A TRANSISTOR HEARING AID

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Some time ago a short report appeared in this Review on the transistor hearing-aid type KL 5500. A more detailed description of this apparatus illustrates clearly the great advantages resulting from the use of transistors.

The entry of the transistor into electronic engineering has opened up entirely new possibilities. The most outstanding advantages of the transistor over thermionic valves are its small dimensions and low power consumption, the latter mainly because no filament current is required. Moreover, the power can be supplied by a source of very low voltage. This is particularly advantageous where the source consists of dry batteries, since the energy (the number of watt hours) is supplied much more cheaply by a battery of a few volts than by a battery of some tens of volts. Furthermore, practice has already shown that, in general, transistors may be expected to have a longer life than valves.

Small dimensions and low battery costs are points of especial importance where hearing aids are concerned. It is not surprising, therefore, that the first practical application of transistors on a large scale has been in hearing aids, particularly since what is required is amplification at audio frequencies and relatively low power outputs, which is precisely the field of application for which transistors were first manufactured on a commercial basis. The transistors in question are nevertheless capable of supplying a higher output power than is economically possible with the subminiature valves used in valve hearing aids.

Transistors offer certain other advantages which make them particularly suitable for hearing aids. In the circuit with a common emitter, which is the circuit mostly employed at low frequencies, the impedances involved are relatively low 1). Even in a very compact construction there is therefore nothing to fear from stray capacitance coupling: the stray capacitances form high impedances carrying negligible currents. What is more, transistors show no microphonic effect; the measures normally needed to combat this effect can therefore be dispensed with, which again makes for compactness.

With the Philips transistor hearing aid described here (type KL 5500) 2), the aim has been to help the largest possible number of users. Accordingly this is still the hearing aid with the widest field of application. Two other types are also being manufactured: type KL 5600, which corresponds substantially to KL 5500 but is smaller (with the sacrifice of some of its possibilities and entailing higher battery costs) and the even smaller type KL 5700, which is in a certain sense a de luxe model, combining minimum dimensions with high quality. In fig. 1 the three hearing aids are shown side by side.

Requirements to be satisfied by a hearing aid

Speech intelligibility, which is of course the most important criterion for the usefulness of a hearing aid, is a problem which has been solved in modern instruments to the satisfaction of a wide circle of the hard of hearing. Although new measures to improve speech intelligibility are continually being developed — particularly as regards special types of deafness — more and more importance is now being attached to requirements of a more secondary nature concerned with the need to hear comfortably without great effort. For all types of deafness, comfortable hearing is determined in the first place by a favourable signal-to-noise ratio, and in the second place by low non-linear distortion (by non-linear distortion, the instrument itself adds new frequencies to the received signal). Noise in hearing aids is produced partly by the circuit itself and partly by friction between parts of clothing near the apparatus or between clothing and the case of the apparatus (case noise).

The more detailed requirements to be satisfied by a hearing aid depend to a large extent upon the nature of the patient's deafness. A hearing aid capable of meeting the needs of a wide circle of users must therefore possess considerable flexibility.

1) For the three principle transistor configurations, viz. the circuits with common emitter, common base and common collector, and for a survey of some of their fundamental properties, see for example J. P. Beijersbergen, M. Beun and J. te Winkel, The junction transistor as a network element at low frequencies. I. Characteristics and parameters, Philips tech. Rev. 19, 15-27, 1957/58 (No. 1).

In most cases a maximum acoustic gain of 55 dB appears to be more than sufficient. Of this, depending upon the degree of his deafness and upon the intensity of sound in the microphone, the patient can use what he needs by varying a volume control. In cases of severe deafness, however, it is desirable to be able to boost the maximum acoustic gain up to, say, 65 dB.

Furthermore, for the amplification to be effective it should be possible to produce a sufficiently large sound pressure in the ear without this being associated with serious distortion. The earphones commonly used can readily produce the required pressure, provided the output transistor in the hearing aid can supply the power. In most cases, a maximum available output power of one milliwatt is more than enough for driving ordinary earphones. In cases of very severe deafness, however, it may be desirable to increase the output to as much as 10 milliwatts. The same higher output may also be needed when bone-conduction earphones are used. With an earphone of this type, which is fixed behind the ear by means of a headpiece, the sound vibrations are conducted to the organ of hearing via the bones of the skull. For this purpose, more power is needed than for the normal conduction of sound via the air in the auditory passage.

For some patients, particularly for sufferers from conduction deafness, an amplification independent of the amplitude of the input signal is suitable. The amount of the amplification will differ for different patients: where a high amplification is needed, a large maximum power output must, of course, also be available.

There are also patients, however, for whom it would be quite wrong to have an amplification independent of the amplitude of the input signal. Such patients include those who can only hear sounds whose intensity lies above a certain level, but for whom the threshold of pain ("acoustic trauma") is about the same as for persons with normal hearing. This situation is found in the case of sufferers from regression deafness 3). For such patients the output power of the hearing aid must be prevented from exceeding the value corresponding to the threshold of pain, as the amplitude of the signal in the microphone increases. This means that the amplification and the maximum available power must be separately adjustable.

Apart from the amplification as a function of the amplitude of the received signal, the amplification as a function of the frequency is of considerable importance. The curve illustrating this dependency, called the response curve, or “fidelity characteristic”, of the hearing aid. A flat curve is not usually required. What is aimed at is an agreeable tone quality, but the meaning of “agreeable” in this context depends upon the nature of the hearing defect and upon the opinion of the patient. This does not exclude cases where the patient must, as it were, reassemble his “library” of sounds from a spectrum which, though he may find it troublesome, perhaps, in the beginning, he finally comes to accept as true.

In order to be able to meet all these diverse re-

requirements, it must be possible to regulate the instrument's response curve.

The hearing aid KL 5500

The amplification and power outputs mentioned above can be attained economically with valve hearing aids only by using batteries of a relatively large volume, and this would make the hearing aid too large to be acceptable nowadays. If the size of such a valve instrument is kept acceptably small by the use of miniature batteries, the battery costs are exorbitant, since small batteries are much less efficient than large ones. The properties of the transistor make it possible to solve the problem. The Philips hearing aid type KL 5500 contains four transistors (three of type 0070 and one, the output transistor, of type 0071), all connected in the common-emitter configuration.

The battery holder is designed for a carbon-zinc rod-type battery, consisting of a single cell which supplies a voltage of 1.5 V. The output obtained is more than 1 mW, which is quite sufficient in all except extreme cases of deafness.

Since the cell used is relatively large (fig. 2), the battery costs are extremely low, amounting to about one tenth of the costs of a comparable valve hearing aid. A larger power output and more amplification become available if the battery voltage is increased, which can be done by using two or three mercury cells of 1.3 V each (fig. 2). The available output power is then 4 and 10 mW respectively. This, however, considerably increases the battery costs. In the first place, current consumption increases in proportion to the voltage; the replacement of the carbon-zinc cell by three mercury cells means, therefore, that the current consumption increases roughly by a factor of 3. Thus, although the number of mA-hours of a mercury cell is about 1.5 times larger than that of a carbon-zinc cell, about six mercury cells will be used up for every one carbon-zinc cell. In the second place a mercury cell costs much more than a carbon-zinc cell (prices differ from one country to another). In order to save battery costs in cases where a supply voltage of about 4 V is needed, an ordinary 4½ V flat torch battery may be connected to the instrument with a plug.

To produce a simple circuit with a flat, reproducible characteristic (to which corrections, if required, can readily be applied), the successive amplifier stages are RC coupled (fig. 3a). No transformers are used, thus saving space, weight and costs. The moving-iron microphone is connected directly to the first amplifier stage, and the earphone (also of the moving-iron type) is directly connected to the output transistor. The volume is controlled by a potentiometer R3 after the second amplifier stage.

To prevent the threshold of pain from being exceeded, the maximum power of the output stage can be limited by a variable resistor R1 in the collector circuit of that stage (this will be dealt with later). A multi-position switch, comprising S1, S2 and S3 in fig. 3, serves for switching the battery on and off and for attenuating the low and high tones. The microphone can be switched over to a listening coil, which enables signals to be picked up inductively from the field of an exterior coil, such as that of a telephone receiver. The listening coil may also be used in combination with a loop circuit fitted in theatres and other buildings for the benefit of the hard of hearing 4).

Details of the amplifier

The functioning of the circuit can best be understood by considering the D.C. and A.C. circuits separately. The D.C. circuit is shown in fig. 3b; it is obtained from fig. 3a by the omission of all branches containing capacitors. The A.C. circuit is represented in simplified form in fig. 3c, in which all capacitors acting as short-circuits to the alternating signal current are considered as ideal short-sircuits and the internal resistance of the supply battery is neglected. Accordingly, resistor R5 has also been omitted in fig. 3b and c. (R5, together with C5, provide decoupling, that is, they prevent alternating voltages, which appear across the internal resistance of the battery,

4) See the article quoted in note 3), page 42.
from being fed back into the preceding amplifier stages."

The transistors in the first three amplifier stages are wired in the same way, both for A.C. and D.C. The resistors $R_b$ and $R_c$ in each of these stages serve for the D.C. biassing. With $R_b = 2.2 \, \text{k}\Omega$ and $R_c = 39 \, \text{k}\Omega$, the battery voltage being 1.3 V, the operating point $P$ shown in fig. 4 is obtained. This point is chosen very low in the family of characteristics (small $I_c$), the object being to conserve the battery by a minimum consumption of current (the collector current $I_c$ less sensitive to temperature changes, which in turn prevents the amplification from varying appreciably with temperature changes of a few degrees centigrade. We shall now consider this subject in more detail.
Stabilizing the amplification against temperature variations

It can be seen in fig. 4 that the characteristics for constant base current \( I_b \) are almost horizontal. We may therefore write, to a good approximation for constant base current \( I_b \),

\[ I_c = I_{c0} + \alpha' I_b. \]

(1)

The two terms of which \( I_c \) is composed are indicated in fig. 4; \( \alpha' \), which is the current amplification factor, is a constant in so far as the lines for constant \( I_b \) are equidistant. What does not appear from fig. 4 is that \( I_{c0} \) is strongly dependent on the temperature; for every 10 °C increase in temperature, \( I_{c0} \) is approximately trebled \(^6\). The current amplification factor, on the other hand, is only slightly sensitive to temperature variations. If \( I_b \) is constant, changes in \( I_{c0} \) will entail the same changes in \( I_c \) (see (1)). Since according to fig. 4, \( I_{c0} \) and \( \alpha' I_b \) in the first three amplifier stages are of the same order of magnitude, the appreciable relative changes of \( I_{c0} \) with temperature variations of a few degrees will have a considerable effect on \( I_c \). If \( R_b \) were connected directly (not via \( R_c \)) to the battery, hence \( \alpha' I_b \), will also decrease, and therefore \( I_c \) will change less than \( I_{c0} \) (see (1)). In this way a measure of stabilization of \( I_c \) is achieved.

For a D.C. circuit as in fig. 5a, the circuit for A.C. would be as shown in fig. 5b. It can be seen that now the transistor by itself occurs as a fourpole (shunted by resistors). Since the output of each transistor would then be virtually short-circuited by the input of the following transistor, the behaviour of the transistor as a fourpole is very simple, for we may take for the input resistance and the current amplification the values obtaining with short-circuited output (see pp. 23-25 and figs. 11 and 12 of the article quoted in \(^1\)). This input resistance decreases sharply with increasing \( I_b \) \(^7\). If \( I_b \) rises with rising temperature, a larger portion of the output current of any stage will therefore flow into the base of the following transistor, and the output current of that transistor will increase in the same proportion. The total gain of the four stages would consequently drift by 7 to 8 dB per 10 °C, if it were not for the feedback actually applied, which reduces the temperature variations of \( I_c \) by a factor which in the present case is 2.5. If we wish to ascertain to what extent this will reduce the influence of temperature on the amplification, we must bear in mind that the stages in fig. 3 are rather more intricate than those in fig. 5, not only for direct current, but also for alternating current. In fig. 3c it can be seen that the transistors actually form fourpoles only when considered together with the resistors \( R_b \). This makes the situation somewhat

\[^{1}\) See, for example, J. P. Beijersbergen, M. Beun and J. te Winkel, The junction transistor as a network element at low frequencies, II. Equivalent circuits and dependence of \( h \) parameters on operating point, Philips tech. Rev. 19, 98-105, 1957/58 (No. 3), particularly page 104, in which the input resistance with output short-circuited is denoted \( h_{\text{in}} \).

\[^{2}\) The fact that the characteristics do show a certain slope, small as it may be for the scale values used here, makes itself perceptible only if \( R_c \) is much larger than the 2.2 kΩ used here. In that case a small change in \( I_c \) is associated with a large change in \( V_{ce} \), and formula (1) can then no longer be used.

\[^{3}\) An article on temperature effects in transistors is shortly to be published in this Review. Ed.
complicated. It will be enough here to report that the total gain of the hearing aid under discussion increases by only 2 to 3 dB per 10°C rise in temperature.

Although the signal negative feedback reduces amplification per stage, it makes the amplification less dependent upon the properties of the individual transistors. Since individual transistors of the same type show a considerable spread in their properties, such stabilization is very welcome: the transistors in the first three stages can now be replaced without any re-adjustments being necessary.

Another adverse influence on the amplification is the fact that the coupling resistors \( R_c \) constitute parasitic loads on the transistors. The advantages of simple circuitry without transformers, and with stabilization against temperature variations, entail quite a considerable sacrifice of gain in the preamplifier. The theoretical maximum power gain of an OC 70 transistor — i.e. the power gain with ideal matching at the input and the output — is about 36 dB at the operating point considered. In the actual circuit, however, the first two amplifier stages produce only 19 dB each and the third 20 dB. The final stage produces 22 dB, making an overall (electrical) gain of about 80 dB.

**The output stage**

The small electromagnetic earphone is connected directly in the collector circuit of the output transistor OC 71. The variable resistor \( R_1 \) (fig. 3a and b), used for limiting the power output, is normally set at zero. It is moreover bypassed by a capacitor \( C_3 \), so that no signal feedback occurs and the output transistor forms, in itself, a fourpole (fig. 3c). The output characteristics of this transistor (with the input current \( I_b \) as the running parameter) are shown in fig. 6.

**Biasing**. The earphone has a D.C. resistance of 75 Ω. If \( R_b = 0 \), the operating point then lies on the line \( AB \) (fig. 6) of slope corresponding to 75 Ω, running through the point \( B \) which represents the battery voltage. By varying the base direct current with \( R_1 \) (fig. 3a and b), the operating point can be shifted along \( AB \). The position of the operating point is chosen with a view to conserving the battery, that is to say it is chosen as low as is compatible with the power required to be available at the earphone. This power, as already stated, is 1 mW for normal purposes. This is the power we wish to have available when using a battery consisting of one cell, that is, at a battery voltage of about 1.2 V (to which the voltage drops when the battery is run down). The family of characteristics is limited on the left (the curves drop sharply) and underneath (since the collector current cannot change sign). Imagining, for the sake of simplicity, the earphone impedance to be replaced by a pure resistance, and assuming that \( P \) is the operating point, we can draw through \( P \) a load line \( CD \). The area of the triangle PDF, which is the smallest of the two hatched triangles PDF and PCE, is then a measure of the available useful power, i.e. the power that the transistor can deliver without serious distortion. If the operating point is moved up along \( AB \) by raising the base current, the areas of the two triangles will then approach each other; they become equal when \( CD \) has moved to \( C'D' \). If the slope of \( CD \), i.e. the value of the load, is chosen such that the available useful power is exactly 1 mW in the situation corresponding to \( C'D' \), we have then found the most economical operating point at the given voltage. In our case the required load is found to be about 300 Ω. The slope of \( CD \) in fig. 6 has been chosen in accordance with this value.

The situation in reality is complicated by the fact that the earphone constitutes a strongly inductive load. For a sinusoidal output signal of a single frequency, the output characteristic is represented by an ellipse drawn around the operating point, instead of a straight line. The diagonal, from top left to bottom right, of the coordinate rectangle tangential to this ellipse, has a slope that corresponds to the impedance of the load. If this diagonal does not extend to regions where distortion may be expected, then neither will the ellipse extend to such regions. The value of 300 Ω mentioned above is therefore the value which the impedance of the earphone (and not the purely resistive portion of this impedance) must have in order that the biasing be such as to give the most economic operating point. Of the available power only that part given

![Fig. 6. Output characteristics of the output transistor OC 71.](image)
by the area of triangle $P'E'G$ is dissipated in the earphone.

Since the impedance of the earphone depends on the frequency, it can only be exactly 300 $\Omega$ for one frequency. Earphones are used which have this impedance at a frequency of 1000 c/s.

A second complication is that no definitive conclusion can be drawn from fig. 6 regarding the distortion to be expected. It is not at all evident, for instance, that serious distortion occurs if the transistor is driven to very small values of $I_c$. This distortion is due to the fact, already mentioned, that the input resistance of the transistor increases sharply at small values of $I_c$. Nevertheless, the method indicated above of determining the most economical operating point and the most favourable load impedance from fig. 6 does lead to results of practical value.

Since the current amplification factor of the OC 71 transistor may vary between 30 and 75 with individual transistors of the same type, the base current at which the most favourable operating point is obtained depends upon the transistor employed. It must therefore be possible to adjust the base current during assembly and subsequently if replacement of the output transistor should be necessary; this is the reason for making the resistor $R_2$ variable.

**Limiting.** The operating point discussed above automatically provides that, with increasing input signal, the power increases only very little from the moment that serious distortion sets in. This is due to the fact that the limiting of the output signal and the serious distortion associated with it both occur equally on both sides of the operating point (symmetrical limiting). In this way the output power is prevented from exceeding a certain upper limit, thereby providing an effective safeguard against "acoustical trauma".

The level at which the limiting becomes operative can be regulated with resistor $R_2$ (fig. 3b). The higher this resistance, the lower the collector voltage. This voltage is also across the base resistor $R_3$ (the slight potential difference between base and emitter is negligible) and thus the base current falls proportionately when $R_2$ is increased. In its turn, the collector current $I_c$ decreases proportionately with the base current, at least as long as $I_c \gg I_{bc}$ (see (1)). The operating point is thus shifted along the line $OP'$ (fig. 6) towards the origin; the symmetrical cut-off is thereby maintained.

Since the amplification of the output stage is not stabilized by negative feedback, the considerable spread in the current amplification factor of individual output transistors would normally appear in full in the total gain. To prevent this happening, a variable resistor $R_3$ is introduced between the first and second stages (fig. 3a and c) with which the total gain can be adjusted during assembly or after the replacement of the output transistor. This also compensates for the residual spread in the characteristics of the earlier stages, still remaining in spite of negative feedback.

As regards direct current, too, there is no feedback in the output transistor when $R_4$ is set at zero, and therefore no stabilization of the operating point against temperature variations. This is not necessary, however, since the collector bias current $I_0$ of the output transistor is adjusted to a much higher value than that of the transistors in the first three stages. The contribution of $I_{bc}$ to $I_0$ is therefore relatively much smaller (see (1)).

If the battery voltage is doubled or trebled by using a battery-consisting of two or three cells, the operating point moves along $OP'$ away from the origin. The maximum amplitudes of current and voltage arc also doubled or trebled and the available useful power is increased by a factor of 4 or 9, as the case may be. Thus, with a battery of three cells the available power is brought up to the 10 mW that is necessary for some cases of severe deafness and when bone conduction is employed. Raising the battery voltage causes an increase not only in the biasing current of the output transistor but also in that of the transistors in the first three stages. Since higher operating currents entail lower input resistance, the loss in the resistors $R_c$ (fig. 3c) is lower. This causes the total gain acoustic to increase from 55 dB for one battery cell to 63 dB and 67 dB for two and three cells respectively.

With all three battery voltages the resistor $R_4$ allows the ear specialist to lower the maximum output power (the ceiling) continuously by an amount from 0 to 20 dB. It can be seen in fig. 3b that the limiting of the output is associated with a reduction in battery current, as one would wish.

**Microphone, earphone and response curves**

The input resistance of the first amplifier stage is relatively low, being somewhere between 1000 $\Omega$ and 1800 $\Omega$, and thus readily permits the direct connection of a moving-iron microphone. Crystal microphones, as normally used in valve hearing aids, call for load impedances of the order of 0.1 to 0.5 $M\Omega$. This would necessitate the use of a matching transformer, and even then less power would be delivered, with more noise. The moving-iron microphone used in the KL 5500 hearing aid has an internal resistance of 1000 $\Omega$ and is particularly suitable for...
use with transistor hearing aids. Its smooth frequency characteristic facilitates the attainment of the desired overall response curve. The microphone functions as follows^8). The vibrations of an aluminium diaphragm are transferred to an armature composed of a material of high permeability. This armature constitutes the "galvanometer" diagonal of a magnetic "Wheatstone bridge". The resistance arms are formed by air-gaps in the magnetic system, and the requisite magnetic flux is supplied by a small permanent magnet forming the other diagonal of the bridge. The magnetic flux through the armature is dependent in direction and magnitude upon its deviation from its equilibrium position. A coil fitted around the armature converts the flux variations into an alternating voltage. The system is extremely sensitive: at 1 kcs the sensitivity is about 0.3 mV/µbar when the microphone is terminated by 1000 Ω.

By means of suitably dimensioned resonant air cavities the frequency characteristic can be made fairly flat between 400 and 3000 c/s, which is the important range for speech (fig. 7). The consequence of these measures is that the characteristic falls more sharply outside this range, which has the advantage, of very efficiently suppressing intermodulation phenomena, which may occur in the presence of "boom", in motor vehicles, for example.

The microphone casing is surrounded by two rings of a metal with a high initial permeability, the purpose of which is to shield the microphone against stray magnetic fields (attenuation by about 16 dB) and to help create a quiet background.

As regards the earphone, the patient has a choice of three types. The type Ph 1 earphone has an almost flat frequency characteristic (fig. 8). Unavoidable resonances have been attenuated as much as possible by the introduction of damping. Fig. 8 also shows the characteristics of the two other earphones, types Ph 0 and Ph 2. In these types the resonances are attenuated to a lesser extent.

With the sum of the frequency characteristics of microphone, amplifier and earphone, an overall response curve (fidelity characteristic) is obtained as shown in fig. 9, using an earphone of the type Ph 1. By switching C₁ or C₂ (fig. 3), a portion of the low or

high frequency range, respectively, can be cut off, producing the three curves illustrated. These curves can also be changed by the choice of earphone, so that many combinations are possible.

Case noise

The extremely low battery costs make it possible to keep this hearing aid in continuous use. This being so, it is more important than ever that the user should be able to hear with the least possible effort. Various factors are involved here, an important one being, as we have seen, that the tone quality perceived by the deaf person should be as agreeable as possible, heard against a quiet background. The most troublesome kind of background interference heard by users of hearing aids is case noise. This is caused by friction between clothing and the case of the instrument, or by friction between a piece of clothing stretched over the case and an adjacent fabric rubbing over it. Modern hearing aids are so smoothly finished, and there is so little movement of clothing with respect to the case, that the first source of case noise may, for all practical purposes, be neglected. The movement between adjacent fabrics bearing on the case, however, is many times greater in amplitude and is always present. It has the nature of "white noise"; that is to say, all frequencies in the band passed by the hearing aid are represented in almost the same intensity. Sufferers from certain types of deafness may find this extremely troublesome, and it is therefore very important to suppress this kind of interference as effectively as possible.

The vibrations produced by case noise can reach the microphone in three ways.

a) The friction may set the case and the chassis of the instrument in vibration; the vibration is transmitted to the microphone via the microphone mounting. This transmission is almost entirely determined by the natural resonance of the system consisting of the microphone (mass) and its elastic mounting (stiffness). The natural frequency can easily be kept below 100 c/s, in which case the amplitude of vibrations within the speech range remains negligible.

b) The vibrations of the case can be transmitted to air cavities inside the hearing aid. These cavities often resonate and thereby pass certain frequency ranges with extra intensity. The vibrations may possibly reach the microphone via these cavities.

c) The vibrations of the clothing material reach the microphone diaphragm via the air in the normal way.

An apparatus has been developed by Philips for making comparative measurements of the sensitivity of different hearing aids to case noise. The results of such measurements make it possible to assess objectively the measures taken to suppress interference due to case noise.

The apparatus contains an endless cotton belt driven by a small motor. The hearing aid to be tested is pressed against the moving belt, either with or without an intermediate piece of clothing fabric stretched over the case. The case noises thus produced are reproducible, and in a certain sense "standardized". The earphone of the hearing aid is fixed in an "artificial ear", and the voltage produced in the microphone of this device is fed to a voltmeter via a band-pass filter (bandwidth one third). The case noise is subsequently stopped and a standardized "acoustic" noise substituted, i.e. a noise whose vibrations reach the instrument's microphone only by the normal acoustical means, that is via the air and not by the means mentioned under a) and b) above. This acoustic noise is produced by a loudspeaker set up nearby the hearing aid and fed by a noise generator. The volume of the acoustic noise is adjusted such that the deflection of the voltmeter is the same as when the case noise was operative. A measurement is then made of the sound pressure of the acoustic noise field at the position of the hearing aid; this is done with the aid of a microphone connected via the same filter to a voltmeter which is calibrated in decibels above a threshold value of $10^{-4}$ dyne/cm$^2$. In this way the sound pressure is ascertained of the acoustic noise which, within a frequency band of one third, produces just as much interference as the standardized case noise. By repeating the measurement with different band-pass filters of one third, the entire

![Fig. 10. Case-noise interference as a function of frequency. 1 with microphone opening partly covered, 2 with opening uncovered.](image-url)
audio frequency-range can be covered. The advantage of this method is that the results depend only upon the extent to which the case-noise vibrations reach the microphone of the hearing aid; and not upon the amplification or the response curve of the instrument.

The method can also be used to investigate the effect of the conditions under which the case noise is generated. As an example, fig. 10 shows the effect of partly covering the microphone opening by vibrating fabric. With a given amplitude of vibration, the variations in air pressure in the small cavity in front of the microphone diaphragm are larger the more completely the opening is covered. It is seen from fig. 10 that when the opening is partly covered the interference is greater at all frequencies than when the opening is uncovered; in the range of about 1000 to 3000 c/s the difference is as much as 10 dB. It is important, therefore, when wearing a hearing aid, to keep the microphone opening entirely free.

The results of case-noise measurements have led to the adoption of various measures in the mechanical construction of the type KL 5500 hearing aid — and in other types too — to suppress this interference. It has been found that apparently minor modifications often have a substantial effect.

Summary. The use of transistors in the KL 5500 hearing aid has made it possible to reduce battery costs drastically and at the same time to increase the available output power and amplification. As a result, the apparatus can serve a wide circle of deaf persons. After a discussion of the various requirements to be satisfied by a hearing aid, a description is given of the amplifier, in which four transistors are used. The effects of temperature variations and of the spread in the properties of individual transistors are largely eliminated by means of negative feedback. The highly sensitive moving-iron microphone is directly coupled to the input stage, without the intermediary of an input transformer. A transformer is also superfluous for the earphone, since with transistors the maximum available power is obtained with a load having an impedance of a few hundred ohms, which is the normal impedance for electromagnetic earphones. The variable limiter prevents the maximum output power from exceeding the threshold of pain. The article concludes with some details of investigations into the interference caused by case noise.