the latter. The impedance of the human mouth cavity is, however, not only much lower than that of the corresponding sound sources in the artificial head described, but varies from moment to moment during speech, so that a close approximation to natural conditions can hardly be expected.

(*c*) A representative test passage was spoken into the lip microphone held to the mouth and again by the same individual into a calibrated pressure microphone at a distance of 3 ft (92 cm) in a lagged room. The speech was in each case recorded and the signal level in each of a series of frequency bands subsequently compared by utilizing a Grassot fluxmeter as an integrating device.

Since the effective frequency response of a lip microphone varies from one speech sound to another, the result obtained by this method depends on the frequency of occurrence of particular sounds in the test passage chosen.

(*d*) As a variant on method (*c*), recordings of individual speech sounds, each sustained for a few seconds, were analysed. For some of the tests, the unobstructed sound field was recorded by substituting a miniature pressure microphone for the lip microphone, thus eliminating, temporarily, effects peculiar to the latter. The spectrum of the sound recorded with the pressure microphone $2\frac{1}{8}$ in. (5·4 cm) from the mouth differed from that recorded with a similar microphone at 3 ft (92 cm) by as much as ± 8 dB at the higher frequencies; with the lip microphone, the corresponding difference was even greater.

5.1.2 *Frequency Characteristics*

All the response curves discussed in this section were obtained by comparison with a standard pressure microphone, the calibration errors of which were less than $\frac{1}{2}$ dB; the errors of comparison were also within $\frac{1}{2}$ dB.

In all cases the equalizer, set where not otherwise stated to the 'medium bass' condition, was included in the measurement; the description 'open-circuit' therefore refers to the equalizer output terminals.

Figs. 6, 7, and 8 show the axial frequency characteristics of a type L.2 microphone. Fig. 6(*a*) gives the plane-wave response, and Fig. 6(*b*) the calculated response assuming a point source at a distance of $2\frac{1}{8}$ in. (5·4 cm). Fig. 6(*e*) is a difference curve showing the change of response produced by addition of the compensating cavity *C*.

Because of the obstacle effect of the head, the high frequency components in the speech sounds, measured in the neighbourhood of the mouth, do not decrease with distance as rapidly as do the lower frequency components, though at long range both follow the same law. As a result, a microphone placed within a few inches of the mouth transmits a smaller proportion of the high frequency components than does a microphone at the usual distance of two feet or more. Fig. 6(*d*) which is calculated from data published by Dunn and Farnsworth[7] on the distribution of speech sounds around the head, shows the frequency response which the type L.2 microphone should have in order to offset the effect; it will be seen that this requirement is approximately met up to 5 kc/s.

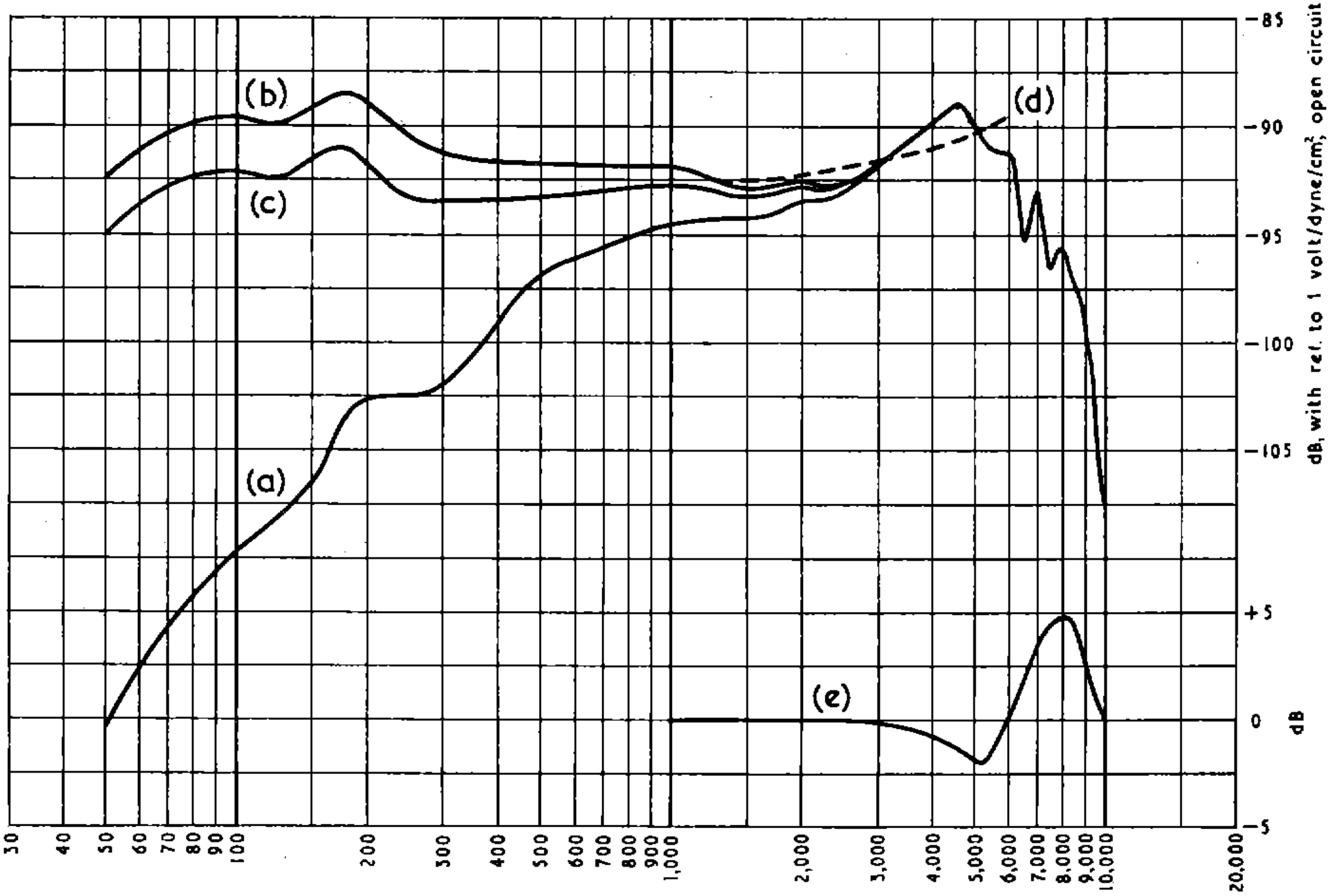

Fig. 6 — *Microphone type L.2*

(a) *Plane-wave axial frequency response*

(*b*) *Calculated axial response to point source at* $2\frac{1}{8}$ *in.*

(*c*) *Calculated axial response to point source at* $2\frac{13}{16}$ *in.*

(*d*) *Rise in microphone response required to compensate for characteristics of voice at short range*

(*e*) *Change in axial response produced by cavity C*

Equalizer set to 'medium bass'

Fig. 6(*b*) was derived by assuming the sound to come from a point in the region of the speaker's lips, at a distance of $2\frac{1}{8}$ in. (5·4 cm) from the ribbon. In fact, the position of the equivalent point source has been estimated[8] to lie between approximately $\frac{1}{8}$ in. (0·32 cm) and $1\frac{1}{8}$ in. (2·9 cm) behind the lips, the greater distances usually relating to the lower frequency components and it is of interest to apply these results to the lip microphone. The output of a pressure-gradient microphone used at short range varies more rapidly with distance at the lower frequencies than at the higher. For the present purpose, therefore, it is reasonable to assess the distance of the sound source behind the lips by averaging the figures given for frequency components below 500 c/s; this procedure leads to a figure of $\frac{11}{16}$ in. (1·75 cm) corresponding to a distance of $2\frac{13}{16}$ in. (6·5 cm) from the ribbon. Fig. 6(*c*) shows the effective frequency response of the microphone calculated on this basis, and Fig. 7 the variation in response with equalizer setting. With the 'medium bass' setting, which had previously been arrived at by subjective test as giving the optimum low-frequency response for the transmission of speech at conversational level, the calculated curve below 1,000 c/s is substantially level.

Figs. 8(*a*) and (*b*) show the frequency response obtained with the artificial head, using the 'mouth' and 'nose' in turn as the source of sound; the strength of the source is assumed in each case to be such as would produce, at a distance of 3 ft (92 cm) or more in front of the head, equal sound pressures throughout the working frequency range. It will be seen that the response of the microphone for sound from the 'nose' is 4 dB to 5 dB lower than that for sound from the 'mouth'. This degree of discrimination between the two sources has little audible effect on the quality of speech.

5.2 *Impedance*

The nominal impedance of the type L.2 microphone alone is 250 ohms and of the microphone with equalizer, 300 ohms, the difference being due to the winding resis-

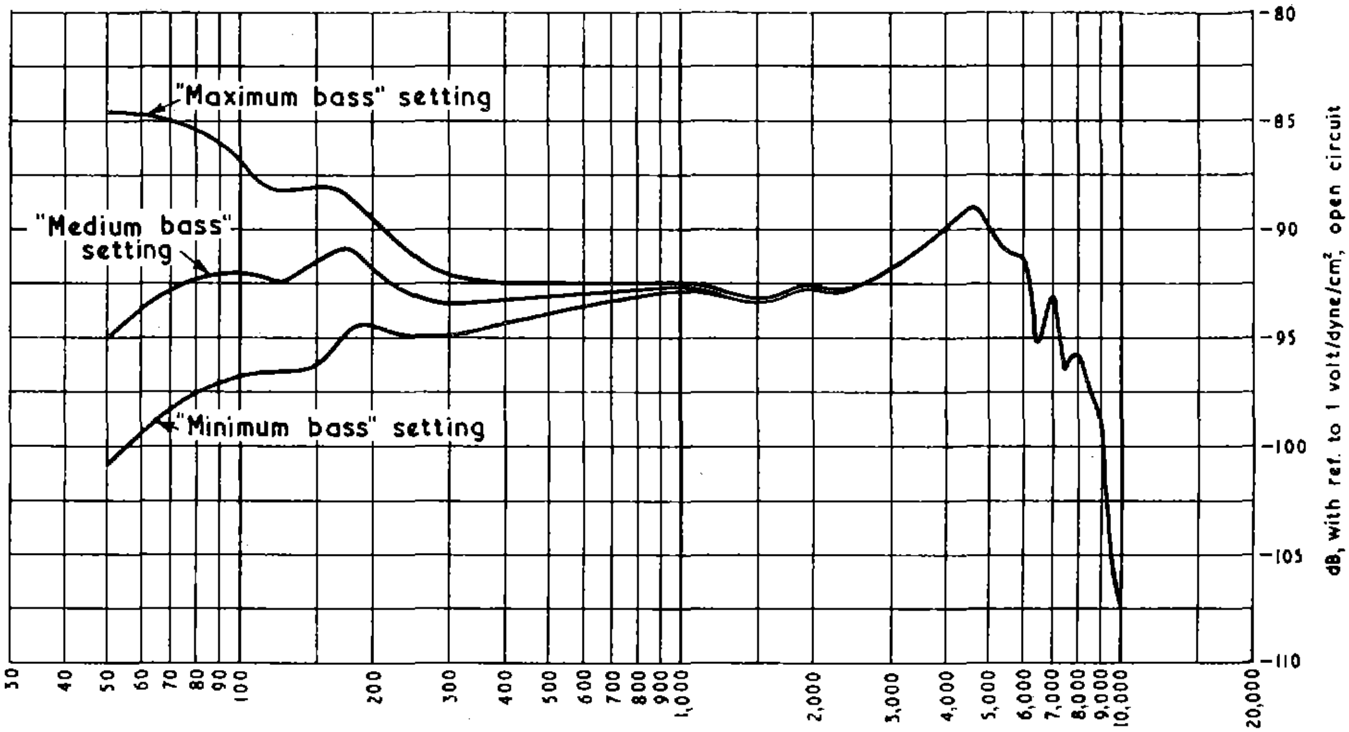

Fig. 7 — Microphone type L.2. Calculated axial response to point source at $2\frac{13}{16}$ in. with equalizer settings shown

tance of a transformer included in the circuit of the latter. Both impedances are substantially resistive over the working frequency range and the frequency characteristics obtained with a resistance load do not differ significantly from the open-circuit characteristics already given.

The variation in impedance of the production microphone is almost entirely due to the variation in thickness of the ribbon material; a tolerance of ± 20 per cent is allowed.

5.3 *Sensitivity*

The open-circuit plane-wave sensitivity of the average type L.2 microphone is -91 dB with reference to 1 volt/dyne/cm^2, but this figure cannot be used as it stands for comparing the output of this microphone under working conditions with that of other microphones placed at a greater distance from the mouth. By calculation on a basis of a point source $2\frac{1}{8}$ in. (5·4 cm) from the ribbon, the output level of the type L.2 microphone is found to be equal to that of a 300 ohm microphone having a uniform plane-wave frequency characteristic and an open-circuit sensitivity of -67 dB with reference to 1 volt/dyne/cm^2, placed at a distance of 2 ft (61 cm) from the speaker. This figure, which is some 7 dB above the sensitivity of the average studio microphone, gives sufficient output for the transmission of even a whispered commentary.

5.4 *Suppression of Ambient Noise*

The degree of suppression of ambient noise achieved with a lip microphone varies with frequency and depends on the effective distance of the microphone from the mouth, the directivity pattern, and the effect of the commentator's head and body on the sound field.

If all sources of ambient sound are assumed to be at least 6 ft (184 cm) from the microphone, the wave fronts which they produce may be regarded as plane. In these circumstances it immediately follows that the ratio of the axial sensitivities of the microphone to signal and to noise is equal to the ratio of the pressure-gradient to the pressure in a spherical sound wave at a distance of $2\frac{1}{8}$ in. (5·4 cm) from its point source. If, in addition, the noise is assumed to be at random incidence, the figure already obtained is increased by the microphone directivity index,* which for a figure-of-eight directivity pattern amounts to 5 dB.

The shielding effect of the head and body on sound at random incidence picked up by the type L.2 microphone was measured in a reverberant room using one-third octave bands of noise. Fig. 9 shows the average of the results obtained with six individuals. The probable error of the results varies with frequency; at 300 c/s, for example, it is $\frac{1}{4}$ dB. It will be seen that the presence of the head and body does not alter the amount of random sound picked up at frequencies above 2 kc/s.

In estimating the improvement in the ratio of speech to background noise obtainable by the use of a lip microphone, it is natural to use an omni-directional pressure microphone as a standard of comparison. Fig. 10 shows the relative attenuation of ambient sound, arrived at by summing the effects due to the various factors discussed above. In practice, however, the minimum working distance of a pressure microphone not protected by some form

* See B.S.I. Glossary of Acoustical Terms and Definitions.

of breath shield is about 6 in. (15 cm), i.e. nearly three times the effective working distance of the lip microphone; if this factor is taken into account, the difference in the noise suppression properties as represented by Fig. 10 must be increased by 9 dB.

The type L.2 microphone can be used to transmit intelligible speech in the presence of ambient noise of such level that the commentator can barely hear his own voice. Since the noise suppression properties of the microphone are greatest at low frequencies, any residual background noises transmitted are high pitched in character; these are commonly masked by noise picked up by other microphones and deliberately introduced at a much lower level than the speech.

5.5 *Electrical Noise*

5.5.1 *Thermal agitation*

In the absence of interfering magnetic fields, the only internally generated noise in the type L.2 microphone and equalizer is that due to thermal agitation. Taking for the sensitivity of the microphone the figure of −67 dB with reference to 1 volt/dyne/cm² arrived at in Section 5.3, and applying the standard C.C.I.F. weighting[9] for noise on broadcast circuits, the self-generated noise of the microphone is found to be equivalent to a sound level at 1 kc/s of +14 dB with reference to 2×10^{-4} dyne/cm²; for comparison it may be noted that the corresponding figures for high-quality studio microphones usually lie between +17 dB and +30 dB.

5.5.2 *Magnetic Induction Pick-up*

Using again for reference purposes the sensitivity figure of −67 dB with reference to 1 volt/dyne/cm², the amount of interference produced by an alternating magnetic field of 1 milligauss can be stated in terms of the sound level, taken with reference to 2×10^{-4} dyne/cm², which at 1 000 c/s would generate in the microphone an equal voltage. For alternating fields at 50 c/s, 1 kc/s, and 10 kc/s, the equivalent unweighted sound levels are −10 dB, +8 dB, and +24 dB respectively.

The practical significance of these figures may be illustrated with the help of the data given in Section 4.4 on the strength of the stray fields produced by a television picture monitor; the interfering voltages in the case cited, when weighted in the manner described in the previous section, are equivalent to sound levels of only +25 dB at 50 c/s and +35 dB at 10 kc/s.

5.5.3 *Wind Noise*

Lip microphones are commonly used out-of-doors; no account of their performance is complete, therefore, without some indication of the effects of wind.

The noise voltage generated in a type L.2 microphone exposed to a steady air stream was measured by mounting the microphone on the end of a whirling arm rotated at rates of up to two revolutions per second, giving peripheral speeds up to 40 miles per hour (64 km/h). To simulate working conditions more closely, some of the tests were carried out with the microphone held against the mouth of a lightweight artificial head, also mounted on the rotating arm.

Fig. 11 shows the spectral distribution of the noise voltage generated in the microphone by a 40 m.p.h. (64 km/h) wind; the analysis was carried out by a series of ⅓ octave filters. The table shows the magnitude of the noise output, expressed in terms of the sound level at

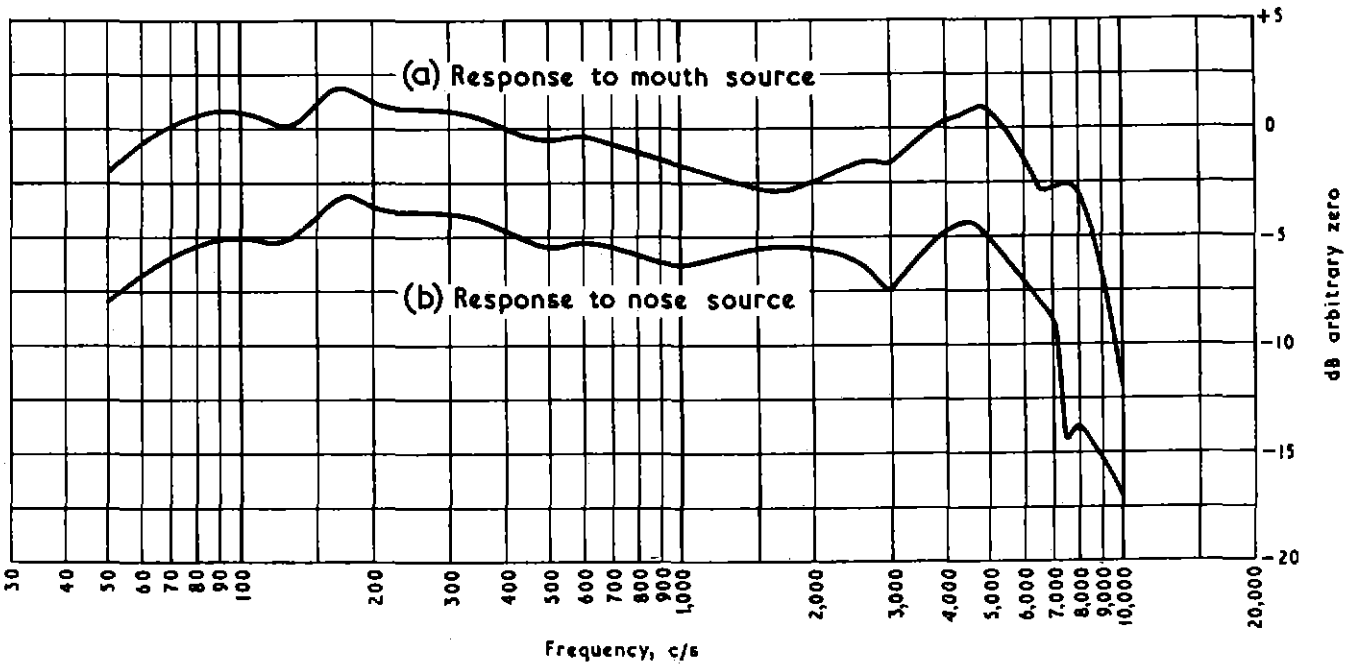

Fig. 8 — Microphone type L.2. Frequency response measured on artificial head. Equalizer set to 'medium bass'

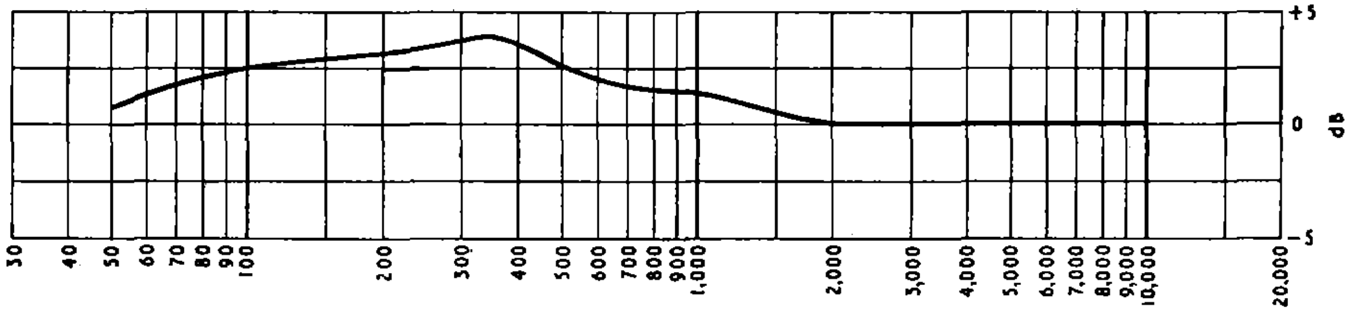

Fig. 9 — Shielding effect of head and body for sound at random incidence

1 000 c/s which would produce an equal voltage. These figures were obtained by using a weighting network[(10)] appropriate to the level being measured; the weighted voltages were read on a standard V.U. meter[(11)]. The noise varies with the angle of incidence of the wind; maximum and minimum figures are therefore given.

For comparison, similar tests were carried out on two commercial moving-coil commentators' microphones, *A* and *B*. *A* was of the noise-cancelling type, designed to be held to the mouth, and *B* a pressure-type instrument which, for the purpose of the present comparison, was assumed to be held at a distance of 6 in. (15 cm). As in Section 5.3 the sensitivity figure used for calculation was in each case that of a hypothetical microphone which at a distance of 2 ft (61 cm) from the commentator would generate an equal signal voltage.

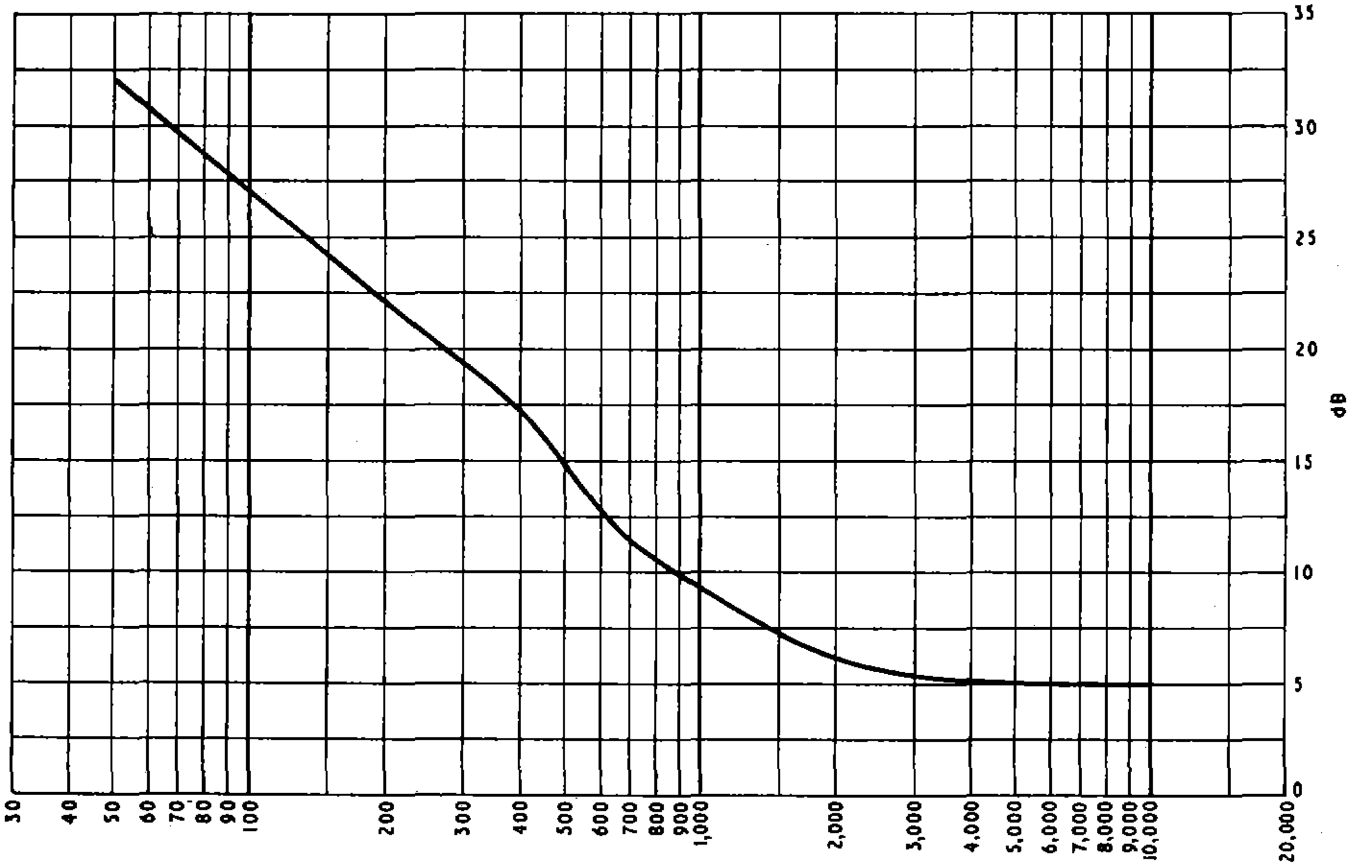

Fig. 10 — Microphone type L.2. Calculated attenuation of ambient noise pick-up compared with that of an omnidirectional microphone of equal sensitivity to direct sound

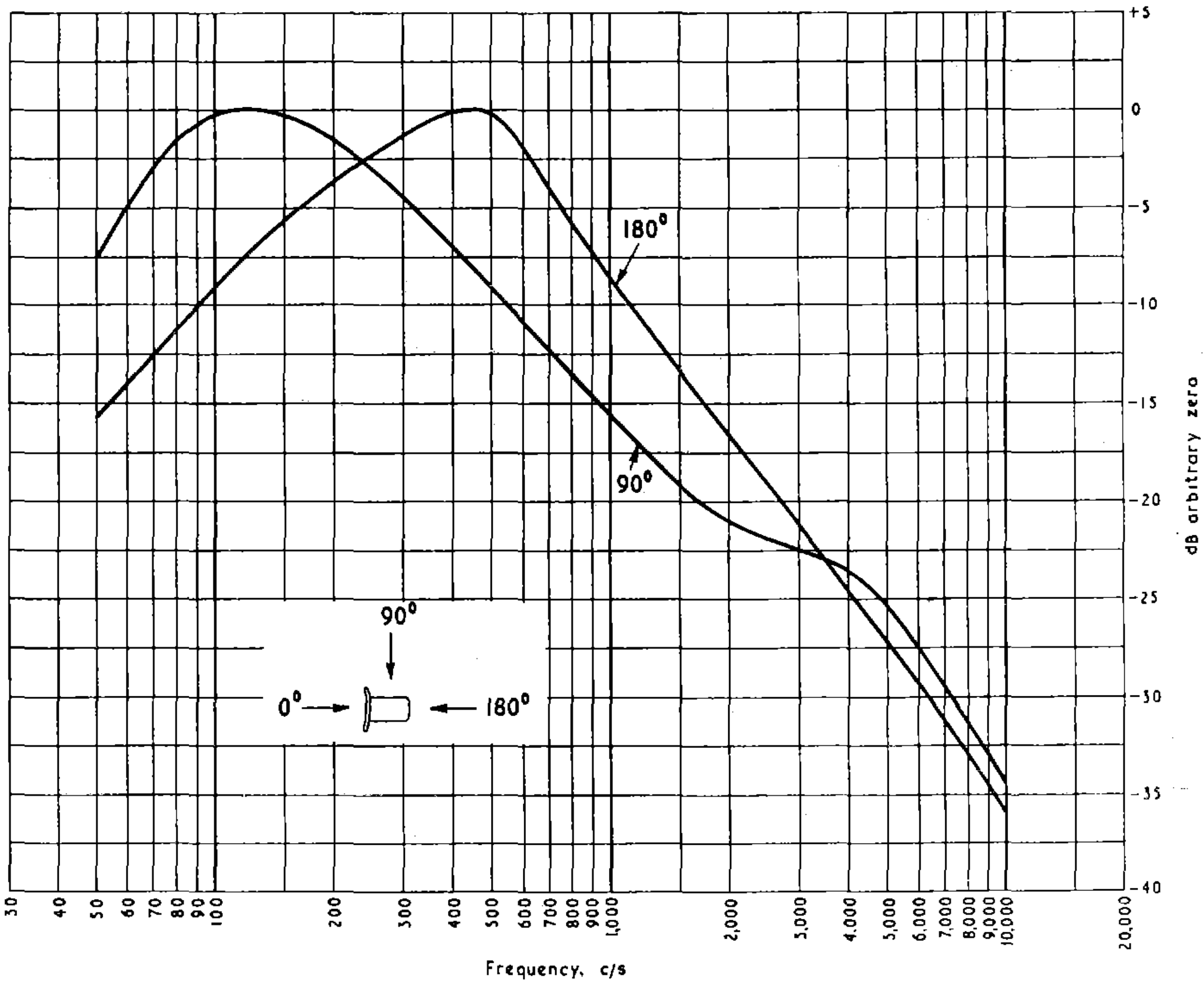

Fig. 11 — Microphone type L.2. Spectral distribution of noise voltage generated by 40 m.p.h. wind. Analysis by one-third octave filters

The response of microphone *A* showed a noticeable deficiency at low frequencies; any attempt to correct this state of affairs, by electrical equalization would have made the relationship between speech and wind noise transmitted even less favourable.

It will be seen that in nearly every case the presence of the artificial head increases the amount of wind noise, presumably by introducing local turbulence into the air. In this connection it should be borne in mind that the air stream to which a microphone is subjected in service is unlikely to be free from turbulence; the figures given in the table are therefore chiefly of value for comparative purposes. The type L.2 microphone has been found in practice to give a satisfactory performance in a 20 m.p.h. (32 km/h) wind. A supplementary windshield permitting satisfactory operation with wind speeds up to 40 m.p.h. (64 km/h) is in course of development.

1000 c/s sound level equivalent to weighted wind noise
Zero level = 0·0002 dyne/cm²

MICROPHONE	WIND SPEED 20 m.p.h. (32 km/h)	WIND SPEED 40 m.p.h. (64 km/h)
Type L.2 without artificial head	+47 dB to +50 dB	+57 dB to +69 dB
Type L.2 with artificial head	+45 dB to +55 dB	+61 dB to +83 dB
A without artificial head	+48 dB to +58 dB	+70 dB to +85 dB
A with artificial head	+63 dB to +73 dB	+74 dB to +92 dB
B without artificial head	+74 dB to +82 dB	+85 dB to +90 dB

6. Conclusion

From the foregoing data it will be seen that the type L.2 lip microphone fulfils in a large measure the requirements laid down in Section 2. The degree of background noise suppression achieved is adequate for the most extreme cases met with in broadcasting, including transmission from aircraft. Because of the high standard of speech quality, the microphone can be employed, not only for commentaries on sporting events but for such purposes as the announcing of musical items in concert halls. The amount of wind noise transmitted is exceptionally low, while the microphone is immune from interference by the strongest alternating magnetic field to which it could in practice be exposed.

The type L.2 microphone is now being manufactured by Standard Telephones and Cables Limited under an agreement with the British Broadcasting Corporation.

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