AN ELECTRONIC HEARING AID

by P. BLOM

Means of compensating auditory deficiencies have been known for some centuries, but until recently these were large and clumsy appliances. The modern electronic hearing aid is small, light and unobtrusive, and it is much wider in its scope. For an electronic hearing aid to have the widest possible field of application it should be easily adaptable to suit the many different forms of deafness that exist. This point is given special consideration in the following description of Philips hearing aids.

The object of a hearing aid is to compensate, in some measure, the auditory deficiency in persons who are hard of hearing. The hearing aid is thus an amplifier of sounds, designed for one specific purpose. Such appliances have been known for some centuries, and everyone will remember the large trumpets which were still in use not so very long ago; their origin, of course, goes back much further than the seventeenth century ear trumpet shown in fig. 1. It is only within the last two decades that acoustic amplification has been achieved by electronic means. The advantages of electronic hearing aids are manifold; they are smaller, lighter and less obtrusive.

In this article a new hearing aid is described (marketed in three models, fig. 2), which differs in certain respects from earlier types. Every effort has been made to ensure not only compactness and low current consumption, but also the widest possible range of application. The design of the instrument provides for automatic volume compression based on several control levels, and a wide choice of response curves. A special characteristic of the design is the method of construction and assembly, which allows for the easy replacement of components and gives a high degree of resistance to tropical conditions.

Fig. 1. Design for a hearing aid by A. Kirchner, 1684. (From G. v. Bekesy and W. A. Rosenblith, Early history of hearing: Observations and theories, J. Acoust. Soc. Amer. 20, 727-748, 1948.)
introduction to the subject. A description follows of the technical features of the hearing aid and the miniature components which were specially designed for this instrument.

through the auditory passage to the middle ear, which is separated from the outer ear by the ear drum. The middle ear comprises the three well-known bones or ossicles of the ear. These ossicles

The organ of hearing

The human ear consists in the main of three parts, each of which can be regarded as quite distinct from the others (fig. 3). Starting from the outside we have first the outer ear which comprises the auricle or shell of the ear, and the auditory passage. The air vibrations of which sounds consist are collected by the auricle and are directed

serve to transfer the vibrations of the ear drum, as produced by the sound, to the membrane of the fenestra ovalis, an oval aperture which forms the connection with the inner ear. The inner ear communicates with the cavity of the nose and throat through the Eustachian tube and so prevents differences of pressure from occurring in the vestibule of the inner ear. Within the inner ear there is a spirally coiled duct of about $2\frac{1}{2}$ turns, narrowing towards the upper end, known as the cochlea. Now, the cochlea is divided lengthwise in two parts by a membrane, one half of which communicates with the fenestra ovalis and the other with a second aperture in the wall of the inner ear, the fenestra rotunda. The membrane is not continued right to the end of the cochlea and the two halves are therefore in communication with each other. The cochlea is filled with a viscous fluid, and the membrane, which is also hollow and filled with fluid, contains the so-called Corti's organ, to which the vibrations are transferred from the fenestra ovalis by the fluid. The cross-section of the cochlea with Corti's organ is not the same throughout its length, and it is due to this fact that each part of this organ responds to a different frequency; that part which is nearest to the fenestra ovalis responds to
the very high frequencies, whereas the top of the cochlea is sensitive to very low frequencies. This mechanical selection of sounds within the cochlea is quite rough, but it is followed by a much finer, but as yet little understood process of selection by the auditory nerve, with which the cells of Corti's organ are in communication. The auditory nerve passes the sound stimuli to the brain, where the sound "signal", analyzed into its various component frequencies, is received; in this way we are enabled to form conclusions as to the quality and origin of a sound.

So far only air-conducted sounds have been mentioned, but sound can also reach Corti's organ by conduction through the bones of the skull (bone-conduction); by this means, however, it is mainly the lower frequencies that are perceived.

Defects of the ear may result in varying degrees of deafness and can be placed in three categories, viz. deficiencies in the conduction of the sound, causing conduction deafness; defects of the cochlea or auditory nerve, resulting in perception deafness; and defects of the brain. The last-mentioned will not be considered, as this cannot be made good by means of a hearing aid.

Conduction deafness may be caused by wax blocking the auditory passage, or it may occur as a result of inflammation. The ear drum can also be a source of conduction deafness, e.g. when wax is deposited on it. Another frequent cause is inflammation of the middle ear, possibly with rupture of the eardrum. Usually this kind of deafness is only temporary, but it can also be permanent (chronic inflammation). A stoppage in the Eustachian tube, resulting in pressures below atmospheric in the cavity of the middle ear will also be accompanied by deafness.

Otosclerosis, a disease of the middle ear manifested in a morbid growth of bone, will sometimes hamper the movement of the auditory ossicles; in many cases this can be overcome by an ingenious operation known as fenestration.

In all these instances it is mainly the air conduction that is impeded or ceases to function altogether.

Perception deafness is frequently caused by a gradual degeneration of Corti's organ; usually this commences at the point where the higher frequencies are registered, and gradually progresses into the region of the lower frequencies. Curiously enough, however, at high sound intensities, high tones can still often be heard, and at their full strength too. There is then an abrupt transition between deafness and hearing (fig. 4). Since the threshold of pain (the maximum sound intensity which may reach the ear without causing actual pain) usually remains at the same level, the range or span of sound intensities that the sufferer can perceive is greatly reduced. This effect is known as regression.

In order to diagnose the nature of a deficiency in hearing, a chart is plotted for the auditory loss of the sufferer, for both air-conduction and bone-conduction, as a function of the frequency of the submitted sound. The auditory deficiency is defined as the ratio of intensities that can just be perceived by the patient, to those in the case of a person of normal hearing; this is expressed in decibels. The curve thus obtained is known as an audiogram and it is plotted with the aid of an instrument called an audiometer 1). A number of audiograms are depicted in fig. 5, and from these it is seen that in serious cases of conduction deafness the sound pressure required to produce a sensation that is only just perceptible can be up to 60 dB, i.e. roughly 1000 times stronger than for persons with normal hearing. A pronounced dependence on frequency is not usually apparent. Perception deafness is distinguished from conduction deafness by the fact that hearing is impaired in both air-conduction and bone-conduction; this can be seen from the audiograms — as a rule, in conduction deafness, bone-conduction suffers no attenuation (2, fig. 5). As already mentioned, perception deafness is usually more evident in the higher frequencies, and in that region it may be absolute, i.e. more than 100 dB.

Many cases of deafness are of a mixed type, as will be seen from fig. 5. Regression cannot be

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1) An instrument of this type is described in an earlier number of this Review; see L. Blok and H. J. Köster, Philips tech. Rev. 6, 234-239, 1941.
diagnosed from a single audiogram; more extensive tests are essential when an examination is to be made.

The task of the hearing aid

The main function of a hearing aid is to so amplify sounds that speech will be intelligible and that local noises will give the user an impression of what is going on around him. The reproduction of music takes second place.

From the foregoing brief review of the major forms of deafness it will be clear that the individual requirements to be imposed on a hearing aid must differ very considerably between one case and another. In addition, it has not yet been found possible to establish any well-defined relationship between the nature of a deficiency in hearing as characterized by the audiogram, and the optimum characteristics required of the hearing aid by the user. For example, chart 3 in fig. 5 would indicate the need, on physical grounds, for a hearing aid with a rising amplification factor (rising frequency response curve), but very often, if not invariably, the practice this can be recovered. Turning of the microphone produces differences in the quality of the signal as received, since the response curve of the instrument depends to a certain extent on the direction from which the sound is picked up 2). Another effect of monaural hearing is the apparent reception of all local sounds from one and the same plane; in other words, the user of the hearing aid is not well able to determine the distance from the sound source, although here, too, a certain amount of judgment is restored in most cases, after some practice.

2) See also K. de Boer and A. Th. van Urk, Some particulars of directional hearing, Philips tech. Rev. 6, 359-364, 1941.
As it is only the patient himself who can be the ultimate judge of the most desirable characteristics for the hearing aid, it is most essential that the characteristic should be variable within wide limits. This applies not only to the response curve, but also to other characteristics. Manufacturers would be able to meet the need for variable characteristics very easily were it not for the fact that they are tied in two respects. First, from the point of view of the user, certain other requirements have to be met, which are also quite important, e.g. lowest possible current consumption, small dimensions, lightness, robustness etc. In view of this it is usual to limit amplification to a range of frequencies of from 100 to 5000 c/s, but even then it is very difficult to adequately fulfil all the requirements mentioned.

Secondly, it is important to the manufacturers themselves to be able to meet the needs of the greatest possible number of users with only one type of hearing aid. In other words, their aim is to cover the various needs with a single type of instrument, capable of simple manual adjustment. This facilitates mass production and reduces costs.

Some details now follow of the manner in which these several requirements have been met in the Philips hearing aid.

Scope of the hearing aid

The basic requirement for the response of a hearing aid may be said to be an amplification of 50 dB in a frequency range of 200-4000 c/s (which includes speech and local sounds). Care must be taken, however, that the sound of loud shouting (input sound intensity about 30 dB above normal speech intensity), or of other very loud sounds, is not distorted, and that the user does not receive such a volume of sound that the threshold of pain is passed. The need for such control on the volume is particularly evident among sufferers from regression deafness, for their margin between the thresholds of hearing and pain is usually smaller than the range of intensities of the sounds which are to be rendered audible.

Control on the amplification can be either abrupt or continuous; the former method is known as signal cut-off, which implies that the signal is prevented from exceeding a certain value at the output. Fig. 6 illustrates a signal subjected to cut-off; it will be seen that considerable distortion is introduced, and this affects the clarity of reproduction. In the Philips instrument, therefore, the continuous method has been adopted, viz. automatic volume compression, as this avoids distortion. In addition, the operating level of the control is variable in seven stages, to meet the need for versatility explained above.

Modification of the response curve of the Philips hearing aid can be effected in the first place by means of a tone switch. The user is thus given the facility of selection from three response characteristics to suit his particular need, the difference between the characteristics lying mainly in the limits of the frequency range. Of even greater importance is the fact that when purchasing his hearing aid the user is given a choice of seven earphones, each having an entirely different response curve. In all, therefore, a selection can be made from $3 \times 7 = 21$ overall characteristics.

The microphone, pick-up coil and earphone

The microphone in the Philips hearing aid is of the crystal type, all the components being so assembled as to form a complete removable unit. A diagram of the microphone is given in fig. 7. The "capsule" of the microphone consists of a round housing in which the acoustically sensitive element, a square crystal of Rochelle salt (sodium potassium tartrate) is mounted. The capsule is mounted flexibly in a rectangular housing which also carries contact pins for connections to the amplifier. Sound vibrations are picked up by a small conical diaphragm of aluminium foil which is connected to one corner of the crystal. The electrical connections through the round and rectangular housings are insulated
with glass "head" bushings which also serve to seal the casing against moisture.

A large part of the background noise that users of hearing aids always hear is produced by friction between the clothing and the microphone or neighbouring parts of the instrument ("case noise"). In order to suppress such noise as much as possible in the new hearing aid, the slots for the microphone are situated in the side of the case.

Rotation of a switch enables the user to connect the microphone to a so-called "pick-up coil". By means of this coil signals may be picked up inductively from the field of an exterior coil, such as that of a telephone receiver. The pick-up coil has a large number of turns, so that the stray field from a telephone receiver induces a signal voltage which is sufficiently large for the hearing-aid amplifier. In this way the acoustical link between the telephone and the hearing aid, which is responsible for considerable distortion, is eliminated. In addition, the magnetic transfer of the signal effectively eliminates all airborne sound, so that background noise — unusually distracting in a telephone conversation due to monaural hearing — is greatly reduced.

The pick-up coil is also being used to an increasing extent at concerts and in theatres and churches. A large loop of wire is laid round the walls of the building and connected to the output of an audio-frequency amplifier; the A.F. magnetic field of the loop induces voltages in the pick-up coil. Those who are hard of hearing need thus no longer be restricted to the front row or other specific places, but are free to move about while listening to reproduced sound which is almost wholly free from auditorium noises and reverberation. This system can also be used to great advantage by persons with normal hearing, for example in conducted parties in museums ("radiophonics" address) (fig. 8), for communication with personnel in large factory bays where the noise level is high or, again, in television or film studios.

The earphone of the hearing aid is attached to the auditory passage by means of a plastic ear-piece (fig. 9). The closure should be as nearly as possible airtight in order to avoid loss of sound and distortion.

As already pointed out, the purchaser of the hearing aid has a choice of seven different earphones. Five of these are of the magnetic type with an impedance of 100 \(\Omega\) (at 1000 c/s) and different response curves; the other two are crystal earphones of 100 000 \(\Omega\) impedance, giving more output in the higher tones. The crystal receiver is also lighter and smaller than the magnetic one. All these receivers are fitted with a standard press-stud, by means of which the earpiece is attached.

![Fig. 8. Visitors to the Municipal Art Gallery, Amsterdam, listening to the "guide" with the Philips hearing aid and pick-up coil.](image)

### The amplifier

The amplifier in the Philips hearing aid is of the conventional 3-stage audio-frequency type. The maximum electrical gain is 72 dB, or an amplification of about 4000, which can be reduced manually by means of a volume control situated after the first valve. The average amplitude of the alternating grid voltage as delivered by the microphone is 1 mV for a normal sound level (speech); the A.C. voltage supplied by the output transformer is then about 5 V. Measurement of the sound pressure of the receiver placed in an artificial ear 4) shows that

![Fig. 9. Plastic ear-piece with press-stud by means of which the receiver is attached to the ear; on the right it is shown with the earphone attached. A wedding ring is shown for comparison.](image)

8) Local noises can also be excluded by using a throat microphone, see Philips tech. Rev. 5, 6-14, 1940.

4) For a description of the artificial ear see K. de Boer and R. Vermeulen, On the improvement of defective hearing, Philips tech. Rev. 4, 316-319, 1939.
the acoustic amplification of the complete hearing aid is 52 dB at 1000 c/s.

The secondary side of the output transformer has an impedance of 100 Ω, matching the impedance of the magnetic earphone. By reversing a plug in its socket the user can increase the impedance at the output terminals of the amplifier to 100 000 Ω, thus providing a matching for a crystal earphone. Fig. 10 shows the circuit diagram of the complete amplifier.

The automatic volume compression mentioned earlier is provided by that part of the circuit shown by heavy lines in the figure. The alternating anode voltage from the output valve B₃ is taken through R₁ and C₁ to a selenium rectifier S₀, which rectifies it, and the resultant D.C. voltage is applied to the grid of the first valve B₁. In this way the bias of the input valve is automatically reduced and the amplification limited when the input voltage rises too much.

It is of course essential that strong sound pulses should be attenuated very quickly, as otherwise the initial components of a word might be distorted (the amplifier would be overloaded). The “attack time” of the A.V.C. is governed mainly by the product of the values of R₄ and C₂, which function as a filter for the control voltage from the selenium rectifier to the input valve. On the other hand, this time should not be too short, as this tends to make the amplifier unstable (motor-boating). This can be avoided, however, by coupling elements of suitable values. In practice an attack time of 150 msec has been found satisfactory.

When the sound reaching the microphone is no longer abnormally loud, the amplification should return to its original level, and the time in which this takes place is the “release time”; in order to avoid a noisy background as a result of the A.V.C. becoming inoperative during the pauses in a sentence, this time must not be too short; it is determined by the time constant of the system C₂, R₄, R₃ in fig. 10, and lies somewhere between $\frac{1}{2}$ and 1 second.

Fig. 11 shows the action of the A.V.C. with acoustic pulses applied to the hearing aid. With
the control at maximum, the amplifier is overloaded for a very short time and therefore gives a distorted signal only for a few milliseconds.

![Fig. 11. The action of the automatic volume compression.](image)

a) A voltage of square wave-form \( V_i \) is applied to the input of the amplifier, the amplitude being such that, without the A.V.C., the distortion of the output voltage would be more than 10%.

b) The output voltage \( V_o \) with A.V.C. operating, exhibits distortion of more than 10% for only a very short period. The significance of the attack and release times of the A.V.C. \( t_a \) and \( t_r \) respectively) is clearly seen from the figure. The scale of \( t_a \) is exaggerated in the diagram.

As mentioned above, the control level can be adapted to the needs of the user. This individual matching is accomplished by means of a resistance \( R_2 \) (fig. 10) placed in series with the receiver. It is not necessary, nor is it desirable, that the user should have control over all the variables in the instrument: he will obviously never require to adjust the instrument to respond to forms of deafness other than his own. For this reason the output level is pre-set at the time of purchase, while the A.V.C. resistor is provided in the reversible plug to which reference has already been made. The patient, assisted by the doctor, has a choice of \( 2 \times 8 \) different plugs, which will give him either uncontrolled output, or control in one of seven different ranges, each differing by 5 dB, either with the crystal or the magnetic earphone.

Some response curves for the complete hearing aid are reproduced in fig. 12; these show the ratio of output sound pressure to input sound pressure in dB, as a function of the frequency. The characteristics depicted are examples of what can be achieved with the seven-times-three combinations of receiver and tone control. This choice of characteristics, together with the eight ranges of A.V.C., provide a very wide range of application of the instrument, capable of meeting different forms of deafness.

**Construction**

The construction of the Philips hearing aid differs in some respects from conventional types. Apart from the necessity for small dimensions, robustness, resistance to tropical conditions etc., easy replacement of the components was made an essential feature of the design. If components can be easily replaced, repair work is greatly simplified. The dealer is then in a position to remedy the more usual faults himself with the aid of a manual only, no soldering or measuring instruments being necessary.

The advantages of the interchangeability of the receiver as well as the reversible plug are obvious. The amplifier is composed of units linked mechanically and electrically by contact pins; the batteries form another unit in themselves. Contact pins and springs complete the circuits of the microphone, tone switch etc., which are also separate units. This method of construction has proved a very satisfactory answer to the problem of the simple replacement of components.

![Fig. 12. Response curve of the complete hearing aid for three of the 21 combinations of earphone and tone control setting.](image)

**Fig. 13** is an exploded view of the various components and shows how they are grouped into their various units. A photograph of the interior of the hearing aid is reproduced in fig. 14, which shows the intermediate model of the range of three (see fig. 2 and below). No individual resistors etc. will be seen, either in the exploded diagram or in the photograph, this being due to the special method employed in incorporating them all in their particular unit. The resistors and capacitors, as well as the output transformer, are first laid out on a resin-bonded paper plate (fig. 15), all the connections being made on the back of the plate. There
is an almost complete absence of soldered joints in this hearing aid: nearly all the leads are spot welded in order to avoid a dangerous rise in temperature during assembly of the components, which are mounted in close proximity to each other. The local “climate” in which hearing aids are generally used differs considerably from that in which most electronic equipment operates. The set is carried either in the breast pocket, or almost in direct contact with the body. In the latter case a relative humidity of 100% is fairly closely approximated. The temperature differs greatly according to the method of carrying and, when the case is worn close to the body, the possible effects of skin secretions must also be taken into account. All these factors are accentuated in tropical climates. In the design, therefore, allowance has been made for temperature variations between 0 and 45 °C and relative humidities between 0 and 100%. Thermal stability has been ensured by specially designing each component; this will be referred to again later. Sensitivity to humidity is avoided by moulding the moisture-sensitive components into the polyester resin block; judicious selection of the constituents of the resin has yielded a polymerization temperature of only 35 °C, so that damage to the components is avoided and only negligible

Fig. 13. Exploded view of the Philips hearing aid. The principal components are numbered: 1 case with microphone slots 2, and clip 3 for attachment to the clothing; 4 earphone with cord; 5 pick-up coil; 6 battery case; 7 block of polyester resin containing the electrical components; 8 contact pins linking the components of the hearing aid electrically and mechanically; 9 valves; 10 plug; 11 valveholder; 12 switch for microphone/pick-up coil; 13 tone switch; 14 volume control; 15 microphone in screened housing.

entire unit is moulded into a block of polyester resin 5) which is then polymerized; the block thus formed is denoted by 7 in fig. 13. Polyester resins have very excellent insulating, damp-resisting and mechanical properties, closely resembling those of polystyrene and, owing to their low surface tension before polymerization, permeate easily into the small spaces between the components.

5) See J. P. Mudde, Polyester casting resins, Plastica 6, 12-15, 1953 (No. 1).
shrinkage stresses (on cooling) occur. In order to reduce still further the shrinkage and increase the physical strength, a quantity of ceramic powder ("Kersima") is added to the moulding powder. This ensures at the same time that the instrument shall be shockproof. Hearing aids belong to a class of equipment which, in contrast to radio receivers for example, are subjected to constant jolting and vibration; robustness, therefore, is an essential requirement.

The miniature components

The smallness of the hearing aid is due to the very compact design of the components. As standard components would require too much space, an entirely new range of components was designed for the new Philips hearing aid, very small in size, but with excellent electrical properties. The use of these components are not confined to hearing aids alone, for there are many other fields in electronics in which an important outlet for such components exists. The more important components of the hearing aid will now be discussed.

The valves (fig. 16) are of course battery valves, of the sub-miniature type. The DF 67 is used in the first and second stages; the output valve is the DL 67, except in the smallest model of the hearing aid which is fitted with the DL 66. The valves are mounted in a special valveholder.

The coupling resistors between the three stages of amplification are very small indeed, viz. $7 \times 1\frac{1}{2}$ mm, and are capable of carrying a load of $1/50$ W (fig. 17). They consist of ceramic tubes coated with graphite suspension, the characteristics of which can be varied to yield resistance values of from $1000 \Omega$ to $15 \mathrm{m}\Omega$. The coupling capacitors, of which a specimen is also shown in fig. 17, are also manufactured from ceramic tube, in this case a grade of "Kersima" of which the dielectric constant is very high, namely 4000. With this material very small capacitors can be made in a range of values up to $6400 \mu\mathrm{F}$. The dimensions are $16 \times 3\frac{1}{2}$ mm. A special feature of these components is that the leads are attached inside the tube of the capacitor, leaving the exterior quite smooth. The capacitors are protected by a coating of insulating material and can therefore be mounted in close contact with each other.

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An electrolytic capacitor \((C_e \text{ in fig. 10})\) is connected in parallel with the anode battery to prevent the amplifier from oscillating (it decouples the anode circuit). There is always some risk of oscillation as the batteries get older; the internal resistance then rises and the coupling between the circuits becomes tighter. Hence the capacitor in the circuit enables the user of the hearing aid to obtain the longest possible service from his batteries, although there is of course a limit, imposed by the ultimate decrease in the amount of power available. The electrolytic capacitor is also quite small; it is housed in an aluminium tube \(18 \times 4 \text{ mm} \) (fig. 17) and is made in two ratings, viz. \(2 \mu \text{F} \) at \(25 \text{ V}\) and \(10 \mu \text{F} \) at \(2 \text{ V}\).

The output valve of the amplifier is matched to the receiver by means of a special transformer (also shown in fig. 17) which provides the impedance matching of \(100,000 \text{ or } 100 \Omega\). When a crystal receiver is used, the coupling consists only of the self-inductance of the primary winding. Owing to the high impedance of the valve, it is necessary, for effective matching, to provide a high self-inductance; to realize this within small dimensions is made more difficult by the presence of a D.C. component of \(200 \mu \text{A} \) which reduces the permeability of the core. The use of high alloy-content laminations and a large number of turns of very thin wire (30 micron) offers a satisfactory solution. At \(1000 \text{ c/s}\) the efficiency is \(60\%\), which is high for such a small transformer, being of the same order as that of output transformers of standard dimensions.

As already mentioned, the transformer is moulded into the polyester resin block with the other components; the penetration of the resin guarantees the resistance of this component to tropical conditions.

The amplification of the hearing aid is controlled manually by means of a potentiometer (fig. 18) connected between the input and second valves. This is a rotary potentiometer and the physical requirements to be met by this component are fairly heavy. The user is continually adjusting it to give the required volume of sound, and a life of 20,000 operations on both directions is essential. To withstand this a robust spindle bearing is necessary, and fine tolerances on the other parts of the potentiometer. An improved carbon track with a moving carbon contact has practically eliminated potentiometer noise, even for resistances up to \(5 \text{ M}\Omega\). The amplification between the potentiometer and the output valve is some \(400 \times\), so that it was further necessary to eliminate ripple voltages induced in the grid circuit of the second valve by the output valve. Such voltages could reach the potentiometer through body capacitance via the finger operating the control, and for this reason the potentiometer is provided with an internal screen.

The need for such screening could have been avoided by placing the potentiometer between the second stage and the output valve, but strong input signals might then have overloaded the second valve.

To a large extent the dimensions of the hearing aid are dependent on the size of the batteries, two of which are required, viz. one of \(1\frac{1}{2} \text{ V}\) for the filaments and another, of \(22 \text{ V}\), for the anodes. As sub-miniature valves are used, very little power is needed (40 mW from the filament battery and 5 mW from the other), so that for a reasonable life, only very small batteries are required (filament battery life about 20 hours; anode battery about 250 hours).
In order to leave the compromise between dimensions and battery life (also economy) to the user, the three models as illustrated were placed on the market, the only difference being in the size of the battery holder (the smallest model, moreover, has no listening coil and is fitted with an output valve of smaller rating). There is accordingly a choice of very small batteries with a correspondingly small case, and larger batteries with larger case, but lower running costs.

Summary. Defects in hearing can assume many different forms. The greater the adaptability of an electronic hearing aid in its applications, therefore, the larger the number of persons who can benefit from it.

This need for adaptability is emphasised in practice by the fact that it has been found impossible to define a unique relation between the desired characteristics of the hearing aid and the nature of the deafness in each individual case. In the new series of hearing aids adaptability is ensured by providing automatic volume compression in a range of seven different levels, from which a selection can be made by ordering the appropriate plug. Further, there is a choice of seven different earphones, five of which are magnetic, and two of the crystal type. These features, in conjunction with a 3-position tone switch offer a total range of 21 different characteristics. The microphone can be switched over to a pick-up coil whereby signals are received directly by induction, for example, from a telephone. In the design of these hearing aids every endeavour has been made to ensure that all the components shall be easily replaceable, so that repairs can be carried out quite simply without any soldering operations. The electrical components are of the miniature type, specially designed for the purpose. All the resistors and capacitors, as well as the output transformer, are moulded into a solid block of polyester resin, ensuring a high degree of robustness and resistance to tropical conditions, and low sensitivity to humidity. All the components, too, were designed with a view to long life and reliable service. Three models of the hearing aid are manufactured, the principal difference between them being in the rating of the batteries.