

ELECTRO-ACOUSTIC DEVICES

Contents	Page
<u>INTRODUCTION</u>	1
<u>MICROPHONES</u>	3
The carbon microphone, including theory of operation	4
Frequency response of microphones	7
The moving-iron microphone	11
The moving-coil microphone	12
The ribbon microphone	14
The crystal microphone	15
The capacitor microphone	18
Microphone tests	23
<u>RECEIVERS</u>	29
Inset type receiver	29
Rocking armature receiver	33
Moving coil receiver	34
Crystal receiver	35
<u>LOUDSPEAKERS</u>	37
Moving iron types	37
Moving coil type	39
Baffles and acoustic labyrinths	41

INTRODUCTION

Alexander Graham Bell invented the telephone in 1876, and since then, particularly with the invention of the multi-electrode valve, the science of electro-acoustics has advanced considerably. Today there are numerous applications where the conversion of sound waves into electrical waves and vice versa forms an important part in the transmission and reception of speech and music. Examples of the applications of this principle are given below, as well as some of the salient features of each application.

The telephone system

In this system the range of audio frequencies to be transmitted between one point and another is about 300-3400 c/s. The essential features are that the received speech should be intelligible, and also that the speaker's voice should be easily recognizable.

A microphone designed for general use in a telephone system must be cheap, easily produced and generally robust. A cheap microphone and telephone receiver are essential owing to the large number in use, otherwise the cost of providing telephone service may be prohibitive. Also, the components must be mechanically strong otherwise the rate of replacement, owing to damage and mis-handling by subscribers, will put an unnecessary financial burden on the telephone administration.

In addition to the economic considerations, both the microphone and receiver must be comparable in performance with the telephone transmission line. For example it would be pointless to provide a microphone or receiver with an audio-frequency response up to 6,000 c/s if the telephone line only transmitted effectively up to 4,500 c/s.

In telephone engineering it is usual to refer to the microphone as a transmitter, but the more general term microphone will be used throughout this pamphlet.

### Broadcasting

The elements of broadcasting on radio systems include a microphone for converting the sound waves into electrical energy, a means of transmitting the electrical energy to the reception point and then a loudspeaker to convert the electrical energy into sound waves again.

For good quality reproduction of music, a band of frequencies 30-8000 c/s is required, but satisfactory quality is obtained if the system is capable of responding to frequencies in the band 50-6400 c/s.

If the frequency response of either the microphone or loudspeaker, or both, is inadequate and does not reproduce all the frequencies exactly as they are produced by the instruments, then the quality of the program will be reduced, and much of the entertainment value will be lost.

In the case of speech waves, a system which has a level response to musical frequencies will also have a level response to speech frequencies, because the latter lie within the music range, so that microphones and loudspeakers suitable for music transmissions are also suitable for speech transmission.

The directional properties of microphones are important; for instance when transmitting the music of a large orchestra, the microphone must be able to pick up sounds coming from all directions in front, while sounds made in the rear should be attenuated.

### Public address systems

A public address system consists of a microphone, audio-frequency amplifier and one or more loudspeakers. One common use of the system arises where a speaker has to address an audience in a large hall; he speaks directly into the microphone and his speech is then amplified by an audio-frequency amplifier and delivered to the audience via the loudspeakers. The audio-frequency response of such a system is not critical, as all that is necessary is a reasonably faithful reproduction of the speaker's voice and sufficient volume to allow the entire audience to hear clearly. The distortion should be low within the range of frequencies transmitted so that the individual character of the speaker's voice is readily appreciated and recognized.

Public address systems have many additional applications in modern life, e.g. for dance-band entertainment, railway station announcements, the control of sports meetings, loud hailers for ship-to-ship or ship-to-shore short-distance communication.

### Deaf-aid systems

Another application of amplified sound is the help given to deaf people by the use of a small microphone and amplifier carried on the person. The sound waves impinging on the transmitter are amplified to a sufficiently high level to enable the deaf person to hear them clearly. In this case, sufficient loudness is the main criterion, but recent investigations into the problem have revealed that the best results are sometimes obtained when a particular frequency or band of frequencies is given emphasis.

## The Cinema

The cinema is well known as a medium of entertainment but there are some interesting technical details from the electro-acoustical point of view. This medium depends very largely upon the reproduction of speech and music and the frequency range required is of the order of 30 to 15,000 c/s.

A directional microphone is used on the set to record the spoken word of the actors. This microphone is suspended above the heads of the actors, between the camera and the scene. The directional properties are such that the speech can be heard, but the noise made by the operation of the camera is excluded.

At the receiving end of the system, i.e. in a cinema, the sound is arranged to come from behind the screen and fill the theatre in such a manner that the audience gets the impression that the image of the actor on the screen actually utters the spoken word. In this case, the reproduced sound must be adjusted to suit the physical construction of the theatre and the reactions of the individual members of the audience must also be taken into account, so that the sound is suitable for the greatest number.

## Microphones, receivers and loudspeakers

From the brief outline of the various electro-acoustic systems in use, it is evident that a microphone or receiver suitable for one system will not necessarily be most suitable for another, as regards frequency response, directional properties and sensitivity. Over a number of years there has been a considerable amount of research and development directed towards increasing the audio-frequency response of the components mentioned, with the result that there is a wide-range of transmitting and receiving devices in use.

### MICROPHONES

#### Introduction

A microphone is a device which converts sound energy into electrical energy for transmission over a circuit.

Microphones have been developed to fulfil various purposes. These range from microphones of high sensitivity and low cost to those of high fidelity and small size.

Microphones may be classified in three main groups and in each group there are alternative constructions. The groups are:-

- (1) Pressure microphones
- (2) Velocity or pressure-gradient microphones
- (3) Combinations of groups (1) and (2)

A pressure microphone is one which responds to changes in sound pressure. A typical example of this type has a diaphragm with a closed cavity behind it. A small aperture in the wall of the cavity allows it to assume the atmospheric pressure. In this group are carbon, capacitor, moving coil, moving iron and crystal microphones.

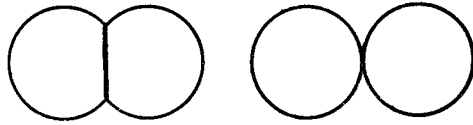
A velocity or pressure-gradient microphone is one which responds to a difference in pressure between two closely spaced points. A typical example of this type of microphone has a diaphragm which has both sides open to the sound waves.

In this group is the ribbon microphone.

A combination pressure and pressure-gradient microphone responds to both the pressure and the pressure-gradient of the sound wave. A typical example of this type of microphone has a diaphragm, and behind the diaphragm is a cavity which is not fully closed. In the wall of the cavity is an opening containing an acoustic resistance. This acoustic resistance may be a fine mesh screen, a silk cloth or a capillary tube.

### The carbon microphone

The operation of a carbon microphone depends on the variation in contact surface between granules of carbon, caused by the varying pressure of a diaphragm. The granules are minute particles of carbon which for the purpose of explanation may be considered to be tiny spheres. Fig. 1 represents two granules.



R34001

FIG. 1.

When the spheres are just touching each other the area of contact is a mere point, but when they are pressed together firmly, both spheres are slightly flattened so that a circular area of contact is created. The resistance between the two spheres varies, therefore, from a maximum when they are just touching to a minimum when they are heavily pressed together. Since a poor conductor is used, this variation in resistance is greater than would be possible in the

case of a good conductor. Movement is greatest at the centre of the diaphragm and least at the circumference, where it is clamped. The granules are, therefore, placed at the centre of the diaphragm so that movements due to sound waves produce the greatest possible changes in resistance.

Practical telephone microphones are all of the carbon-granule type. Carbon granules are used because they are cheap, infusible, do not oxidize under the conditions existing in a microphone, have low conductivity, and have a contact resistance which decreases with increasing pressure.

The carbon microphone can also be used in broadcasting systems and talking picture recording when the microphone has been modified to give a more uniform response over the audio-frequency range than that required for telephony. The carbon microphone possesses greater sensitivity than any other type.

### The Post Office Inset type microphone

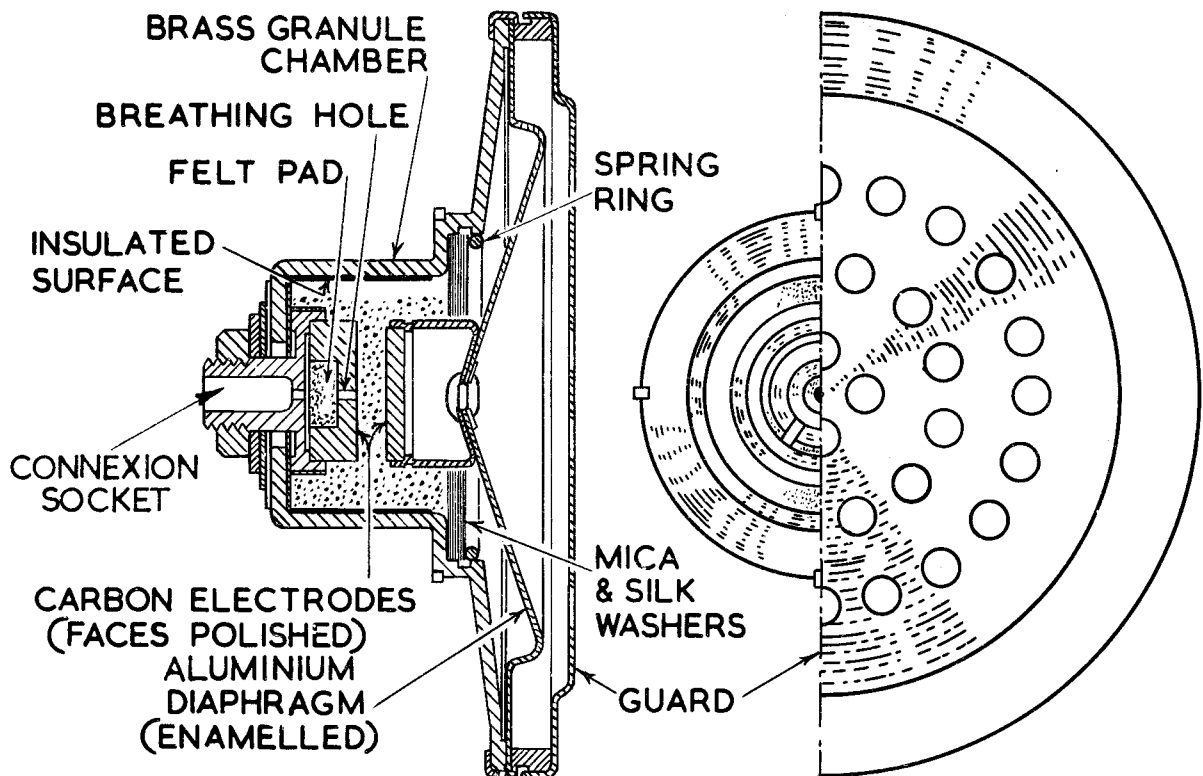
Fig. 2 shows the constructional details of the type of carbon granule microphone in general use.

This type of inset microphone is now used instead of all previous types, such as the solid back microphone which had many disadvantages.

The operation of the inset microphone is as follows:-

Sound waves impinge upon the diaphragm which moves in sympathy with the compressions and rarefactions, thus causing the pressure on the carbon granules to be varied. The variation in pressure on the granules causes the resistance between the electrodes to vary in the same way.

The variations in pressure caused by speech waves impinging upon the diaphragm are small so that, if the microphone is to function properly, the resistance of the carbon granules must be capable of variation for small changes in the displacement of the diaphragm.



R34002 A

FIG.2. P.O. INSET CARBON MICROPHONE.

The carbon microphone has a high sensitivity and for this reason it is employed in telephone communication systems, where sensitivity is required rather than a uniform response over a wide range of audio frequencies.

The connexions to the microphone are made by means of a pair of springs and a plug, both of which are mounted in the telephone handset housing. The springs bear against the metal case of the microphone and the plug fits into the insulated socket at the rear.

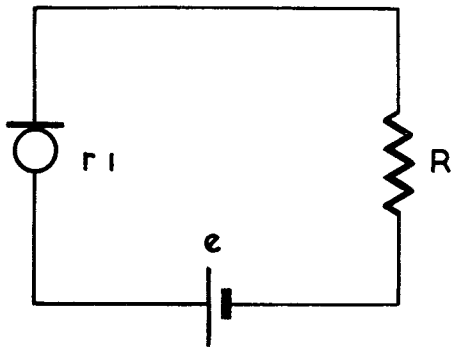
The advantages of this microphone over previous types are as follows:-

1. The light moving system gives a good frequency response and therefore, better articulation than had previously been obtained.
2. Freedom from "frying" noises which were produced due to action within the microphone.
3. Universal application. This inset microphone is used in various types of telephone and consequently must function in any position without change in efficiency or d.c. resistance. This is generally attained by immersing the moving electrode in the carbon granules.
4. Ease of maintenance. Faulty insets can be changed easily due to the method of connexion.
5. Size. It is small, neat, compact and light in weight.

A previous type of inset microphone which was similar in construction to the one in present use, had an oiled silk cover in front of the diaphragm. There were certain fundamental weaknesses which became apparent as the result of use in damp situations.

One of these being the adhesion of the outer silk membrane to the front guard.

Theory of operation of Carbon granule microphone.



R34003

FIG. 3.

The circuit diagram of a carbon microphone is shown in Fig. 3.

It can be assumed that for small displacements of the diaphragm the resistance varies uniformly with the displacement. Suppose the displacement to vary in a sinusoidal manner.

Then if  $i$  = current in the circuit  
 $r_1$  = resistance of microphone when displacement is zero  
 $R$  = resistance of remainder of circuit  
 $x$  = amplitude of displacement of diaphragm  
 $k$  = constant for the carbon granules  
 $\omega$  =  $2 \pi f$   
 $f$  = frequency of applied sound wave  
 $e$  = voltage applied to the circuit

the expression for the instantaneous current in the circuit may be written:-

$$\begin{aligned}
 i &= \frac{e}{r_1 + R + kx \sin \omega t} \\
 &= e (r_1 + R + kx \sin \omega t)^{-1} \\
 &= \frac{e}{r_1 + R} \left( 1 + \frac{kx \sin \omega t}{r_1 + R} \right)^{-1}
 \end{aligned}$$

On expanding by the binominal series we get:-

$$i = \frac{e}{r_1 + R} \left[ 1 - \frac{kx \sin \omega t}{r_1 + R} + \frac{k^2 x^2 \sin^2 \omega t}{(r_1 + R)^2} - \frac{k^3 x^3 \sin^3 \omega t}{(r_1 + R)^3} \dots \text{etc.} \right]$$

If the powers of the sines are converted into the multiple-angle form, the output will be seen to include harmonics as well as the fundamental frequency, together with a d.c. component. The production of harmonics is thus a basic feature of this transmitter.

In addition to the purely electrical distortion indicated by the form of the equation, the physical dimensions and shape of the transmitter, and its mounting arrangements also introduce distortion. The equation assumes that the resistance of the carbon granules varies uniformly with the displacement of the diaphragm. This may not be exactly the case in practice, but by using a large number of granules per electrode (of the order of 3,000) the errors in the assumption are reduced to a negligible factor. The sensitivity of the transmitter may alter with a change in its physical orientation, due to the packing of the carbon granules. The type illustrated in Fig. 2 is an improvement on earlier types in this respect.

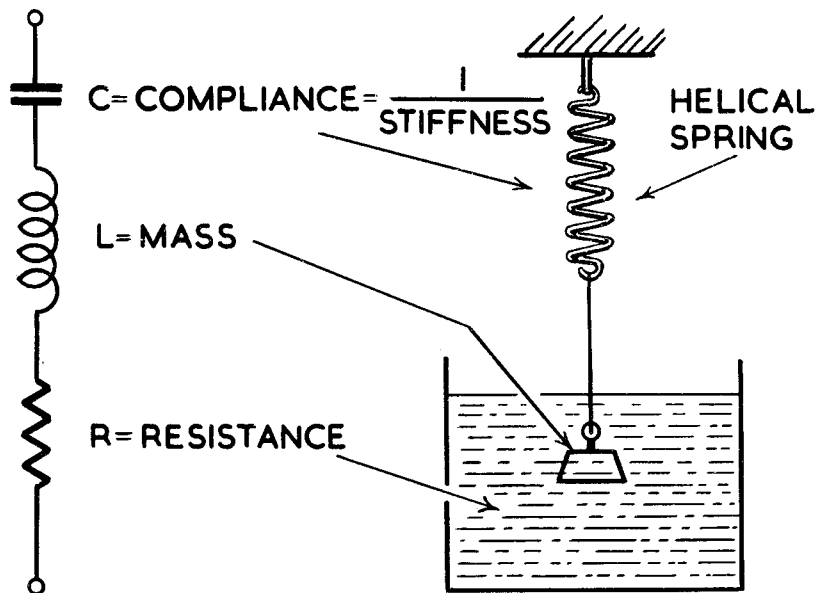
#### FREQUENCY RESPONSE OF MICROPHONES

The nature of the metal diaphragm, its method of mounting, and the shape of the containing case all influence the frequency response of the instrument.

The moving parts possess a particular resonant frequency of their own depending upon their mass and stiffness. This "mechanical" resonance can be compared with electrical resonance; the mass being analagous to inductance, the reciprocal of stiffness to capacitance, and the mechanical resistance to electrical resistance. Fig. 4 shows the two resonant arrangements compared.

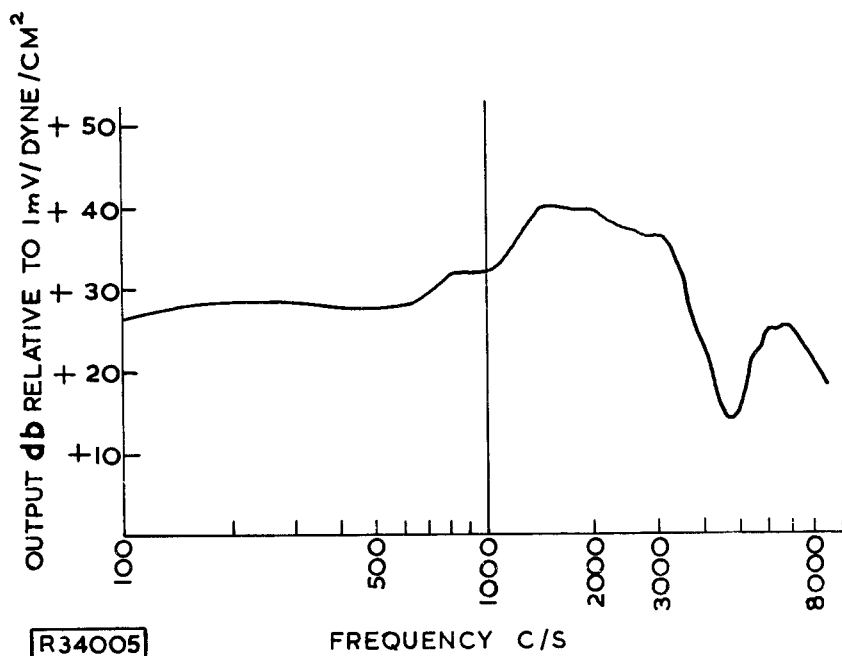
Generally the degree of stiffness depends upon the nature of the diaphragm and method of mounting, the mass upon the weight of the diaphragm assembly, and the resistance to the air behind the diaphragm and the friction due to the silk washers and carbon granules. The resonant frequency of the whole is determined by the relationship between the stiffness and the mass in the same way as the resonant frequency for the electrical case is determined by the relationship between inductance and capacitance.

A further factor determining the frequency response is the effect of the air spaces behind the diaphragm. A cavity behaves as a Helmholtz resonator and has a natural resonant frequency depending upon its size and shape.



R34004

FIG. 4.



R34005

FIG 5



The output voltage from a microphone is measured at a number of test frequencies. From these results a curve is plotted showing how the output voltage varies with the testing frequency. To enable comparison to be made between various types of microphone a standard reference level must be adopted. The reference which has been established is that a pressure of 1 dyne per square centimetre gives an output of 1 mV. The output voltage of a particular microphone, at any frequency, may be expressed in decibels relative to this reference level, the decibel is often used. The decibel (db) is a logarithmic method of presenting voltage, current or power ratios.

For comparisons of output voltage to a standard voltage

$$\text{Ratio expressed in db.} = 20 \log_{10} \frac{\text{output voltage}}{\text{standard voltage}}$$

More recently a ratio known as the decilog has been introduced but at the present time the use of this method of presenting the output characteristics of a microphone has not been universally adopted. The decilog is a division of the logarithmic scale used for measuring the logarithm of the ratio of two values of any quantity. In the case of comparison between microphone output voltages and a standard voltage

$$\text{Ratio expressed in decilogs} = 10 \log_{10} \frac{\text{output voltage}}{\text{standard voltage}}$$

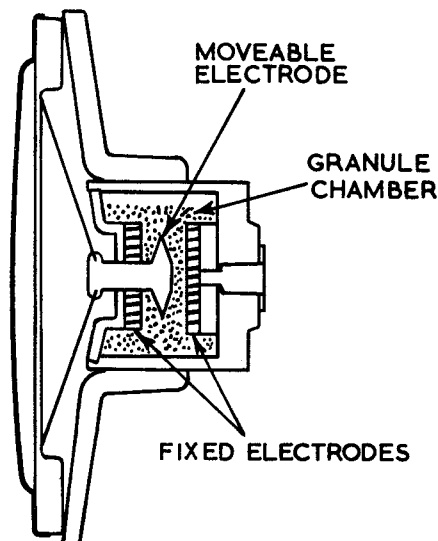
To conform with the present practice the decibel will be used throughout this pamphlet, but it can be seen from the information just given that the conversion from decibels to decilogs presents no difficulty.

Fig. 5 shows the output characteristics of a P.O. inset carbon microphone.

#### OTHER TYPES OF MICROPHONE

##### The double-button (differential) carbon granule microphone

A high quality carbon microphone is illustrated in Fig. 6.



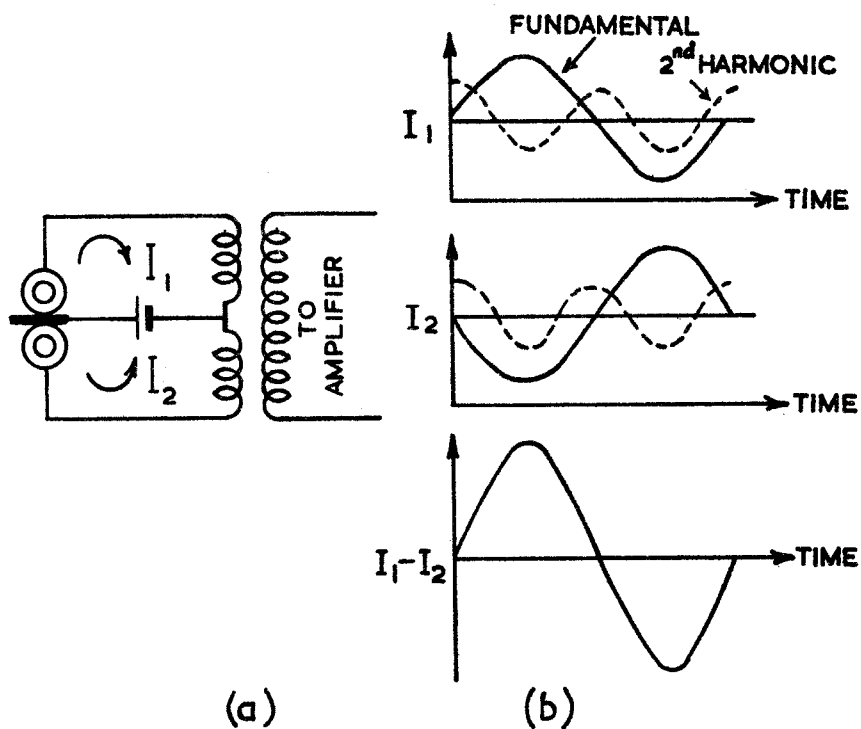
In this type of microphone two fixed electrodes are attached to the inner surfaces of the carbon granule chamber. A third moveable electrode is fixed to the diaphragm. When the diaphragm moves under the influence of speech waves, the moveable electrode varies the pressure on the carbon granules in a push-pull manner.

R34006

Fig. 6

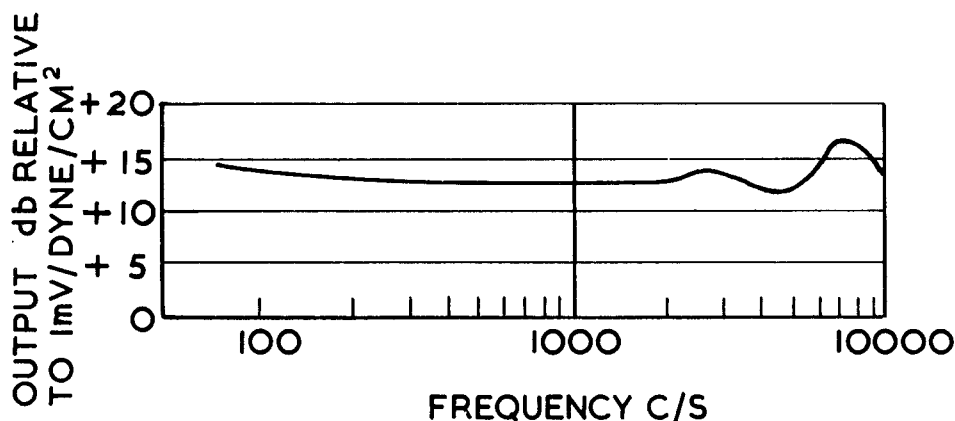
The circuit arrangement is shown in Fig. 7 (a). A movement of the diaphragm to one side causes the resistance on that side to decrease while that in the other increases. Thus the current  $I_1$  in one half of the primary winding of the transformer increases while the current  $I_2$  in the other half decreases. The input to the amplifier thus depends upon the difference between the two currents. As with a push-pull amplifier even harmonics cancel out in the output transformer as shown in Fig. 7 (b).

The resonant frequency is usually placed between 5,000 and 8,000 cycles per second, thus ensuring an even audio frequency response up to the resonant frequency. The response curve is shown in Fig. 8. The use of the carbon microphone is limited by the carbon noise, which is usually attributed to the heating of the points of contact of the granules.



R34007

Fig. 7



R34008

Fig. 8

A common fault experienced with this type of microphone is the "cohering" or "sticking together" of the carbon granules. This effect is usually caused by breaking the current flowing through the microphone.

#### Moving-iron microphone

This type of microphone is used in "sound powered" telephones, its advantage being that no energising current is needed. The general construction is such that a diaphragm is mechanically coupled to an iron armature which carries the magnetic flux supplied by a permanent magnet. When sound waves impinge on the diaphragm the armature is driven in sympathy and moves in an air gap between the pole pieces of the permanent magnet. This alters the value of magnetic flux in the armature and e.m.f.s. in the coils wound over the pole pieces. The coils supply the electrical output from the microphone.

Fig. 9 shows the essential features of a balanced armature moving-iron microphone. It has a thin corrugated metal diaphragm which is linked to one end of the armature. The other end of the armature is clamped between one end of the pole pieces by non-magnetic spacers which prevent a magnetic short circuit of the permanent magnet. When the diaphragm is driven by sound waves, movement of the armature in the free air gap between the pole pieces gives rise to variation in the magnetic flux in the armature which induces e.m.f.s in the coil.

The output of this type of microphone is lower than the carbon one.

The moving-iron transducer may be used as a microphone or a receiver and in a sound powered telephone the same insert may be used for both purposes.

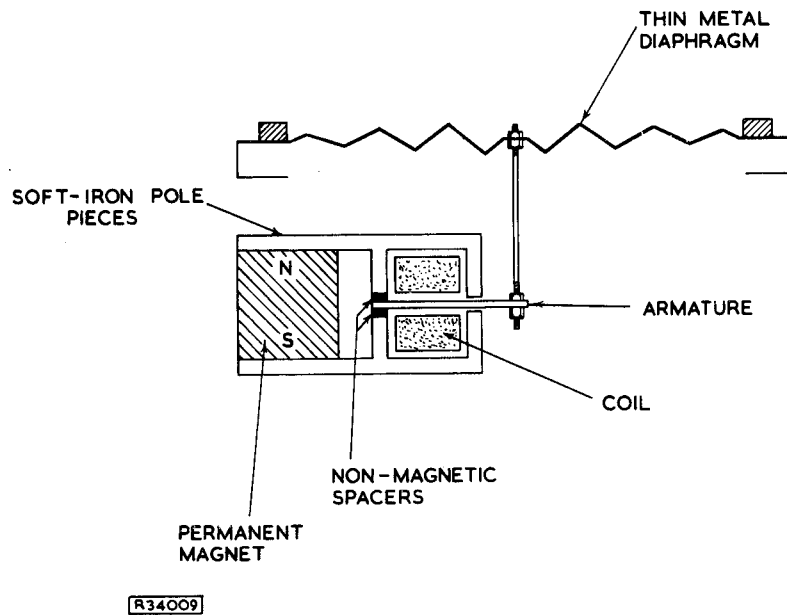


Fig. 9

### The moving-coil microphone

The moving-coil microphone consists, in principle, of a conductor moving in a magnetic field under the influence of sound waves. The voltage induced in the conductor is proportional to its velocity in the magnetic field, and in order to produce a flat audio-frequency response, the conductor must have the same velocity per unit of pressure of the sound waves at all frequencies.

Fig. 10 shows a common form of moving coil (or electrodynamic) microphone

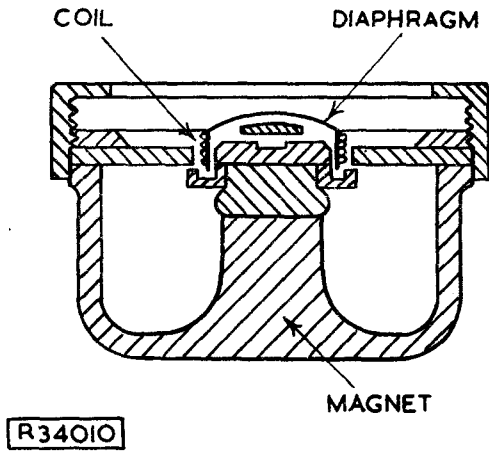


FIG. 10.

The coil consists of a number of turns of fine wire and is rigidly fixed to the diaphragm so that it moves between the circular pole-pieces of the magnet.

A typical response curve for a microphone of this type is shown in Fig. 11, in this case the output in db. is negative. This indicates that the output from the microphone is below the standard of 1 mV/dyne/cm<sup>2</sup>, thus giving a negative characteristic to the logarithm.

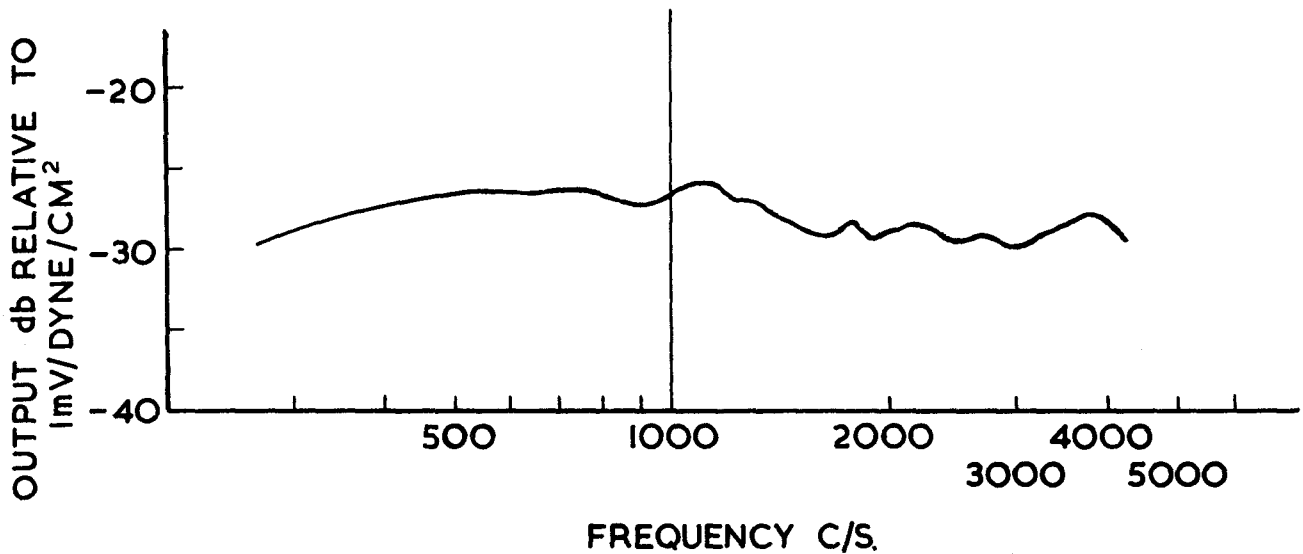
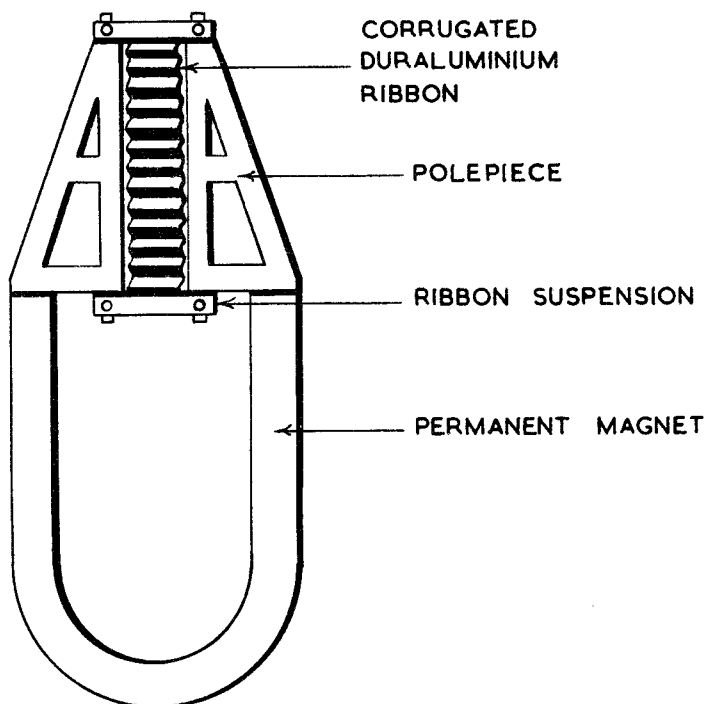


FIG. 11.

### The ribbon microphone

A typical ribbon-microphone is illustrated in Fig. 12. The device consists of a strong magnet which has a corrugated ribbon of duraluminium foil lightly suspended between its pole pieces.

The duraluminium foil vibrates between the pole pieces when actuated by sound waves, thus producing an audio frequency current in the diaphragm itself; this current is subsequently amplified and used as required. This type is particularly directional and is very suitable for broadcast work where it is often desirable to pick out one instrument from an orchestra or one person from a group.



R34012

FIG. 12. RIBBON MICROPHONE.

Another method of obtaining the required audio frequency response is to mount the diaphragm in a suitable slit at the end of a closed pipe. The pipe is then loaded with tufts of felt so that it exhibits a pure acoustical resistance of constant value over the audio frequency range. By suitable arrangement of the tufts of felt the response of the ribbon microphone can be kept constant over the audio and music ranges.

The output is transformer-coupled to the input of a valve amplifier.

A typical audio-frequency response curve is shown in Fig. 13, again the output is below the standard voltage.

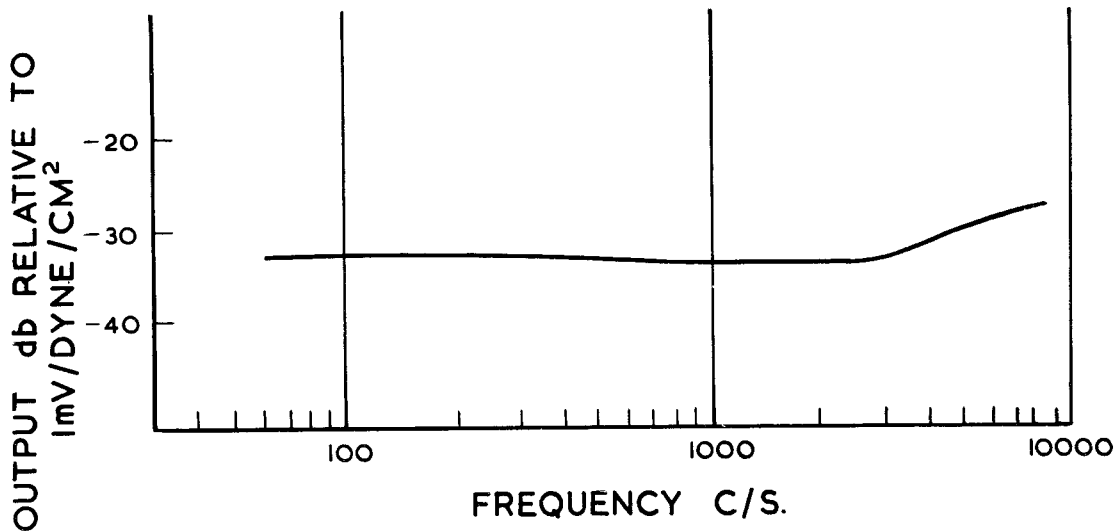


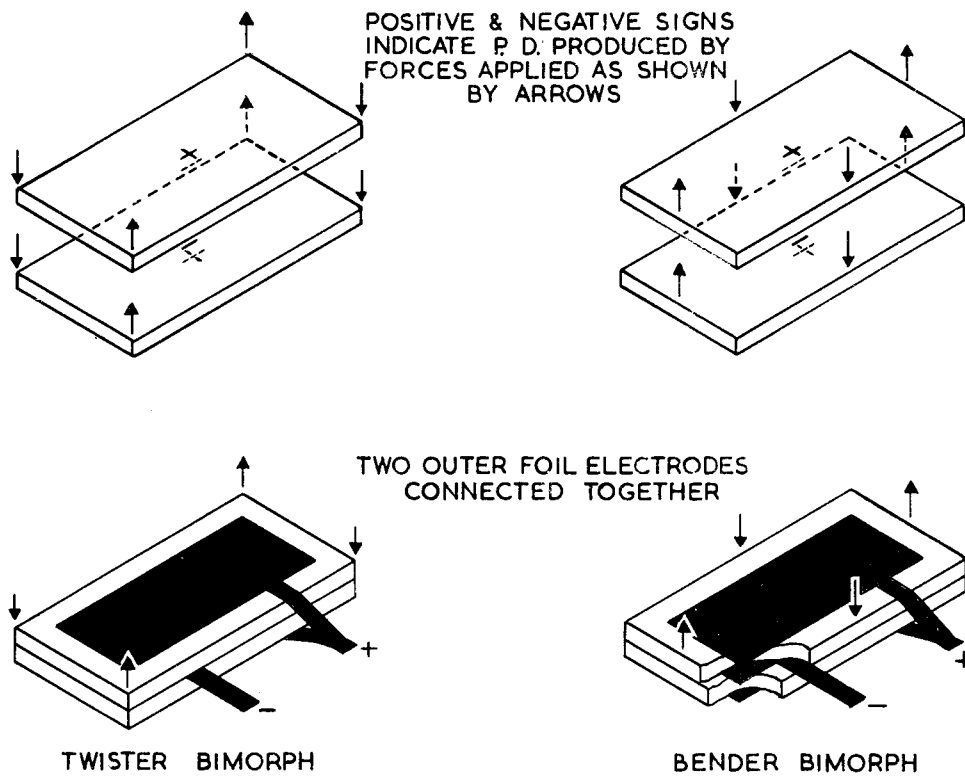
FIG. 13. RESPONSE CURVE OF RIBBON MICROPHONE.

R34013

The audio-frequency response of this type of microphone has a generally low level, but nevertheless is flat to 3000 cycles per second, after which a gradual rise takes place as the frequency is increased.

#### Crystal Microphones

The operation of a crystal microphone depends on the fact that certain crystals have piezo-electric properties, i.e. the crystal develops electrical charges on certain surfaces when subjected to mechanical stress. The usual construction of the microphone is such that the sound pressure causes either bending or torsion of the crystal. As a consequence of the mechanical strain due to this deformation, voltages are produced which are proportional to the pressure of the sound waves. The majority of crystal microphones use crystals of Rochelle salt (sodium potassium tartrate). This has a piezo-electric sensitivity very much greater than quartz, i.e. a much greater voltage is generated between the crystal surfaces for a given pressure on the crystal. It has the disadvantages of lower mechanical stability than quartz and variation of sensitivity with temperature. The sensitivity decreases with rise of temperature and at 100°C the response is so small that a microphone would be inoperative. The crystal may be directly actuated but, in general, practical microphones consist of a diaphragm mechanically linked to the crystal so that lever action enables a greater force for any given sound pressure to be applied to the crystal.

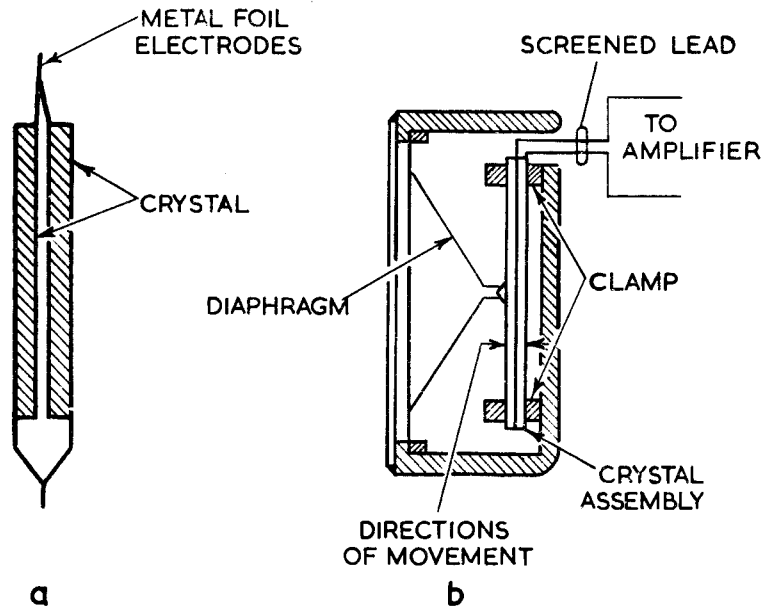


R34014

FIG 14

The crystal element itself is in the form of a "bimorph" consisting of two thin slices differentially cut as shown in Fig. 14 and cemented together with foil electrodes. Two types are used, "twisters" and "benders". The twister type is mounted in the microphone housing with three corners clamped and the diaphragm is connected to the free corner. The bender type is clamped along two opposite edges and the diaphragm is attached at the centre of the bimorph, as shown in Fig. 15.



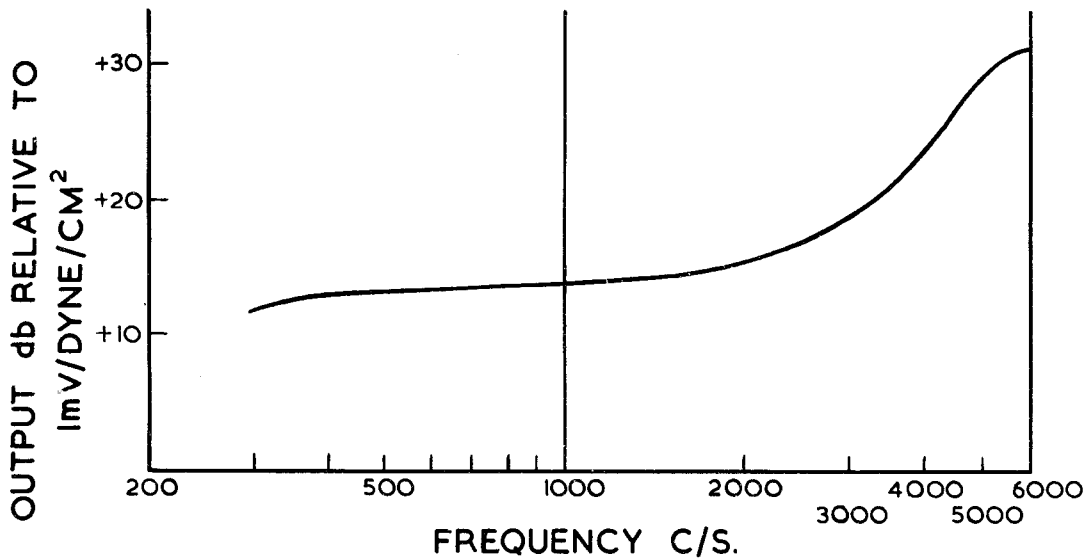


R34015

FIG 15

The outputs from the two halves of the bimorph are in parallel, so that the bimorph crystal has half the internal impedance of a single crystal slice of the same dimensions as the bimorph, these dimensions being determined by mechanical matching considerations. This reduction of internal impedance is important, since the internal impedance of the crystal is very high and the crystal is used to drive the grid of an associated valve amplifier. Electrical matching between the bimorph and the valve input circuit is more easily accomplished than would be the case with a single crystal. The bimorph construction has also important mechanical advantages, leading to a considerable gain in sensitivity compared with the single crystal, and reducing temperature variations of both mechanical and electrical properties.

A typical frequency response curve is shown in Fig. 16.



FREQUENCY RESPONSE CURVE OF CRYSTAL MICROPHONE.

FIG. 16.

R34016

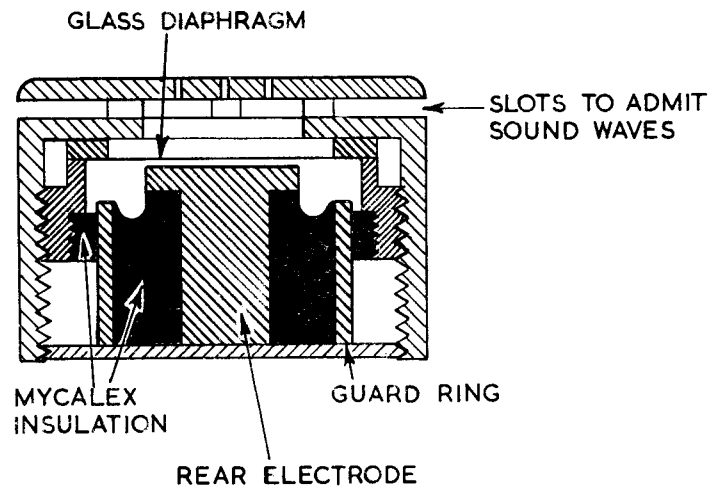
The electrostatic or capacitor microphone (formerly termed condenser microphone)

The electrostatic or capacitor microphone depends for its operation upon the fact that the capacitance of a parallel plate capacitor varies inversely as the distance between the plates.

The essential elements of the transmitter are a stretched diaphragm, behind which is a fixed plate, thus forming a capacitor having a thin layer of air as the dielectric. When sound waves impinge on the diaphragm, the air space between the plates of the capacitor, and hence the capacitance, varies. The plates of the capacitor are continuously charged from a constant voltage supply via a resistor, hence the variation in capacitance produces corresponding variations in the charge. The variation in the charge is accompanied by a current flow in and out of the capacitor in accordance with the movements of the diaphragm, thus converting the original speech wave into an electrical wave.

The air gap between the plates is generally about 0.002 inches in modern types of microphone so that the capacitance formed is small, and any variations result in only a small output.

A good audio-frequency response is obtained by using a stretched diaphragm having a natural resonant frequency in free air of between 10,000 and 20,000 cycles per second, thus ensuring a uniform response over a wide range of audio frequencies.



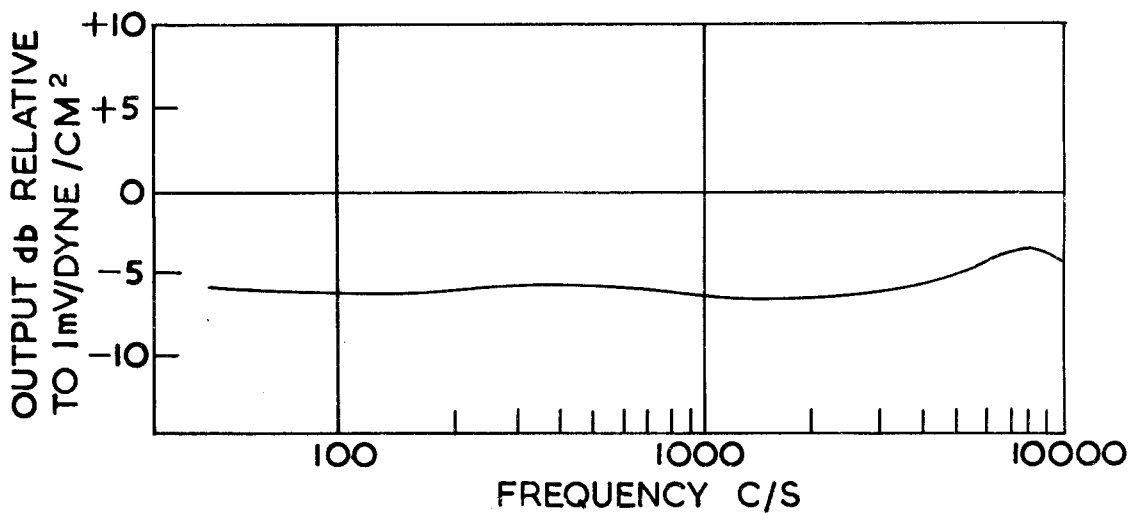
R34017

FIG 17

Fig. 17 shows one form of electrostatic microphone. The diaphragm is of glass, about 0.002 inches thick, on the surface of which is a layer of evaporated gold. The gold layer together with the upper surface of the rear electrode forms the microphone capacitance. The air gap between the diaphragm and the rear electrode is about 0.001 inches. The inter-electrode insulation provided by the glass diaphragm prevents the occurrence of a short circuit even under blast conditions. The cap with the holes in it serves both for protection and as an acoustic network at high frequencies.

This microphone is under one inch in external diameter and consequently does not disturb the sound-field appreciably.

A typical response curve is shown in Fig. 18.



R34018

FIG 18

An equation can be derived to show the theoretical operation of the microphone. For a parallel plate capacitor we have,

$$C = \frac{\epsilon_r \epsilon_0 A}{d}$$

where C = capacitance in farads

$\epsilon_r$  = relative permittivity

$\epsilon_0$  = permittivity of free space

A = area of the plates in m<sup>2</sup>

d = distance between the plates in m

In the case of a capacitor having air as the dielectric,  $\epsilon_r = 1$  and,  $d$ , the distance between the plates can be written as  $x_0 + x \sin \omega t$  where  $x_0$  is the equilibrium, or static distance between the plates, and  $x \sin \omega t$  is the sinusoidal variation of the distance caused by a sound wave having a frequency of  $\omega$  radians per second. Therefore at any instant,  $t$ , we may write

$$\begin{aligned}
 C &= \frac{\epsilon_0 A}{x_0 + x \sin \omega t} \\
 &= \epsilon_0 A (x_0 + x \sin \omega t)^{-1} \\
 &= \frac{\epsilon_0 A}{x_0} \left(1 + \frac{x}{x_0} \sin \omega t\right)^{-1} \\
 &= \frac{\epsilon_0 A}{x_0} \left(1 - \frac{x}{x_0} \sin \omega t + \left(\frac{x}{x_0}\right)^2 \sin^2 \omega t \dots\dots\dots\right) \\
 &= \frac{\epsilon_0 A}{x_0} \left(1 - \frac{x}{x_0} \sin \omega t\right) \text{ approx. (as } \frac{x}{x_0} \text{ is small)}
 \end{aligned}$$

if  $C_0 = \frac{\epsilon_0 A}{x_0}$  and  $C_1 = \frac{x}{x_0} C_0$

then  $C = C_0 + C_1 \sin \omega t$

$C_0$  represents the static capacitance while  $C_1$  represents the variation in the capacitance caused by the sound wave.

Consider the microphone connected through a resistor to a source of d.c. potential as shown in Fig. 19.

Assume the current in the circuit to be of the form

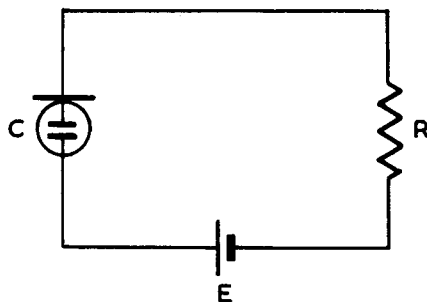
$$i = I \sin \omega t$$

Then charge  $Q$  on capacitor =  $CV$

$$= C(E - iR)$$

But  $Q = \int i dt$

$$\therefore E - iR = \frac{1}{C} \int i dt$$



R34019

FIG 19

This is the fundamental equation for the capacitor microphone but its solution need not be considered at this stage.

The total alternating voltage set up by the variation of  $C$  is proportional to the polarizing voltage  $E$  and the ratio of the varying capacitance  $C_1$  to the static capacitance  $C_0$ . This voltage can be expressed as  $E \cdot \frac{C_1}{C_0} \sin(\omega t + \theta)$ , the angle  $\theta$  being the phase change due to the series combination of resistance and capacitance.

The portion  $v$  of this voltage developed across the resistor  $R$  is thus given by the expression

$$v = \frac{E.R}{\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}} \cdot \frac{C_1}{C_0} \sin(\omega t + \theta)$$

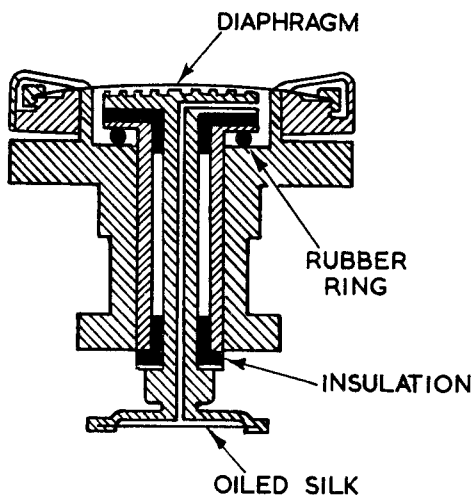
Now  $\frac{C_1}{C_0} = \frac{x}{x_0}$  and if  $R$  is large compared with  $\frac{1}{\omega C}$  we have

$$v = E \cdot \frac{x}{x_0} \sin(\omega t + \theta)$$

which shows that the amplitude of the alternating voltage developed across  $R$  is independent of frequency, but proportional to the alternating displacement of the diaphragm. Thus the e.m.f. produced will follow faithfully the movement of the diaphragm, and hence the frequency response will depend upon the ability of the diaphragm to follow the waveform of the sound wave.

In the practical case the presence of the back plate has an important bearing on the performance of the microphone. During the action of the microphone the layer of air forming the dielectric experiences two types of motion, namely compression and a lateral movement towards the outer edge of the instrument. The compression adds to the apparent stiffness of the diaphragm and so increases the natural resonant frequency of the diaphragm; the lateral movement of air causes appreciable damping due to the viscosity of the air. At low frequencies the air has sufficient time to escape and the stiffness effect is small, at high frequencies very little air can escape laterally, the net effect being an increase in the stiffness of the diaphragm.

In practice it is desirable to adjust the mechanical resistance of the diaphragm in order to obtain the best results, this can be done by increasing the distance between the plates, but this action reduces the sensitivity of the microphone. In consequence, a design is employed which makes the best use of close adjustment of the diaphragm and backing plate, but facilitates the escape of air from the dielectric space by cutting grooves in the backing plate, so that the correct combination of mechanical resistance and stiffness is obtained. The effect of the grooves on the backing plate decreases the natural resonant frequency of the diaphragm, due to the fact that the stiffness has decreased, and increases the response at low frequencies, where the stiffness due to the film of air is frequently the greater part of the total stiffness.



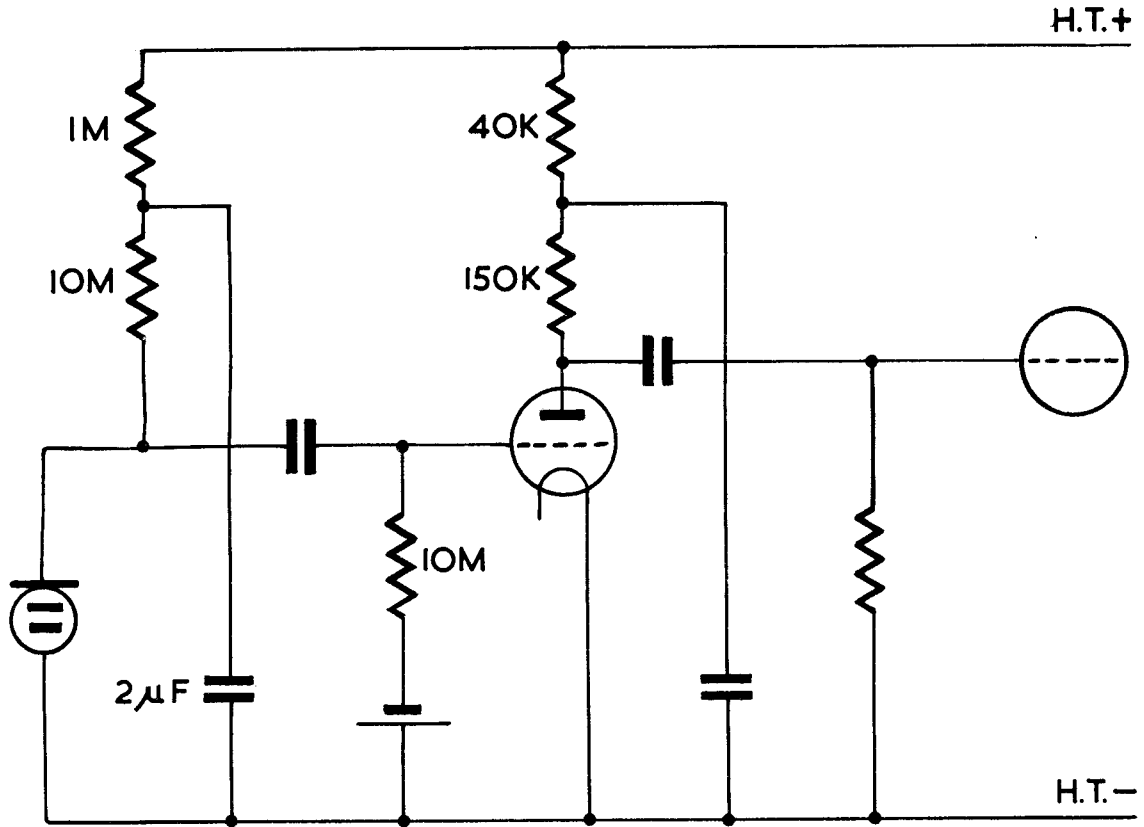
R34020

FIG 20

Fig. 20 shows another form of the electrostatic microphone. The oiled silk diaphragm at the base equalises the pressure on both sides of the primary diaphragm. The essential features are similar to those already described. In the finished form the instrument is generally enclosed in a pear-shaped case.

Pre-Amplifiers for Electrostatic Microphones

The output of the majority of microphones is of such a low level that a pre-amplifier is necessary before the speech currents are brought to a satisfactory input level for a power amplifier. In the case of a capacitor microphone if this pre-amplifier were situated at the end of the microphone lead, the capacitance of the transmission line would have a masking effect on the capacitance variations of the microphone. Consequently the pre-amplifier is usually incorporated in the microphone stand. A typical circuit of this amplifier is shown in Fig. 21, its operation should be easily understood.



R34021

FIG. 21.

Methods of testing microphones

The following paragraphs give a brief description of the testing methods used to obtain response characteristics of microphones, such as those which are reproduced in this pamphlet. The treatment is not exhaustive and is intended only to illustrate the principles involved, and to give an understanding of the vertical scales used in the graphs.

Tests are carried out in a room whose walls are specially designed to reduce acoustic reflection as much as possible. The source of sound is a high-grade loud-speaker which is operated from a constant voltage audio-frequency a.c. supply. It is important that the waveform of the supply should be sinusoidal in order that the sound produced should be free from harmonics. Due to the difficulty of constructing a loudspeaker that will satisfactorily reproduce the full frequency range, tests are usually carried out in two stages, one loudspeaker being used for the frequency range 60-3000 c/s and another for the range 3000-10,000 c/s.

A standard microphone is first suspended so that its diaphragm is normal to the direction of propagation of sound waves from the loudspeaker as shown in Fig. 22.

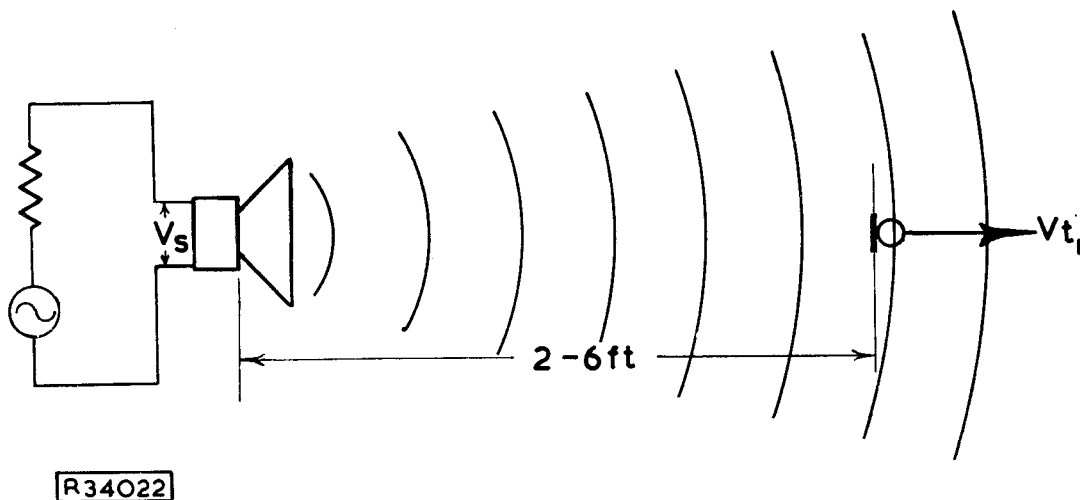


FIG. 22.

The loudspeaker is then operated over a range of frequencies, the supply voltage  $V_s$  being kept constant, and the output voltage  $V_{t_1}$  from the standard microphone is recorded at each frequency. From the known calibration curve of the standard, the free-field sound pressure  $P_0$  at the position of the microphone is thus determined for each test frequency. The "free-field sound pressure" is the r.m.s. value in dynes/cm<sup>2</sup> of the alternating air pressure (superimposed on the normal atmospheric pressure) which would exist at the measuring point in the absence of the microphone. This value is normally obtained directly from the calibration curve.

Having determined  $P_0$  for each of the test frequencies, the calibrated microphone is then replaced by the microphone to be tested and the output p.d. measured over the range of frequencies, the supply voltage to the loudspeaker being kept constant as before. Thus a series of voltage output readings corresponding to known free-field pressures is obtained. These readings are reduced to those corresponding to unit pressure, i.e. 1 dyne/cm<sup>2</sup> and expressed in decibels relative to 1 mV per dyne per cm<sup>2</sup>.



Thus if the free-field sound pressure at the position of the microphone at a given frequency is  $P_0$  dynes/cm<sup>2</sup> as determined from the test with the calibrated microphone, and the output from the microphone under test in the same position and at the same frequency is  $V_{t2}$  millivolts, then the output of the test microphone relative to 1mV/dyne/cm<sup>2</sup> . is:-

$$20 \log_{10} \frac{V_{t2}}{P_0} \text{ decibels}$$

To give some idea of the magnitude of the pressure unit, it is of interest to note that at a point 1 ft. from the mouth of a speaker engaged in ordinary conversation  $P_0$  is of the order 10 dyne/cm<sup>2</sup>.

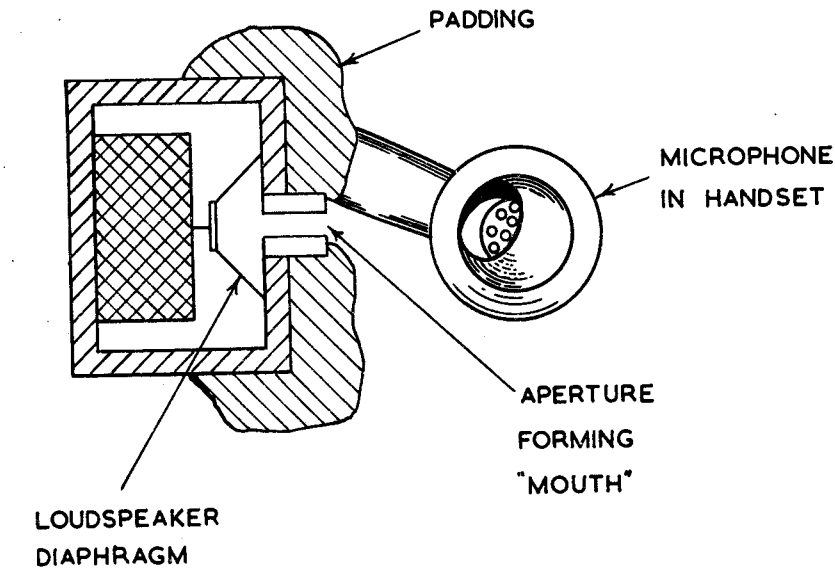
To measure the output of the microphone a valve voltmeter may be used, but greater accuracy is obtained by using a null-reading potentiometer method because of the very small p.d.s involved.

The distance from the loudspeaker to the microphone during the test is usually of the order of 2 - 6 feet, depending on the degree to which the wall surfaces of the room are made non-reflecting. The limiting position is that at which the strongest reflected wave is 20 db. below the direct wave at any test frequency used. The less reflection there is from walls, floor and ceiling, the farther will this limiting point be from the loudspeaker. Locating the microphone at the maximum distance from the loudspeaker has two main advantages. Firstly, since the pressure variation with distance from the source follows the inverse square law, small differences in the positions of the standard and test microphone will introduce negligible errors if the distance is large. Secondly, at a distance of several feet the radius of curvature of the spherical wave-front from the loudspeaker is large enough for the sound falling on the microphone diaphragm to be regarded as a plane progressive wave.

#### TESTING TELEPHONE-TYPE MICROPHONES

The method of testing previously described, while suitable for microphones which are intended for use at a distance from the source of sound, may give misleading results if applied to telephone-type microphones, which are used within a few inches from the mouth of the speaker. In this case the interaction between the microphone diaphragm and housing and the mouth and face of the user have to be taken into account. Microphones of this type are therefore tested under conditions which simulate closely the actual conditions when in use. The loudspeaker unit is of the pressure unit type used to drive an exponential horn, with an aperture  $\frac{3}{4}$ " in diameter. The microphone is mounted in a handset and this is clamped so that the microphone is at normal speaking distance from the "mouth".

The housing of the speaker unit surrounding the aperture is padded so as to introduce conditions acoustically similar to those produced by the flesh of the talkers face. The arrangement is shown schematically in Fig. 23. The testing procedure follows the same lines as that already discussed, but since the microphone is so close to the source, the tests may be carried out without special acoustical treatment of the room.

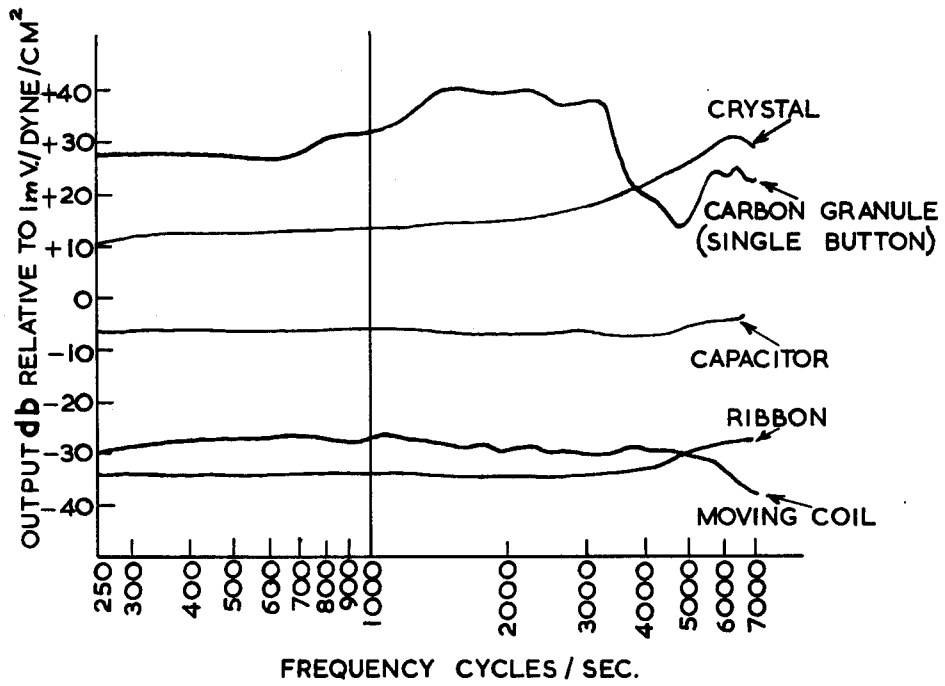


R 34023

FIG. 23.

COMPARISON OF MICROPHONES

Fig. 24 shows typical characteristics plotted on the same base relative to an output of 1 mV per dyne/cm<sup>2</sup> of sound pressure. Usually most types of microphone, the main exception being the telephone microphone, require subsequent amplification to operate loudspeakers and therefore the voltage output is of greater importance than a large power output. It follows therefore that when comparing sensitivities it is necessary to take into account the differences in impedances of the various types of microphones. For example, the moving coil type has an impedance of the order of 20 ohms and the voltage output can be readily stepped up by means of a transformer. The crystal and capacitor types have output impedances equivalent to capacitors of approximately 3000 pF and 250 pF respectively, these types are not suitable for voltage step up due to their low output powers.



R34024

FIG 24

The advantages and disadvantages of the various types of microphone are listed in Table 1.

Type of Microphone	Advantages	Disadvantages
Carbon	Robust and reliable. Low cost.	Uneven frequency response. Background hiss. Requires polarizing current. Granules liable to pack - Subject to directional effects. =
Capacitor	Good frequency response and absence of background noise.	Requires associated amplifier. The amplifier must be placed close to the microphone. Fragile and effected by moisture. Subject to directional effects. =
Moving-coil	Good frequency response and absence of background noise. Robust and reliable.	Diaphragm liable to flutter in wind. Directional types have frequency discrimination. =
Ribbon	Very good frequency response and absence of background noise. Robust and reliable. Good directional effect.	Low power output and extremely liable to flutter in wind.
Crystal	Very good frequency response and absence of background noise. Non-directional types have only slight frequency discrimination with direction. =	High capacitive impedance; requires local amplification. Diaphragm types possess directional frequency discrimination =
Moving iron	Robust and reliable.	Uneven frequency response. Subject to directional effects =

Table 1

= The directional effect, i.e. variation of sensitivity with the angle of incidence of the sound wave relative to the principal plane of the microphone is closely related to the frequency response.

Both frequency and directional discrimination depend to a large extent on diffraction of the incident sound waves round the microphone and are thus influenced by the shape of the microphone housing. Least diffraction is experienced with a spherical housing, which is used for non-directional types together with a horizontal diaphragm. It should be appreciated however that diffraction only becomes important at frequencies such that the wavelength in air is comparable with the dimensions of the microphone housing.

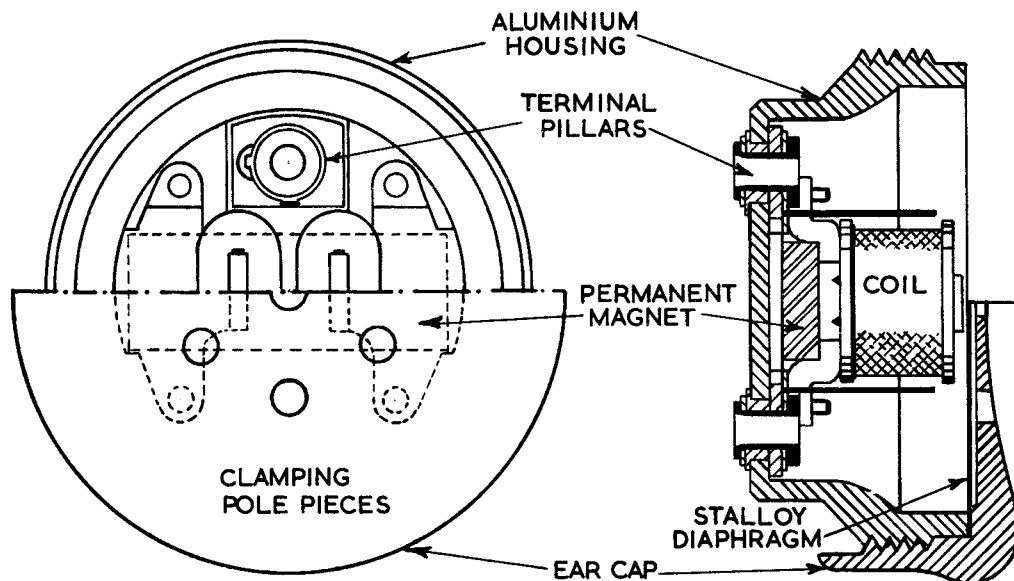
## Receivers

### Introduction

A receiver is an electro-acoustic device which converts electrical energy into sound energy, thus enabling the alternating current output of a microphone to be reproduced as sound. The original receiver used with the pedestal telephone set is now obsolete, but its principle of action was the same as the one at present in general use with the handset, the main difference being the shape of the receiver, which accommodated a large U-shaped permanent magnet.

### The Inset Type Receiver

The unit type receiver is designed to fit in a handset, connexion to the coils being made by the two fixing screws, the leads being moulded into the handset body. One or two such receivers may be mounted as a headset.



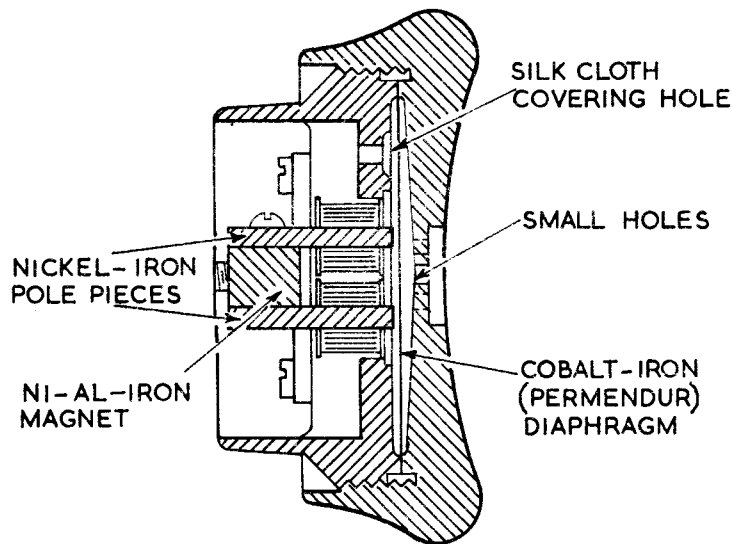
R34025

FIG 25

This earlier type of inset telephone receiver had several disadvantages, the main ones being:-

1. The lack of precision possible in the distance between the polepieces.
2. The low permeability of the diaphragm.
3. The resonance of the cavity between the diaphragm and the inner face of the case.

A later type of inset receiver, known as type 2P is illustrated in Fig. 26.



R34026

FIG 26

Nickel-iron pole pieces are used with an Alnico permanent magnet. The length of the air gap between pole pieces and diaphragm is reduced to the minimum safe limit. The diaphragm is of Permendur - a cobalt-iron alloy which has a very high permeability. It is made thinner and lighter than the equivalent Stalloy diaphragm. The ear cap is specially shaped to suit the shape and acoustic peculiarities of the human ear. The air cavity immediately behind the diaphragm is greatly reduced by fitting a rigid plate through which the pole pieces protrude. The plate is pierced by a small hole, packed with silk, to form an acoustical resistor.

The cavity resonator so produced results in a fairly even response over the speech frequency range (See Fig. 28)

#### Theory of operation

The diaphragm is normally attracted to the permanent magnet by a steady force proportional to the square of the flux density. The passage of an alternating current through the coils causes a further flux - an alternating one - to be set up thus altering the effect of the steady flux.

Suppose an alternating current  $i = I \sin \omega t$  flows in the coils producing a flux density  $b \sin \omega t$  weber/metre<sup>2</sup>. Let the flux density due to the permanent magnet be  $B$  weber/metre<sup>2</sup>

Then force on diaphragm  $\propto (B + b \sin \omega t)^2$

Or force =  $K \sqrt{B + b \sin \omega t}^2$  where  $K$  is a constant

$$= K \sqrt{B^2 + 2B b \sin \omega t + b^2 \sin^2 \omega t}$$

$$= K \sqrt{B^2 + 2B b \sin \omega t + \frac{b^2}{2} (1 - \cos 2 \omega t)}$$

$$= K \sqrt{B^2 + \frac{b^2}{2} + 2B b \sin \omega t - \frac{b^2}{2} \cos 2 \omega t}$$

From this expression it will be seen that the force on the diaphragm has the following components:-

- (i)  $B^2 + \frac{b^2}{2}$  representing a steady force
- (ii)  $2B b \sin \omega t$  representing an alternating force at the fundamental frequency.
- (iii)  $\frac{b^2}{2} \cos 2 \omega t$  representing an alternating force at the 2nd harmonic frequency.

Component (ii), representing the output at the fundamental frequency, depends upon the flux density  $B$  of the permanent magnet. The sensitivity (force per unit current) can thus be increased by having a permanent magnet of high flux density.

Component (iii), representing an unwanted output, depends upon  $b^2$ . This output can be minimized by making  $b$  small relative to  $B$ .

It is desirable, therefore, to use a permanent magnet of high magnetizing force both to increase the sensitivity of the receiver and to minimize the 2nd harmonic distortion produced by it. The presence of the permanent magnet also prevents the frequency doubling effect which would otherwise occur.

Consider the force on the diaphragm caused by the flow of a current  $i = I \sin \omega t$  in the absence of a permanent magnet.

Force on diaphragm  $\propto (b \sin \omega t)^2$

Or force =  $K b^2 \sin^2 \omega t$  where  $K$  is a constant

$$= K b^2 \left( \frac{1}{2} - \frac{1}{2} \cos 2 \omega t \right)$$

$$= K \left( \frac{b^2}{2} - \frac{b^2}{2} \cos 2 \omega t \right)$$

The expression shows that the force on the diaphragm has two components:-

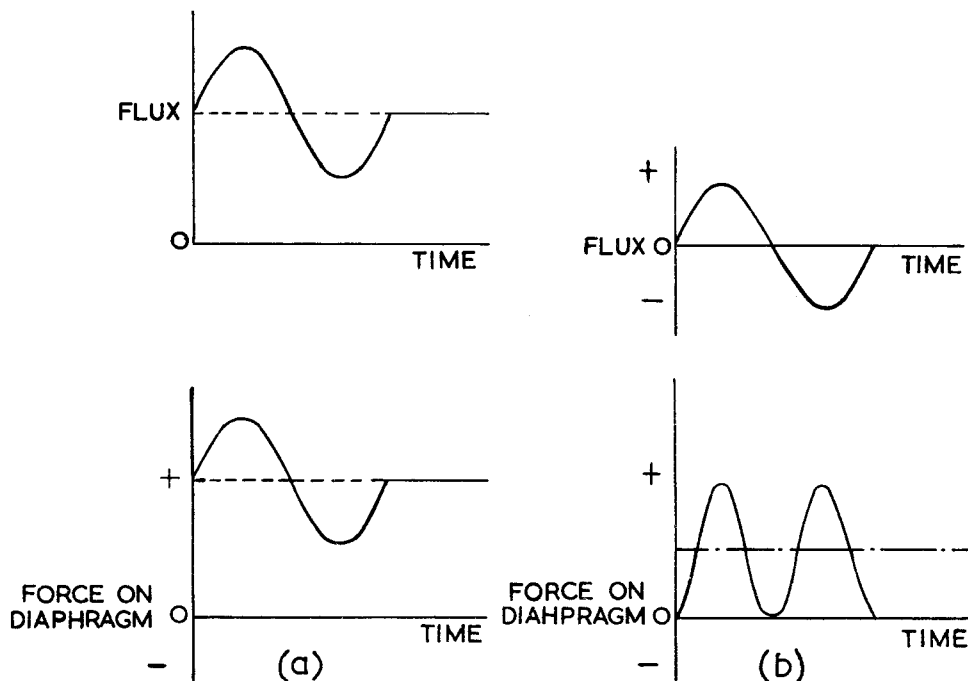
- (a)  $\frac{b^2}{2}$  representing a steady force proportional to the square of the peak flux.
- (b)  $\frac{b^2}{2} \cos 2 \omega t$  representing an alternating force at the 2nd harmonic frequency.

In this case the output is entirely at the 2nd harmonic frequency i.e. it appears to be one octave higher than the input signal.

When the permanent magnet is fitted the input signal only varies the total flux without changing its direction. The movement of the diaphragm therefore follows the shape of the input signal as shown in Fig. 27(a). In the absence of the permanent magnet, however, the input signal alters the flux in both magnitude and direction, but the movement of the diaphragm is independent of the direction of the flux and is thus attracted twice in each cycle as shown in Fig. 27(b).

Fig. 28 shows frequency characteristics (modulus of impedance about 300 ohms at 1000 c/s) of typical magnetic receivers. The G.P.O. type 1L (illustrated in Fig. 25) exhibits a marked peak at about 1000 c/s. The G.P.O. type 2P (illustrated in Fig. 26) shows a much more uniform response over the audio range. The levels on the y axis are expressed as db. relative to 1 dyne/cm<sup>2</sup>/volt, the reference level, in this case corresponding to 0 db being a pressure of one dyne per square centimetre produced by an input of one volt. When the response curve of a given receiver is to be calculated, the sound pressure at each test frequency is determined with a constant input voltage. The input voltage which would give a pressure of 1 dyne per cm<sup>2</sup> is then calculated and the ratio of this voltage and the standard voltage (1 volt) is then expressed in db. Receiver sensitivities may also be calculated using decilogs, as described earlier.

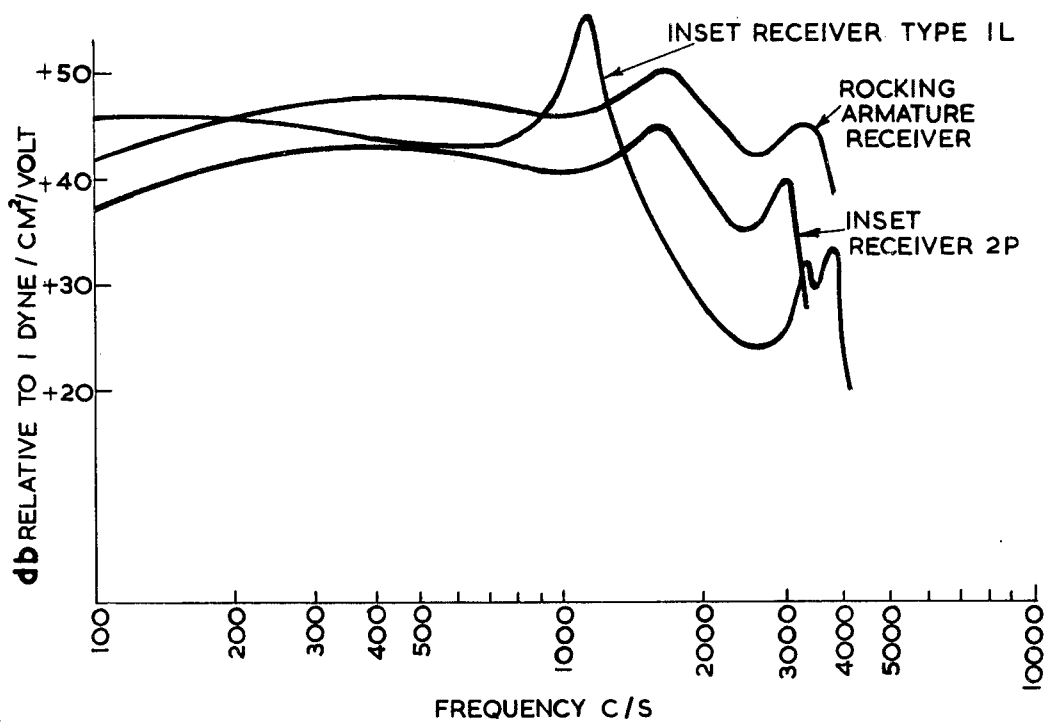
It is estimated that less than 1% of the electrical power input to a telephone receiver is converted into sound. A reasonable degree of loudness is experienced when an electrical input of 0.1 milliwatt is applied to a telephone receiver which is held to the ear.



R34027

FIG 27



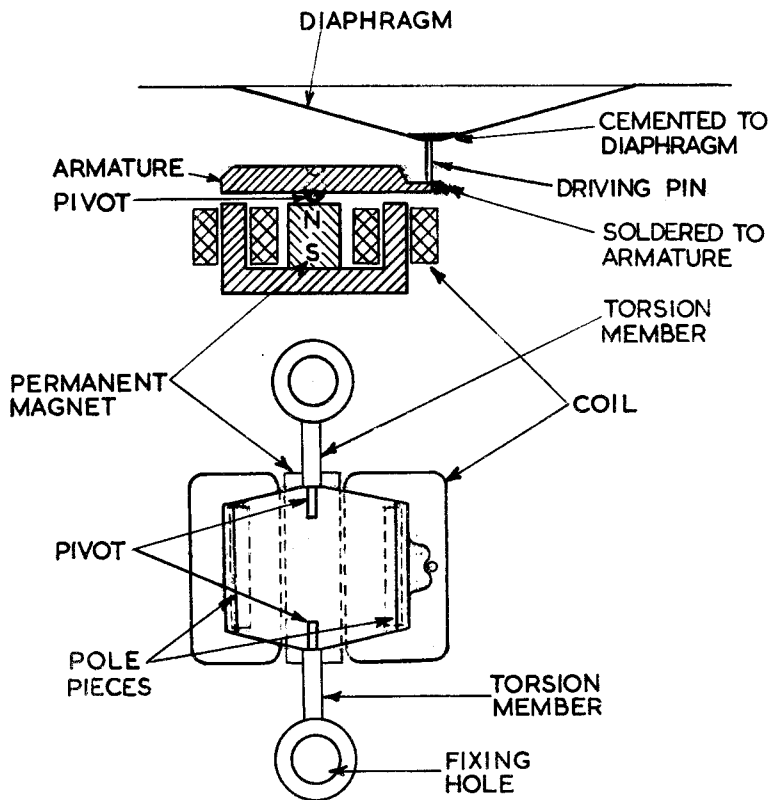


R34028

FIG 28

Rocking armature receiver

Fig. 29 shows the essential features of a modern development in the telephone receiver. This is known as the rocking armature receiver.



R34029 A

FIG 29

polarizing magnetic flux has two paths, one through each coil core, therefore the total reluctance of the magnetic circuit is reduced. This produces a greatly increased flux density per unit of magnetizing force (ampere-turns) and thus increases the overall sensitivity of the receiver.

Fig. 28 shows the response characteristic of the rocking armature receiver, this can be compared with the characteristics of the inset receivers 1L and 2P.

#### Moving Coil Receiver

In this type of receiver the force operating the diaphragm is obtained by the interaction of a magnetic field due to a permanent magnet and a magnetic field due to a coil carrying the audio frequency currents.

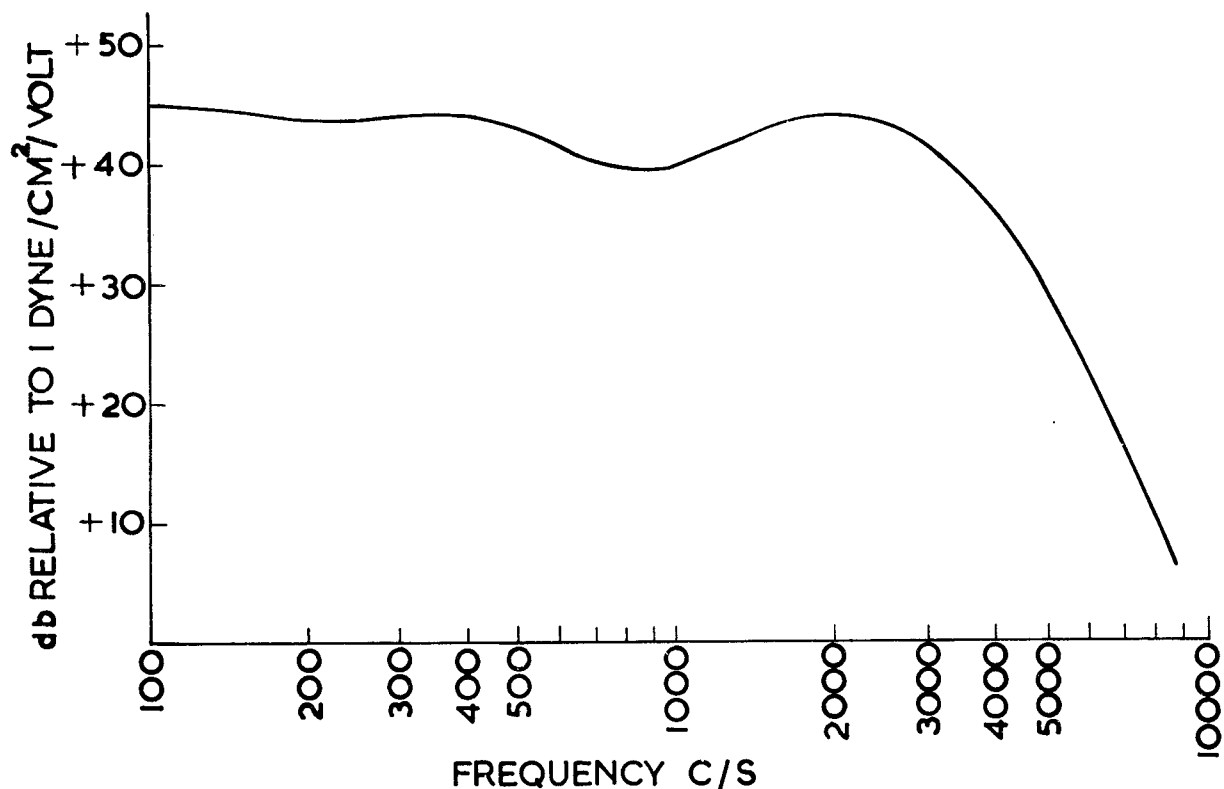
The construction is similar to that of the moving coil microphone previously described. A current in the coil sets up a magnetic field which tends to move the coil relative to the permanent field as in an electric motor. An alternating current in the coil thus causes an alternating movement of the coil to which the diaphragm is attached.

The diaphragm, which is made of a light non-magnetic alloy, is connected at its centre by the driving pin to one side of the armature. The forces acting on the armature are equal around the pivot point with no audio input, and the armature is retained in position by the two torsion members.

The two coils are series connected and wound in opposite directions on the polepieces, thus depending on the direction of the energizing current, the flux density is increased at one end of the armature and decreased at the other end. When an alternating current energizes the coils the flux, at a given instant, increases at one poleface and reduces at the other. The pull on the armature therefore increases at one end and reduces at the other resulting in a rocking motion about its fulcrum which displaces the diaphragm with a piston type movement.

The type of construction employed in this receiver has the advantage that the

Fig. 30 shows a frequency characteristic of a typical moving coil receiver (modulus of impedance about 20 ohms).



[R34030]

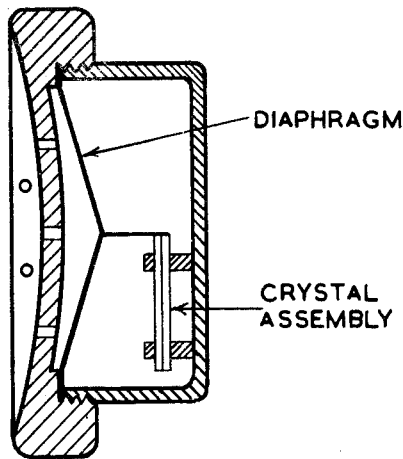
FIG 30

This type of receiver, unlike the magnetic diaphragm receiver, does not give a 2nd harmonic output and is thus to be preferred from the harmonic distortion point of view. The magnetic diaphragm type is preferable for a commercial telephone system, however, because of its comparable sensitivity, robust construction and lower cost.

#### Crystal receiver

Fig. 31 shows a drawing of a crystal receiver.

In the crystal receiver, two crystals of Rochelle salt are cemented together, and one end of the pair is firmly attached to the centre of the diaphragm as shown in the figure. When an alternating audio frequency voltage is applied to the crystal element the reversals cause the crystal to bend first in one direction and then in the other thus setting up a mechanical vibration in sympathy with the applied voltage. The mechanical vibration is transferred to the diaphragm.

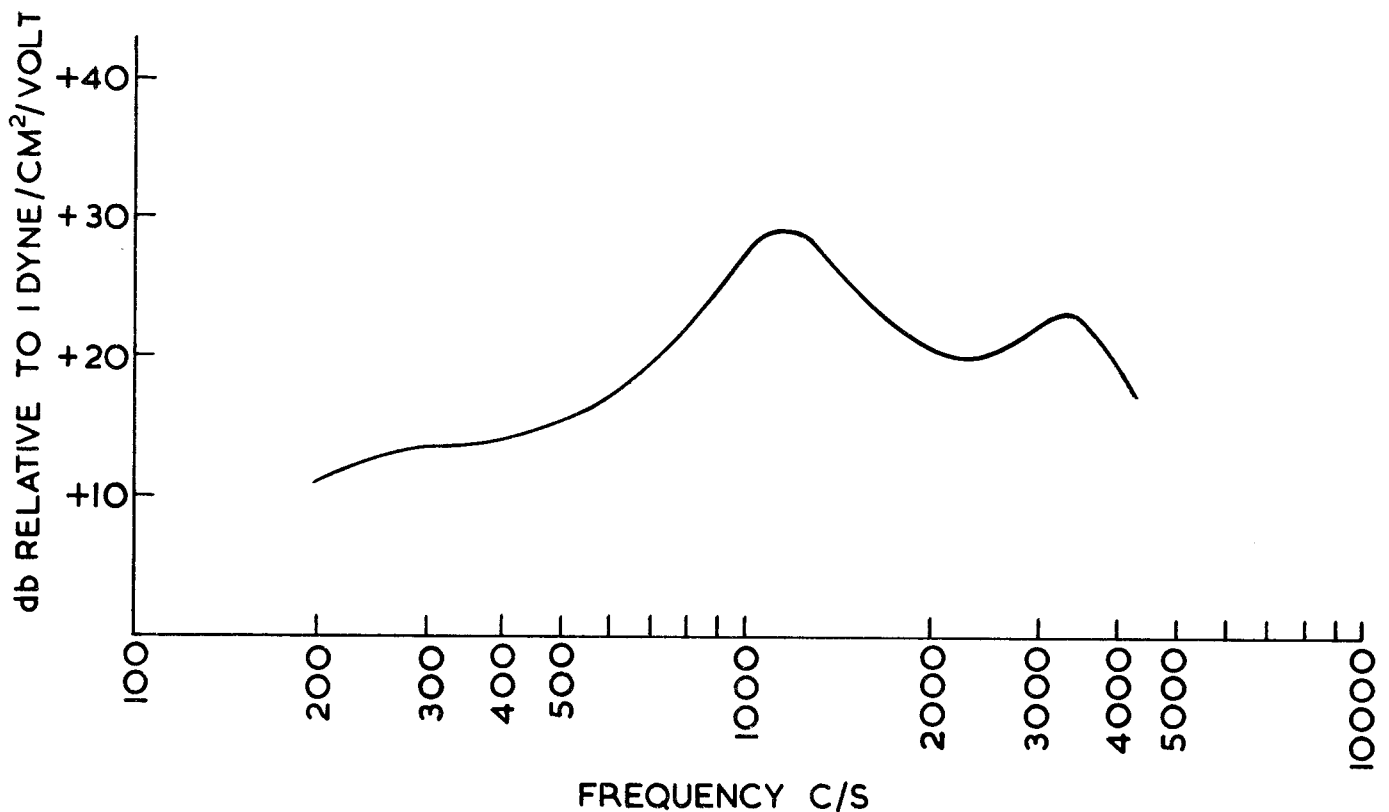


The impedance of the instrument is high, being several times that of the magnetic type. The audio frequency response of the receiver is good and maintains its sensitivity at high values. The instrument is suitable for speech and music reproduction.

R34031

FIG. 31.

Fig. 32 shows the frequency characteristic of a typical crystal receiver (about 2000 pF) over the speech range. It actually responds at higher frequencies than those shown in the figure.



R34032

FIG. 32.

Capacitor receiver

This type of receiver is not often met. The sensitivity is low but the frequency response is very good. A comparatively large diaphragm displacement and high polarizing potential are required.

Ribbon or band receiver

This type is not common but it has properties similar to those of the capacitor receiver.

LOUDSPEAKERS

Introduction

A loudspeaker consists essentially of a drive unit, such as is used in an ordinary receiver, and some kind of radiating device by which the resultant sound waves may be transferred to free air.

Although the moving coil or electro dynamic type is most likely to be encountered, a description of the main electro-acoustic driving systems in previous use will be given.

Moving Iron Type (electro magnet)

Reed type

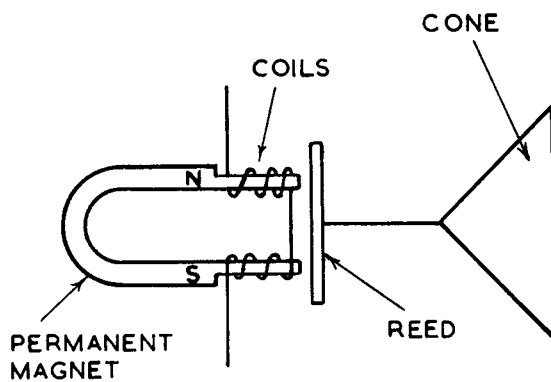
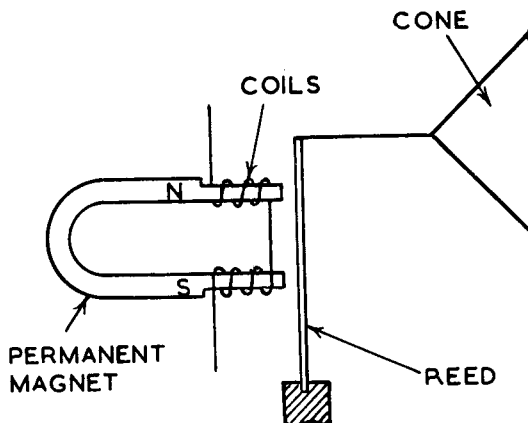


FIG. 33a.

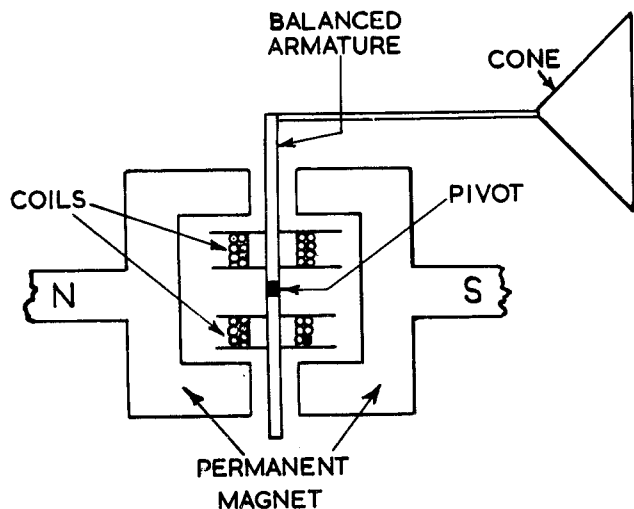
The elements of the reed type of drive unit are shown in Fig. 33(a) and (b). This consists of a permanent magnet and an operating coil wound upon it. The armature or reed being of a ferrous material and having a radiating cone rigidly fixed to it.

The disadvantages of this type was that the resonance of the reed and a poor response to the lower notes.



R34O33

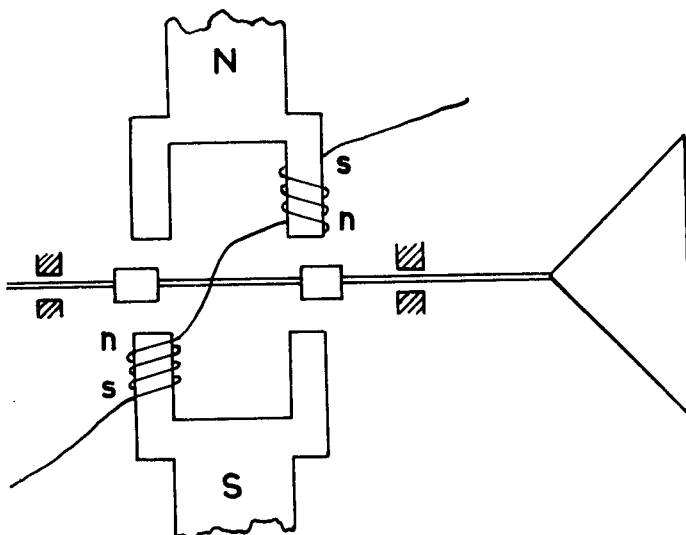
FIG. 33 b.



R34034

FIG 34

In this type of drive the armature was suspended in the centre and its operation was similar to that of a polarised relay. Although this type was an improvement on the reed type the bass response was still poor. The arrangement of the Balanced Armature is shown in Fig. 34.

Inductor Type

R34035

FIG. 35

In the inductor type of loudspeaker (Fig. 35) the iron armature is supported in a manner which allows considerably greater freedom of movement than either of the previous types. The action of the armature is like a piston moving towards and away from the poles of the magnet. The current through the coils causing the flux through one side of the system to be strengthened while the flux through the other side is weakened. An alternating current thus causes to and fro movement of the armature which is radiated via the cone.

The main disadvantages of this type of loudspeaker lie in the fact that direct current should not be allowed to flow through the operating coil as this would cause the armature to be permanently operated in one position, thus reducing its sensitivity. The sensitivity is also reduced because a considerable amount of the

flux produced by the operating current is not in the direction of motion.

Moving Coil (electro dynamic type)

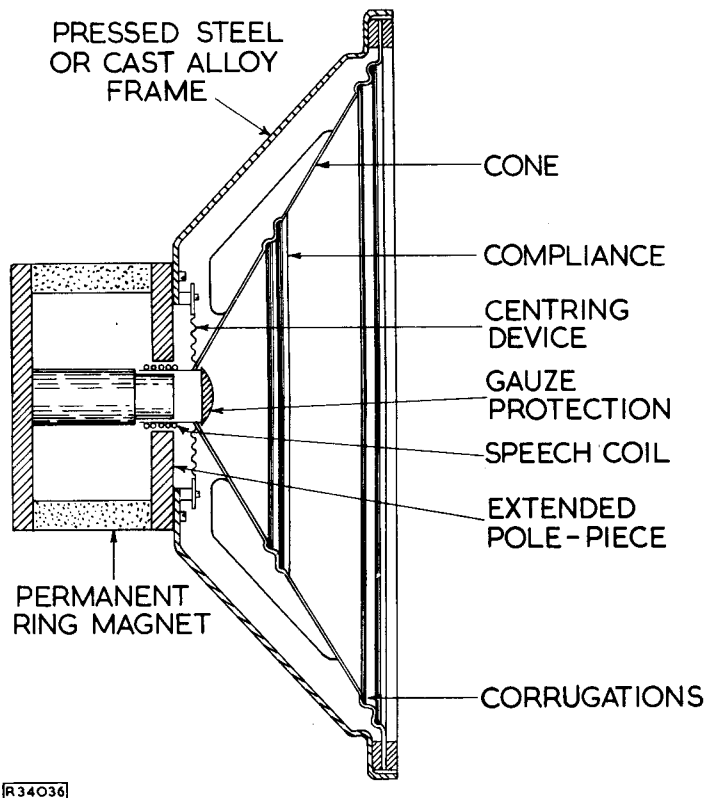


FIG 36.

In the moving coil drive, a conductor of non-magnetic material is placed in a magnetic field whose lines of force are transverse to the direction in which motion is desired. In the moving coil type shown in Fig.36 the conductor takes the form of a coil of wire wound on a light cylindrical former. It is suspended so that it can travel backwards and forwards through a distance of about 0.25 to 0.5 inch, but is not capable of movement in any other direction. It lies in the field of a permanent magnet whose field is radial and therefore at right angles to the coil of wire at every point.

The coil when carrying current, is thus acted on by an electro-magnetic force, which sets it in

motion at right angles to the direction of its own current, it therefore moves in the direction of its axis as determined by Fleming's Left Hand Rule. When an alternating current flows in the coil, the direction of motion is reversed every half cycle, thus the coil undergoes a vibratory motion. The coil is rigidly secured to the cone which, in moving in the same way, sets up air vibrations or sound waves of corresponding amplitude and frequency.

The chief advantage of the moving-coil drive is the relatively large movement permitted by the free suspension. This has the effect of giving a better reproduction at low frequencies than is the case with other types of drive.

Modern designs of coil suspensions, magnets and cones, have given the moving-coil type loudspeaker superiority over all previous types and consequently they are universally used, the only difficulty experienced is due to cone resonance, which tends to accentuate frequencies near the resonant frequency.

## Commercial types of Moving-Coil Loudspeaker

### General

Fig. 36 also shows the construction of a modern moving-coil loudspeaker of the type to be found in domestic and commercial use. The usual diameter of the paper composition cone is around 10", although diameters from 3" to 15" are common. Loudspeakers with elliptical cones are often used in table model television receivers, the object being to achieve a maximum cone area with minimum height. A large cone increases the radiation resistance and improves the bass response. The corrugations around the periphery control the fundamental resonance and the frequency can be lowered by making the corrugations thinner.

With larger diameter loudspeakers the additional weight of the cone tends to prevent the cone following the rapid vibrations necessary to reproduce high notes, and to overcome this difficulty a flexible compliance is placed near the middle of the cone. This allows the centre part of the cone to follow the more rapid vibrations alone but the whole cone is brought into play by the lower notes.

As the objective is lightness with rigidity the straight-sided cone is generally used, but exponentially curved cones are sometimes used to improve the high note response.

### Magnets

The magnet has a radial field and is usually about  $2\frac{1}{2}$  inches in external diameter, the material used being of an aluminium, nickel and cobalt alloy such as Alnico or Alcomax. These alloys are capable of high-flux densities, thus improving sensitivity and giving higher power handling capacity at low frequencies, than was obtained with the chrome and cobalt composition magnets previously used.

### Cone suspension

The cone must be mounted in such a way that it can only move axially, any sideways movement would allow the speech coil to foul the magnet poles and produce extreme distortion. The movement of the speech coil is controlled by a centring device two examples of which are shown in Fig. 37 (a) and (b). The device shown in 37(a) is a stamping from a sheet of bakelised fabric, the shape permitting to-and-fro motion only. The device shown in 37(b) is a form of pressed paper, similar to the cone material and permits a somewhat freer motion with less tendency to resonant "rattles" than the bakelised fabric type. Both types are fitted to the speech coil former immediately behind the centre of the cone.



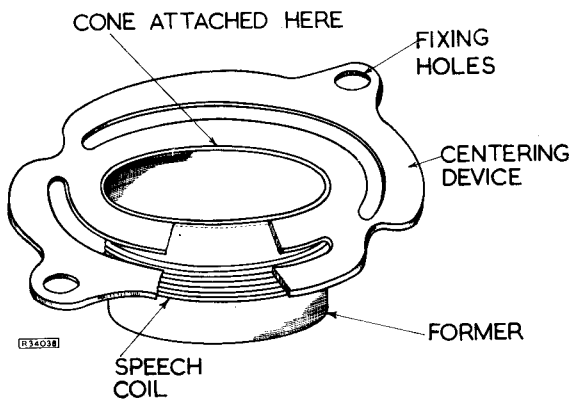


FIG. 37a

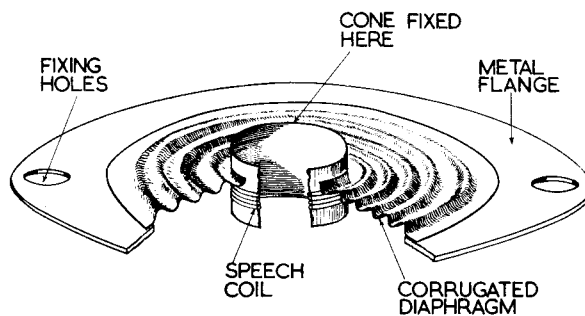


FIG. 37b

Use of a baffle

With a cone loudspeaker it is necessary to isolate the front of the cone from the back in order to prevent serious reduction of radiation which would otherwise occur.

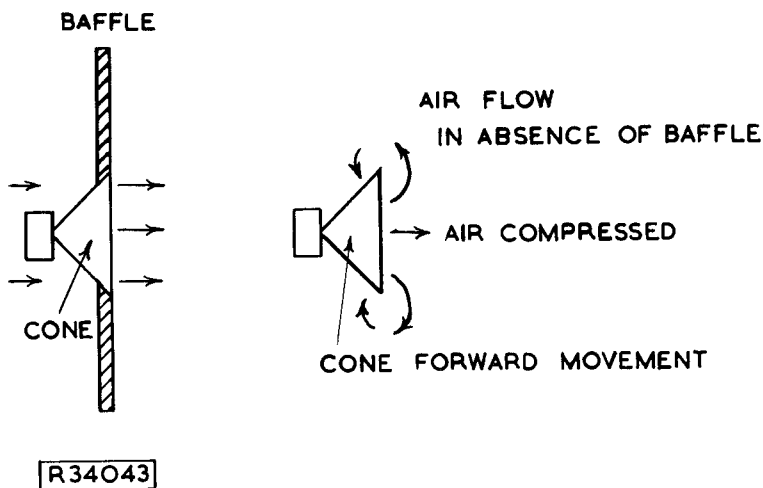


FIG. 38.

As can be seen from Fig. 38 when no baffle is employed the compressed air at the front of the cone is allowed to pass round to the rear of the cone where the air is rarified, thus the full effect of the sound is lost, this is not the case where the baffle board is in position but the board must be quite large in order to totally prevent the passage of the compressed air to the rear of the loudspeaker. The diameter of the baffle should be at least half the wavelength of the lowest frequency required at full power. Thus a 5 ft. baffle starts to cut off at 110 cycles. All baffle resonances should be avoided by using substantial material such as  $\frac{3}{4}$ " plywood.

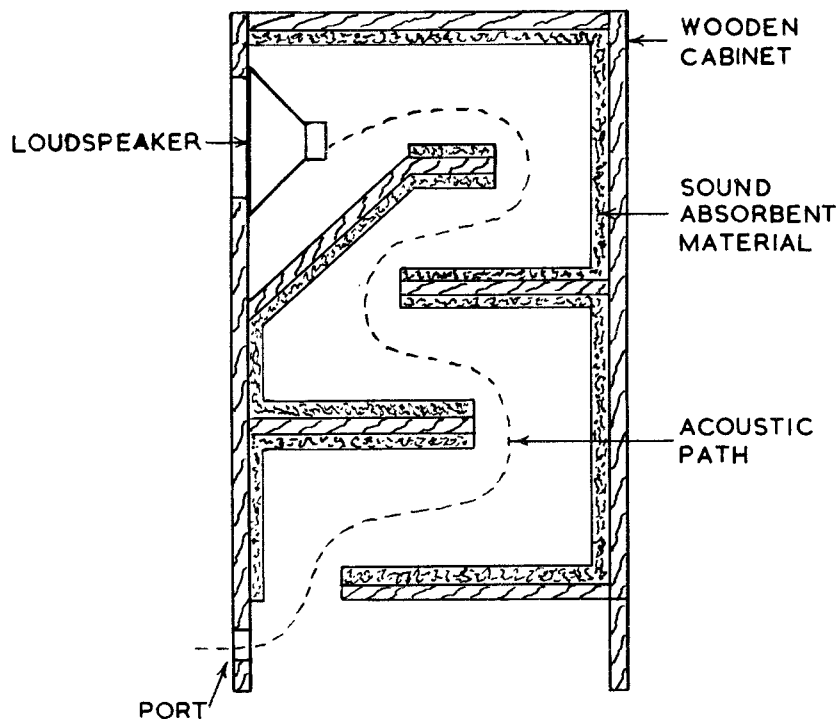
A large baffle board is not always practicable due to its physical dimensions, and a great deal of research has been carried out to try and achieve the characteristics of a large baffle within smaller physical dimensions.

### Open back cabinet

Characteristics approaching the effects of a large baffle can be obtained if the loudspeaker is mounted in an open back cabinet. The quality of reproduction is good, provided the sides are not deep in relation to frontal area, and the interior of the cabinet is not filled with equipment. Baffle area is increased by width of sides.

### Acoustic Labyrinth

A type of cabinet which has been employed to overcome the air column resonance and to produce the effects of an infinite baffle is shown in Fig. 39. An effort is made to balance the cone or air resonance by designing the rear path of the sound waves to have a phase relationship to the sound waves from the front. Thus if the column of air at the rear of the speaker had a resonant frequency of 50 cycles then a labyrinth path of about  $5\frac{1}{2}$  feet long (i.e.  $\frac{\lambda}{4}$ ) would cause the sound issuing from the port to be out of phase with the frontal sound, thus reducing the overall output at that frequency. The labyrinth must be lined with a sound absorbent material to prevent any reflections.



R34039

FIG. 39.

Crossover networks

It is difficult to construct a loudspeaker which will satisfactorily reproduce the complete audio frequency range without resonances occurring at some frequencies within the range. In an attempt to overcome this difficulty a method of using two different sized loudspeakers has been devised. Initially a large and small loudspeaker were placed in the same circuit, the object being that each loudspeaker would give a better response to a different band of frequencies. The small speaker, sometimes known as a "tweeter" would emphasize the higher notes, and the larger speaker or "woofer" the lower notes.

This principle was quite sound in use, but a further development has taken place, where circuit elements have been incorporated in the feed to the loudspeakers. A crossover network separates the output from the amplifier into two bands of frequencies, above and below say 1000 c/s, the lower frequencies are applied to the larger speaker and the higher frequencies to the smaller speaker.

The circuit of this type of network is shown in Fig. 40

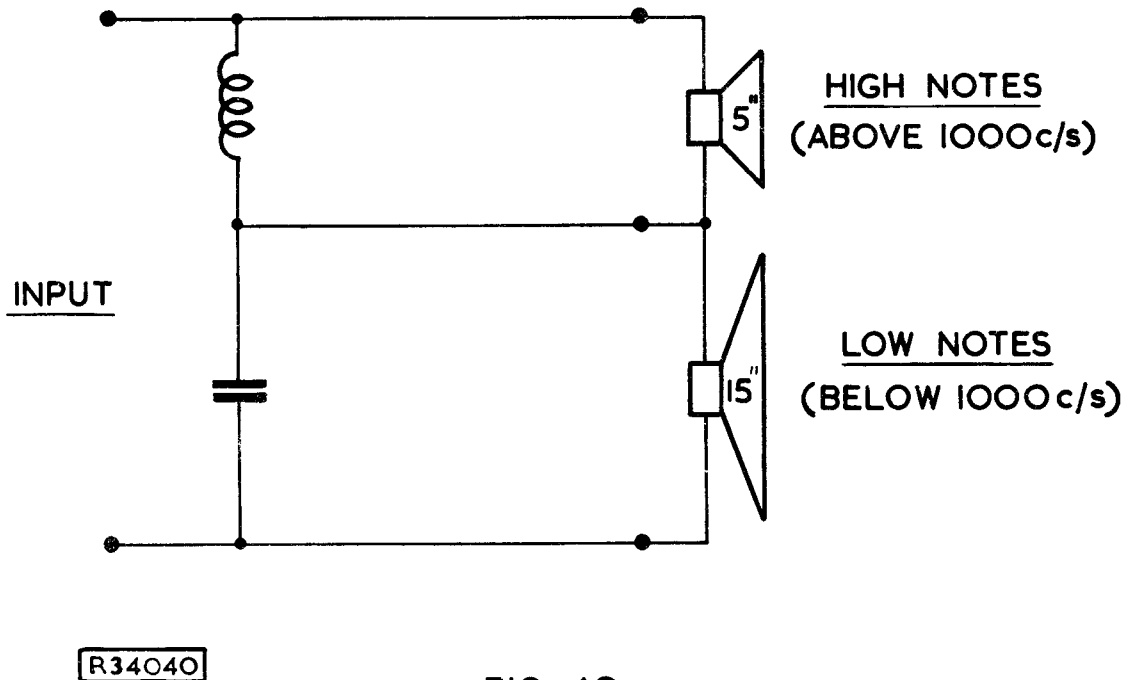


FIG. 40.

Exponential Horns

An exponential horn and moving coil drive unit is shown in Fig. 41. This type of reproducer is now used mainly for outdoor work and large buildings where a large volume is required, the efficiency of exponential horns results in important economies in amplifier requirements.

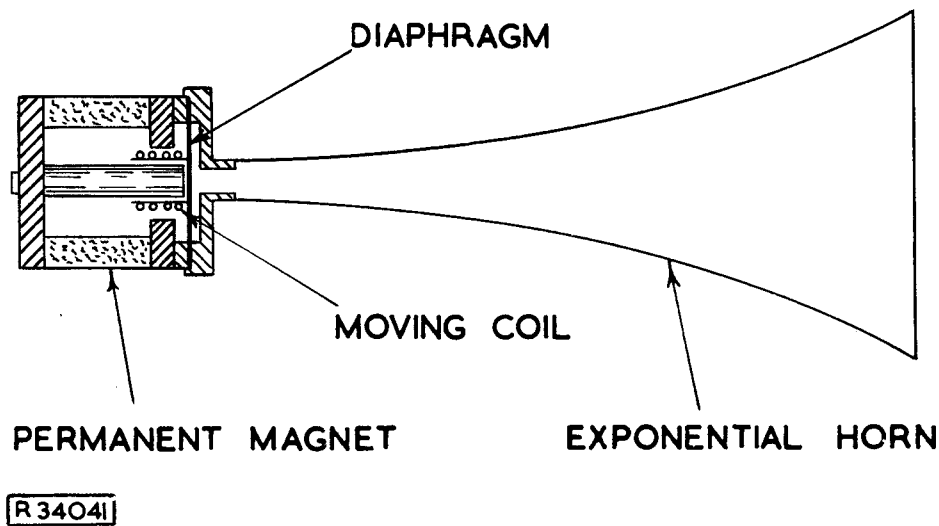


FIG. 41.

The moving-coil, generally consists of a few turns of copper wire, wound on a light cylindrical former which is sometimes made of aluminium. It is suspended so that it can travel backwards and forwards in the direction of its axis through a distance of  $\frac{1}{4}$  to  $\frac{1}{2}$  inch. The coil moves in the radial field produced by the permanent magnet. The diaphragm is rigidly fixed to the coil so that as the coil moves under the influence of the currents flowing in it, the diaphragm moves correspondingly. In this type of loudspeaker a small diaphragm is able to produce a big moving column of air with the aid of the horn.

To obtain higher efficiencies it is necessary that the axial intervals from the diaphragm are such that the ratio of the area of any one, to the succeeding one, is constant.

$$\text{Area at distance } x \text{ from throat} = Ae^{bx}$$

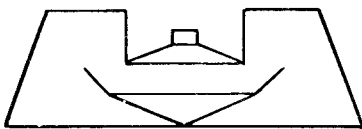
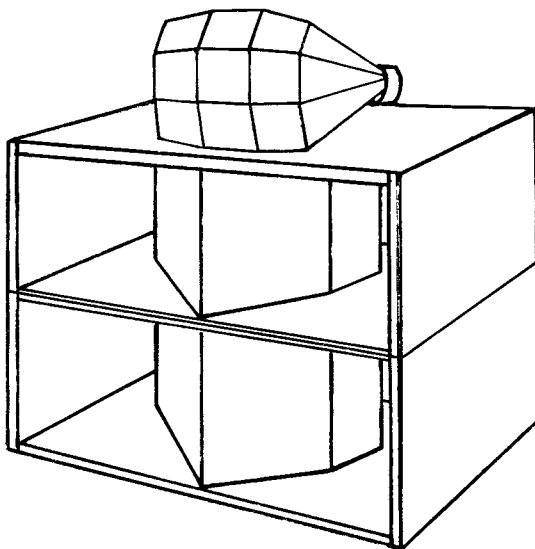
$$A = \text{throat area}$$

$$b = \text{constant determining the rate of opening out of the horn}$$

$$e = 2.718 \text{ approx.}$$

The relative intensity of sound from a horn falls off sharply when the frequency is reduced below a value known as the "cut-off frequency", e.g. a horn 15' long and 4' in diameter at the open end will have a cut-off frequency around 60 c/s. The frequency response of horn speakers is fairly uniform from the lower cut-off frequency up to a frequency of 2000 or 3000 c/s, at which point the sound intensity commences to fall off gradually as the frequency is raised. Within these frequency limits, one half or more of the electrical energy may be converted into sound - i.e. the efficiency may be 50% or more. Horns which are folded in order to reduce the overall dimensions tend to have reduced response at low and high frequencies. Multiple horns - i.e. several horns flaring out from a single drive unit - can be designed to give greater efficiency over a fairly wide frequency range.

Loudspeakers for Cinema and Auditorium Use



R34042

FIG. 42.

The quality of reproduction required for use in cinemas etc. should be as perfect as possible and to this purpose loudspeakers and cabinets have been designed employing most of the principles previously described. A factor which has to be taken into account is the radiation angle, as a full coverage of the auditorium is required. A typical arrangement is shown in Fig. 42, this employing a folded low frequency unit and a multicellular horn high frequency unit.

END