

## AUDITORY FILTERS IN SENSORINEURAL HEARING IMPAIRED SUBJECTS

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The study is devoted to determination of the shape of the auditory filters in subjects with sensorineural hearing loss. Apart from the classical sensorineural hearing loss, changes in the auditory filter shapes have been analysed in the subject diagnosed with dead regions. The dead region is an area on the basilar membrane over which the functioning of the inner hair cells and/or neurones innervating them has ceased. This type of hearing impairment means that the information on the sounds whose frequencies correspond to the dead region of the basilar membrane are to a very limited degree if at all, transmitted to higher levels of the auditory path. This transmission, if happens, is performed through the auditory filters at the centre frequency other than that of the signal. This phenomenon and the fact that in the dead region the hearing loss is theoretically infinite, affect the transmittance of the auditory filters. Results of the study reported here have shown that in general, the subjects with sensorineural hearing loss develop broadening of the auditory filter accompanied by reducing of its dynamics. This fact explains a considerable decrease in speech intelligibility presented at a background of a noise. In the subject with the dead regions the broadening of the filters was the greatest in the region of the dead one. The results also indicate the lack of correlation between the shape and width of the auditory filter and the shape of the audiogram.

### 1. Introduction

The peripheral auditory system is often modelled by a system of hypothetical linear band-pass filters of overlapping bands (GLASBERG, *et al.*, [4]). It is assumed that the activity of the basilar membrane of the cochlea with inner and outer hair cells can be approximated by the behaviour of a system of such filters, called the auditory filter bank. The concept of auditory filters enables interpretation of many psychophysical phenomena including e.g. the frequency selectivity, which determines the ability to hear out the sound components.

In general the frequency selectivity of the auditory system can be determined by two methods: either by measurement of the psychophysical tuning curves (PTC) (VOGTEN, [20]) or determining the transmittance of the auditory filter from the measured detection thresholds of the tones masked by band-stop noise. In the first approximation it can be assumed that the reversed PTC describe the shape of the auditory filter (GLASBERG, *et al.*, [4]). However, the psychophysical tuning curves are asymmetric, in particular for the frequencies distant from their minima. For moderate levels of masking noise the auditory filters are symmetrical (PATTERSON and NIMMO-SMITH, [17]). Moreover, it has not been unambiguously resolved that the PTC reflects the activity of only one

auditory filter or that when detecting a tone against noise the listener applies the off-frequency listening. Therefore, not the PTC but the auditory filters are more suitable for characterisation of the frequency selectivity of hearing (MOORE and GLASBERG, [10]; MOORE and GLASBERG, [11]; MOORE, [6]).

The procedure of determination of the auditory filter transmittance proposed by PATTERSON ([15]; [16]) has been often used till now. It is based on the measurement of tone masking by the band-stop noise, so-called notched noise, with the tone always placed in the stopped band (i.e. in the notch). Assuming that the auditory filter is described by the function  $roex(p, r)$  (GLASBERG and MOORE, [2]) it is possible to determine the basic parameters of the filter, including its bandwidth.

In subjects with normal hearing it is usually assumed that the bandwidth determined at 3 dB below the maximum transmittance of the auditory filters is from 10 to 15% of their centre frequency. An alternative measure of the auditory filter width is the equivalent rectangular bandwidth (ERB)<sup>(1)</sup> which in subjects with normal hearing makes 11–17% of its centre frequency. For such subjects the auditory filter has a rounded top, steep skirts (slopes), dynamics not lower than 50 dB and is symmetric for low and intermediate levels of the tone (MOORE [7]).

The subjects with cochlear hearing loss often have problems with speech intelligibility especially when the speech is presented on a background of masking noise. The problems first of all originate from the elevated hearing threshold, which is related to a decrease in the power of the speech signal effectively used in the higher levels of the auditory path. However, according to recent data, the problems with speech intelligibility when it is presented on a background of masking noise originate not only from the above reason, but also at least to some degree, from the frequency selectivity significantly reduced due to the broadening of the auditory filters (MOORE, *et al.* [12]). Often the subjects develop three times larger ERB values and a significant decrease in the filters' dynamics. Moreover, they often have large asymmetry of the filters usually assigned to the different degree of hearing loss in different frequency bands. For instance, a subject can have normally inclined filter slope from the high frequency side, while significantly changed slope on the low frequency side.

It is expected that some information helpful to explain the above problems can be obtained by determination of the auditory filter shapes in the so-called dead regions of the basilar membrane of cochlea or at the border of such dead regions. The dead region or area is the hearing loss caused by complete loss of the inner hair cells over some regions of the basilar membrane and/ or the loss of afferent neurones innervating these regions (MOORE, [8]). This impairment means that the auditory stimulus may produce mechanical vibrations of the dead regions of the basilar membrane but these vibrations are not transformed into action potentials and the information on the sounds of these specific frequencies is not available in the higher levels of the auditory path or is available in the limited form in the channels transmitting sounds of other frequencies (see below).

It is reasonable to suppose that the auditory filters for frequencies bordering on the dead regions will be characterised by much greater asymmetry and lower dynamics that

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<sup>(1)</sup> Equivalent rectangular bandwidth of a filter is the bandwidth of a rectangular filter which has the same peak transmission as that filter and which passes the same total power for a white noise input.

the filters in the subjects with typical cochlear hearing loss. This asymmetry and the reduced dynamics of the filter can be explained by the fact that the dead region theoretically means infinite hearing loss in this region and the sound frequencies corresponding to those of the dead regions are detected as a result of the activity of the basilar membrane bordering on the dead regions.

The aim of the study reported here was to determine the shape of the auditory filters in subjects with typical sensorineural hearing losses and those with the dead regions, and compare them with the corresponding shapes obtained for subjects with normal hearing.

## 2. Dead regions in the cochlea

Sensorineural hearing loss is often associated with damage to inner or outer hair cells (MOORE, *et al.* [13]; MOORE and ALCÁNTARA, [9]). The mechanism of response of these two types of cells to sound is similar, although the functions they have in the auditory systems are different. A damage to the outer hair cells leads to impairment of the active process in the cochlea. In normal conditions, for the stimulating signals of very low intensity levels, the active physiological process enhances the response of the basilar membrane. When it malfunctions or does not function at all, the response to sounds of very low intensity is lower than in normal conditions (RUGGERO, [19]; YATES, [21]). Thus, when the outer hair cells are damaged the input sound level must be much higher to generate such vibrations of the basilar membrane that could produce hearing sensation.

A damage to the inner hair cells reduces the neural activity of the cochlea. If the inner hair cells do not function over a certain area of the basilar membrane, the afferent fibres connected to these cells do not transmit any information to higher levels of the auditory path. However, it does not mean that no information of such a signal reaches the higher levels of the auditory path. If the hair cells are damaged over a narrow region, then even if the maximum of the signals lies in the range corresponding to the damaged cells, the vibrations on the border of the damaged area can be large enough to cause effective stimulation of the hair cells in the neighbouring areas<sup>(2)</sup>. Thus the signal can be perceived by the auditory filter of the centre frequency other than the signal frequency but close to it. The area over which the inner hair cells or afferent fibres are damaged are called the dead regions and are classified as sensorineural hearing loss.

The dead region can be characterised by the characteristic frequencies of the inner hair cells or neurones directly adjacent to the dead region (Huss, *et al.*, [5]). It should be emphasised that it is usually assumed that in the dead region the mechanical properties of basilar membrane are preserved (e.g. tonotopic organization) and only the process of the transformation of vibrations into action potentials is degraded. It means that the neurones innervating the dead region do not discharge, although the basilar membrane vibrates in response to the sound. The vibrations of the basilar membrane in the dead

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<sup>(2)</sup> Similarly it can be shown that when the dead region is wide, the tone detection is possible when its frequency is close to the dead region border.

region are determined by the physical parameters of the shell it constitutes such as volume density, stiffness, mode of fixing, shape and size.

Correct diagnosis of dead regions on the basis of the audiogram is practically impossible. Although theoretically the hearing loss over the dead region is infinite, the hearing threshold may be measurable due to off-frequency listening phenomenon (MOORE, [7]). Therefore, there is a possibility to detect the basilar membrane vibrations in the dead region through the neurones innervating the areas neighbouring to the dead regions.

The maximum amplification of the active process in the cochlea, determined by the outer hair cells, is 50 dB for low frequencies and 65 dB for high frequencies (YATES, [21]). Thus, the hearing loss caused by dysfunction of the outer hair cells should not be greater than 50 dB for low and 65 dB for high frequencies. In view of the above, the cochlear hearing loss greater than given above must be at least partly due to a damage to the inner hair cells or afferent fibres. The frequency limits of the dead region are determined by the psychophysical tuning curves or the TEN test (MOORE, HUSS *et al.* [5]).

The TEN method is based upon measurements of the detection thresholds of a sinusoidal tone masked by specially prepared noise. The noise was designed to produce equal masked thresholds (in dB SPL) over a wide frequency range (125–15000 Hz), for normally hearing subjects and for subjects with hearing impairment but without dead regions. This noise is called “threshold-equalising noise” (TEN).

To determine the spectral characteristics of the TEN it was assumed that the power of the signal at threshold,  $P_S$ , is constant on the detection threshold and given by the equation:

$$P_S = N_0 \cdot K \cdot \text{ERB}, \quad (1)$$

where  $N_0$  is the noise power spectral density,  $K$  is the signal-to-noise ratio at the output of the auditory filter required for threshold and ERB is the equivalent rectangular bandwidth of the auditory filter. The noise level is specified in terms of the level in a one-ERB wide band around 1000 Hz (i.e. the level in the frequency range from 935 to 1065 Hz). A rationale for the TEN test is a well known fact from masking audiograms for normally hearing subjects and for hearing impaired subjects without dead regions, that the detection threshold of a tone masked by a band of noise at a given level is lower by some decibels than the level of the masking noise. The TEN is prepared in such a way that it produces equal or no more than 10 dB higher masked thresholds than the nominal masker level in one-ERB for normally hearing subjects or for hearing impaired ones without dead regions in a wide frequency range (125–15000 Hz). For a tone falling into the dead region, its detection threshold in the presence of the TEN masker is much higher (more than 10 dB) than the TEN level in one-ERB. The tone level must be high enough to evoke an excitation perceived in the presence of TEN on the threshold level in neurones immediately adjacent to the dead region.

### 3. Measurements and shape estimation of the auditory filters

The majority of psychophysical methods of determination of the auditory filters assume that when a given tone (signal) is masked by broadband noise the listener detects

signal using the filter in which the signal to noise ratio is the greatest and the detection is performed when this ratio is higher than certain threshold value (MOORE, [7]).

One of the most effective methods for determination of the auditory filter characteristics, applied in our study, is the notched noise method (PATTERSON, [15, 16]). It is based on determination of the threshold of tone masked by a masking signal composed of two bands of noise i.e. the notched noise. For a given tone frequency (equal to the centre frequency of the filter under determination) the detection threshold of the tone is measured for different widths of the notch in the noise  $\Delta f$ , for the tone placed symmetrically or asymmetrically with respect to the notch. In this method it is assumed that the auditory filter is described by the function  $roex(pr)$  of the form:

$$roex(p, r) = (1 - r)(1 + pg) \exp(-pg) + r, \quad (2)$$

where  $p$  is the slope of the filter,  $g$  – relative deviation of frequency, and  $r$  describes the filter dynamics. The broadening of the notch means that the auditory filter used for the detection of a given signal passes less noise masking this tone. If we assume that the threshold corresponds to a constant signal  $P_s$  to noise  $P_{sz}$  power ratio at the output of the filter:

$$\frac{P_s}{P_{sz}} = C, \quad (3)$$

where  $C$  is a constant depending on the frequency and the listener, then the detection threshold as a function of the width of the notch will be expressed through the change in the power of the noise assigned to the analysed filter depending on  $\Delta f$ . Thus, if the power spectral density  $N_0$  is constant at the filter input, the power of the noise at the output can be found from the relationship:

$$P_{sz}(\Delta f) = 2 \int_{\Delta f}^{\infty} W(f) N_0 df. \quad (4)$$

Making use of (4) one can get

$$P_s(\Delta f) = 2C \int_{\Delta f}^{\infty} W(f) N_0 df, \quad (5)$$

where  $W(f)$  is the characteristics of the auditory filter according to the Eq. (2).

By differentiating the signal detection threshold  $P_s(\Delta f)$  as a function of the half width of the notch:

$$\frac{\partial P_s(\Delta f)}{\partial(\Delta f)} = \frac{\partial P_s}{\partial(\Delta f)} \left[ 2C \int_{\Delta f}^{\infty} W(f) N_0 df \right] = C_1 W(\Delta f) \quad (6)$$

we obtain the relative response of the filter for a given value of  $\Delta f$ . In other words, the relative response of the filter  $W(f)$  is equal to the slope of the tangent to the function of the signal detection threshold versus the half width of the notch  $\Delta f$ . Determination of

the basic parameters describing the course of the auditory filter transmittance, i.e. the values of  $p$  (for the range above and below the centre frequency of the filter separately) and the filter dynamics  $r$ , is usually performed by an iteration procedure and the least square method, looking for such values of the parameters which would satisfy Eq. (6) with the lowest deviation.

The equivalent rectangular bandwidth of the auditory filter is usually equal from 11 to 17% of the centre frequency. The equation describing the equivalent rectangular bandwidth as a function of the centre frequency  $F$  (in kHz) is as follows (GLASBERG and MOORE, [2]):

$$\text{ERB} = 24.7(4.37F + 1). \quad (7)$$

#### 4. Stimuli, apparatus and the method of study

The transmittance of the auditory filters was determined by means of the Patterson method, described in Sec. 3. The detection thresholds were determined for the tones of frequencies 1000, 2000 and 4000 Hz masked with the notched noise with different width of the notch. The band stop of the masking noise was symmetric with respect to the masked tone. Its width expressed as the ratio of the limiting frequencies and the tone frequency was 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5. The relative width of the masking noise bands (also referred to the tone frequency) was 0.4. The power spectral density of the masking noise was 41 dB/Hz for the centre frequency of 1 kHz for all listeners. For the centre frequencies of 2 kHz and 4 kHz, the power spectral density of the noise was 38 dB/Hz and 35 dB/Hz, for all subjects, except the subject TD, for whom the power spectral densities of the noise were 48 dB/Hz and 45 dB/Hz.

The method applied was two-alternative forced choice method (2AFC) in which the detection thresholds of the signal were established on the basis of 71% correct responses. The listeners were presented with the two observation intervals, each of them contained the notched noise and only one of them, chosen randomly, contained the masked tone. The tone level was changed according to the adaptive procedure, that is it was increased after each incorrect response and decreased after two subsequent correct responses. The subjects were asked to identify the observation interval containing the tone. For each run, 12 reversal points were determined and the detection threshold was calculated as the arithmetic mean of the eight last reversals. The threshold values discussed in the following are the arithmetic means of at least three independent measurements. The signals were presented at random. Duration of each signal in pair was 500 ms, the interval between signals in pair was 200 ms. The pairs of signals were presented monaurally via Sennheiser 580 headphones in an acoustically isolated booth. The signals were generated by the Tucker-Davis Technology system II.

#### 5. The subjects

The subjects were five persons with different types of sensorineural hearing losses, from 24 to 65 years of age. The audiograms of the subjects are presented in Fig. 1.

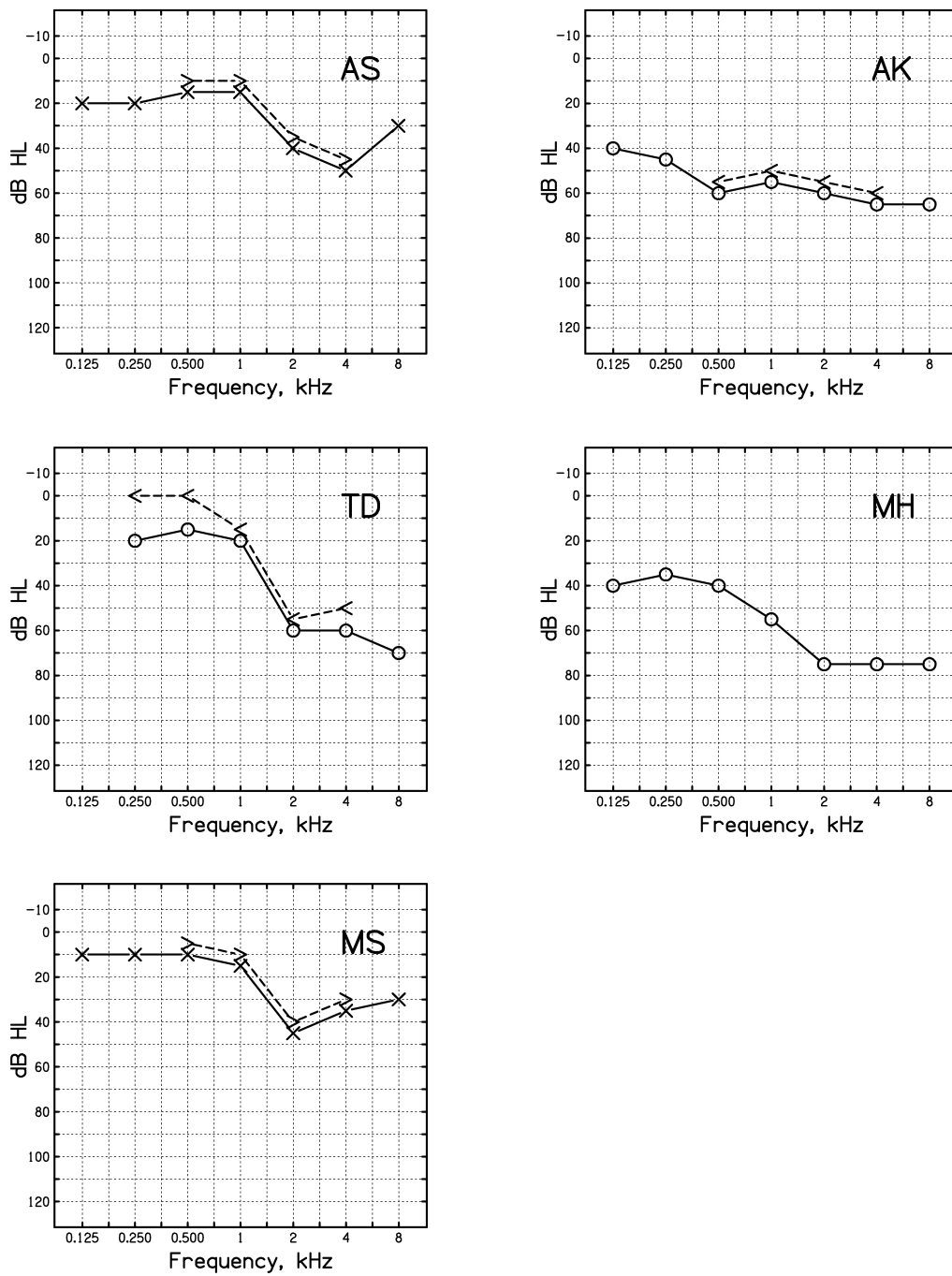


Fig. 1. The audiograms of the subjects (AS, AK, TD, MH, MS) taking part in the experiment.

The subject AS was diagnosed with a hearing loss in the left ear for frequencies higher than 1 kHz. The lack of the cochlear reserve and the SISI test results confirmed the sensorineural nature of the hearing loss. The subject also experienced tinnitus at the level of 25 dB for the frequency of 1 kHz.

The subject AK was diagnosed with a hearing loss in the right ear at the level of 60 dB HL in the frequency range 500-4000 Hz. The lack of the cochlear reserve and the SISI test results indicate the sensorineural nature of the hearing loss. The same subject was found to have tinnitus of tonal character, at the frequency of 8 kHz and the level of 70 dB.

The subject TD was found to have sensorineural hearing loss for frequencies above 1 kHz.

The audiometric test results of the subject MH indicate the sensorineural hearing loss of the descending character. The occurrence of dead regions was established on the basis of the standard TEN test (MOORE, *et al.* [13]) and PTC measurements. The subject MH was diagnosed to have a dead region in the right ear, with the lower frequency limit of about 4000 Hz. In the other subjects no dead regions were revealed.

The subject MS was diagnosed with sensorineural hearing loss in the left ear, with the minimum at the frequency of 2 kHz, which is the so called acoustic trauma.

## 6. Experimental results and their analysis

Figures 2–6 present the results of the study for the five subjects. The upper parts of the figures present the detection thresholds of tones of the frequencies 1, 2 and 4 kHz, as a function of the half width of the notch  $\Delta f$ . The lower parts of the figures present the courses of transmittance of the auditory filters determined on the basis of the data corresponding to the masked detection thresholds. The auditory filters determined for the subjects that took part in the experiment are displayed as solid lines. The dashed line corresponds to the courses of the auditory filters transmittance of subjects with normal hearing (GLASBERG and MOORE [3]). Table I presents the values of the parameters of the auditory filters determined for each subject and the centre frequencies of the filters. The auditory filters for subjects with normal hearing have been well established and their equivalent width varies from 11 to 17% of the centre frequency (GLASBERG and MOORE, [1]; GLASBERG and MOORE, [2]; MOORE, *et al.*, [14]; PETERS and MOORE, [18]). In this study we assumed that the equivalent rectangular bandwidth of subjects with normal hearing amounts to 16% of the centre frequency of the filter.

In Fig. 2 the experimental data and the auditory filters determined for the subject AS are shown. The audiogram of this subject shows no hearing loss for the frequency of 1 kHz and the parameters and shape of the auditory filter for the centre frequency of 1 kHz can be treated as normal. The detection threshold on a background of the notched noise as a function of the relative frequency deviation has the dynamics of 40 dB, which is also considered as normal (GLASBERG and MOORE [1]). For the frequencies of 2 and 4 kHz the course of the detection threshold of the tone masked by the notched noise is much flatter than for the frequency of 1 kHz. The auditory filters determined for the



frequencies of 2 and 4 kHz have low dynamics and are much broader than those recorded for subjects with normal hearing. Due to very low dynamics of the filter for the frequency of 4 kHz, determination of the accurate values of parameters describing the slopes of the filter on the low and high frequency side was impossible. The value of  $ERB/f_0$  for the filter of the centre frequency of 4 kHz is approximate. It is worth noting that the shapes of the filters determined for the subject AS are symmetric.

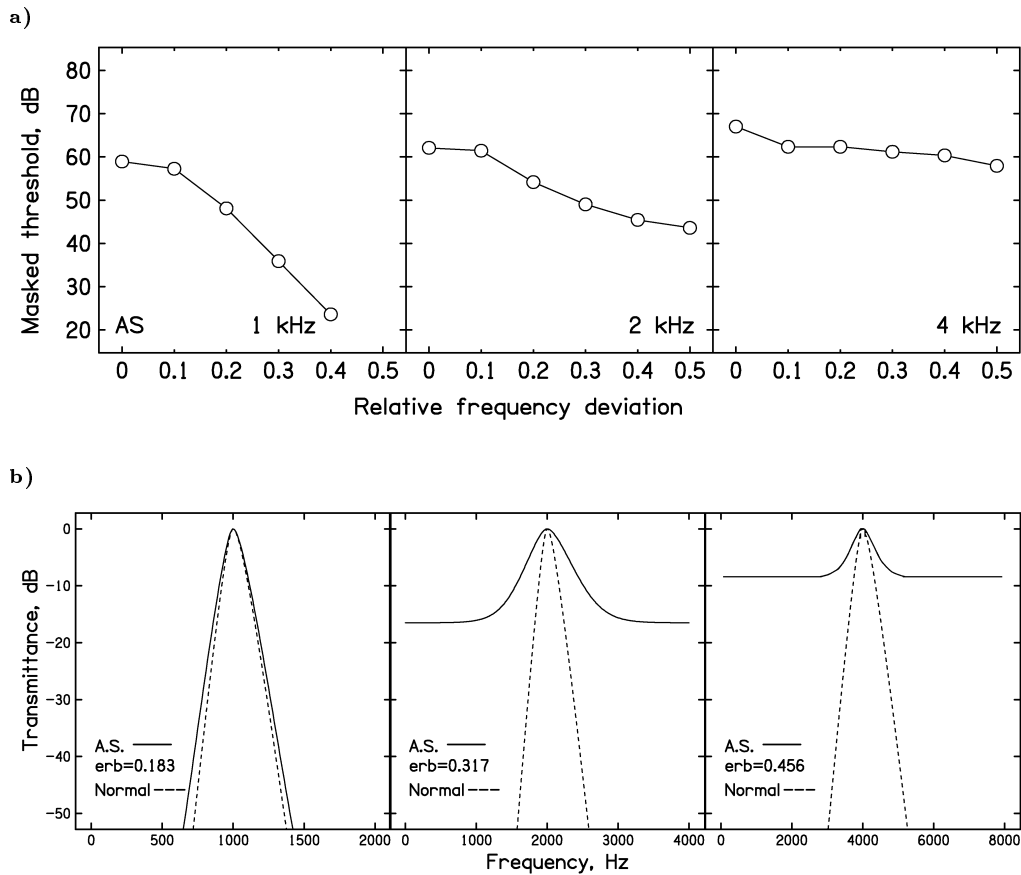


Fig. 2. The results for the subject AS: a – the masking threshold versus the relative frequency deviation, b – the auditory filters (solid line) and the auditory filters of a normal hearing subject (dashed line).

In Fig. 3 the detection thresholds and filters obtained for the subject AK are presented. All the filters determined for this subject are broader and their dynamics is much lower than that of the filters of subjects with normal hearing. The filter of the centre frequency of 2 kHz is asymmetric and its high-frequency slope is much smaller than that in the normal hearing subjects. For the tone frequency of 4 kHz it was impossible to determine the auditory filter parameters because of the low dynamics. On the basis of the data illustrating the transmittance of the auditory filter shown in the bottom part

of this figure, it is difficult to talk about the shape of the filter or about its presence for the tone frequency of 4000 Hz.

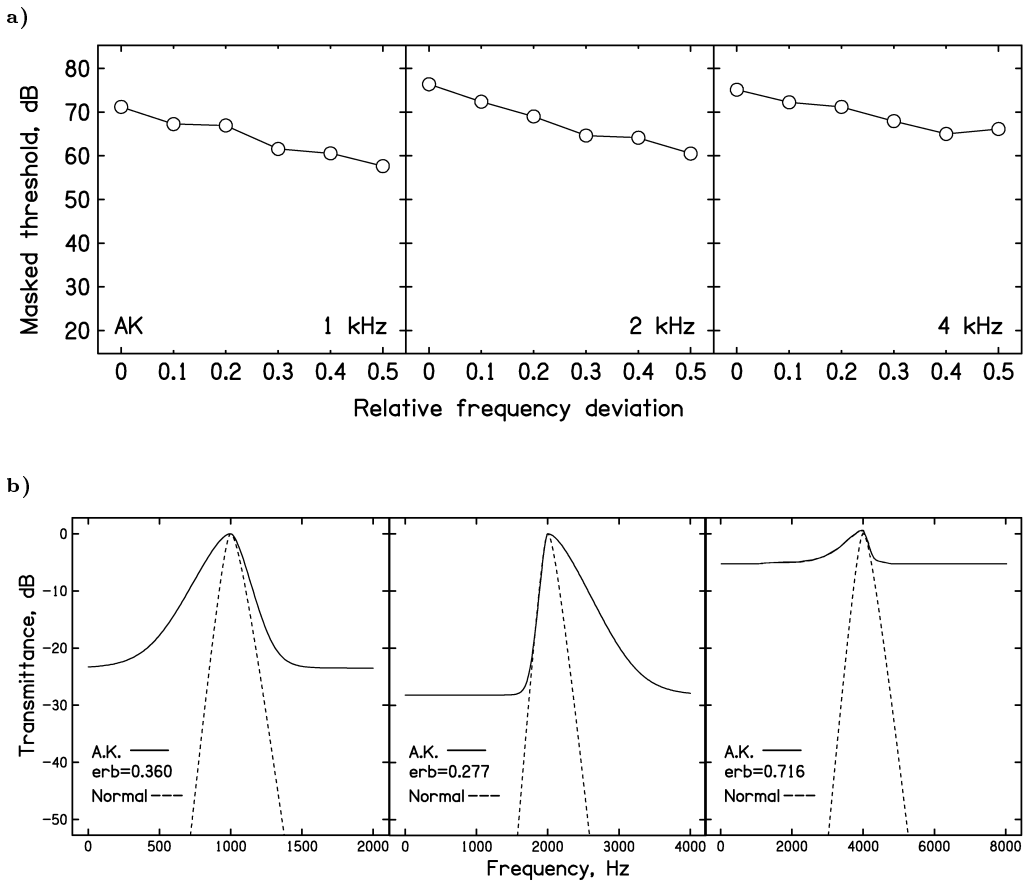


Fig. 3. The results for the subject AK: a – the masking threshold versus the relative frequency deviation, b – the auditory filters (solid line) and the auditory filters of a normal hearing subject (dashed line).

Figure 4 presents the detection threshold as a function of the relative frequency deviation and the shapes of the auditory filters obtained for the subject MS. The course of the former dependence indicates that the shape of the filter of the centre frequency of 1 kHz is slightly different from that in subjects with normal hearing, as illustrated in the bottom part of the figure. The filter shows slight asymmetry, its low-frequency slope is greater, while the high-frequency one is lower than the corresponding slopes of a subject with normal hearing. The dynamics of the filter is similar to that of the filter characteristic of subjects with normal hearing. The filter of the centre frequency of 2 kHz is also asymmetric, its high-frequency slope is much smaller and the dynamics much lower than those in the normal hearing subjects. The filter of the centre frequency of 4 kHz is broadened and symmetric, showing low dynamics.

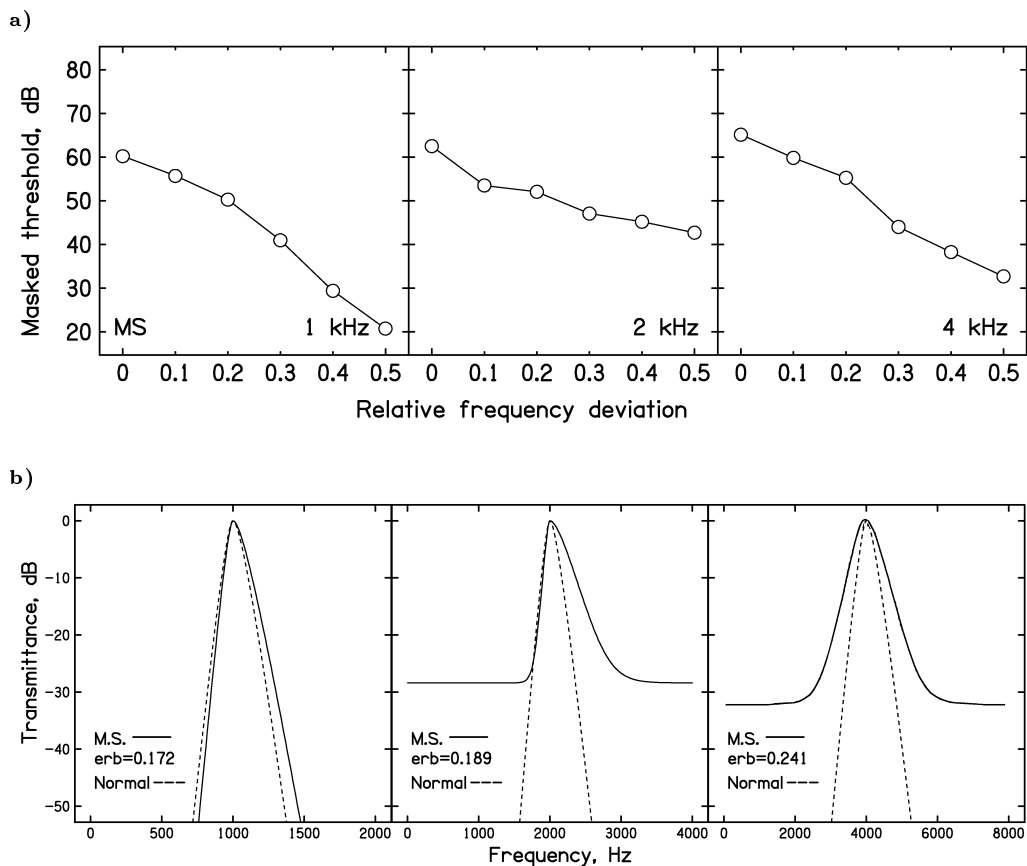


Fig. 4. The results for the subject MS: a – the masking threshold versus the relative frequency deviation, b – the auditory filters (solid line) and the auditory filters of a normal hearing subject (dashed line).

In Fig. 5 the experimental data collected for the subject MH are depicted. The filters at the centre frequencies of 1 and 2 kHz are much broader, asymmetric, with the low-frequency slopes much greater than the high-frequency ones and with low-dynamics. It was impossible to determine the filter for the centre frequency of 4 kHz, because the detection thresholds as a function of the notch width were nearly flat irrespective of the total noise level (70, 90 dB). The absolute threshold for this frequency was  $\approx 75$  dB HL, similarly as for the frequency of 2 kHz, at which there was practically no problem with determination of the auditory filter. The infinite bandwidth of the filter of the centre frequency of 4 kHz can be explained in terms of the concept of excitation pattern<sup>(3)</sup>. However, it should be regarded that this subject has been diagnosed as having a high-frequency dead region starting from about  $\sim 4.0$  kHz. The centre frequency of this filter fell onto the border of the dead region. It has been established that the filters, whose

<sup>(3)</sup> Excitation pattern is defined as the outputs from the auditory filters as a function of their characteristic frequencies.

centre frequencies are lower than the dead region bordering frequency, are wide, e.g. the filter with the centre frequency of 2 kHz, Fig. 5. Irrespective of the noise level, the hypothetical stimulation produced by a tone of the frequency of 4 kHz at the detection threshold should be more or less constant in whole notch available on the low-frequency side. The part of the notch covered the dead region frequency range did not influence the tone detection. Although the basilar membrane could vibrate as a result of the stimulation, the afferent neurones could not transmit any signal because the inner hair cells did not function. As the stimulation was very wide and the tone detection occurs for a constant signal to noise ratio, the threshold level of the tonal signal should also be more or less constant for all notch widths, which has been confirmed by our results.

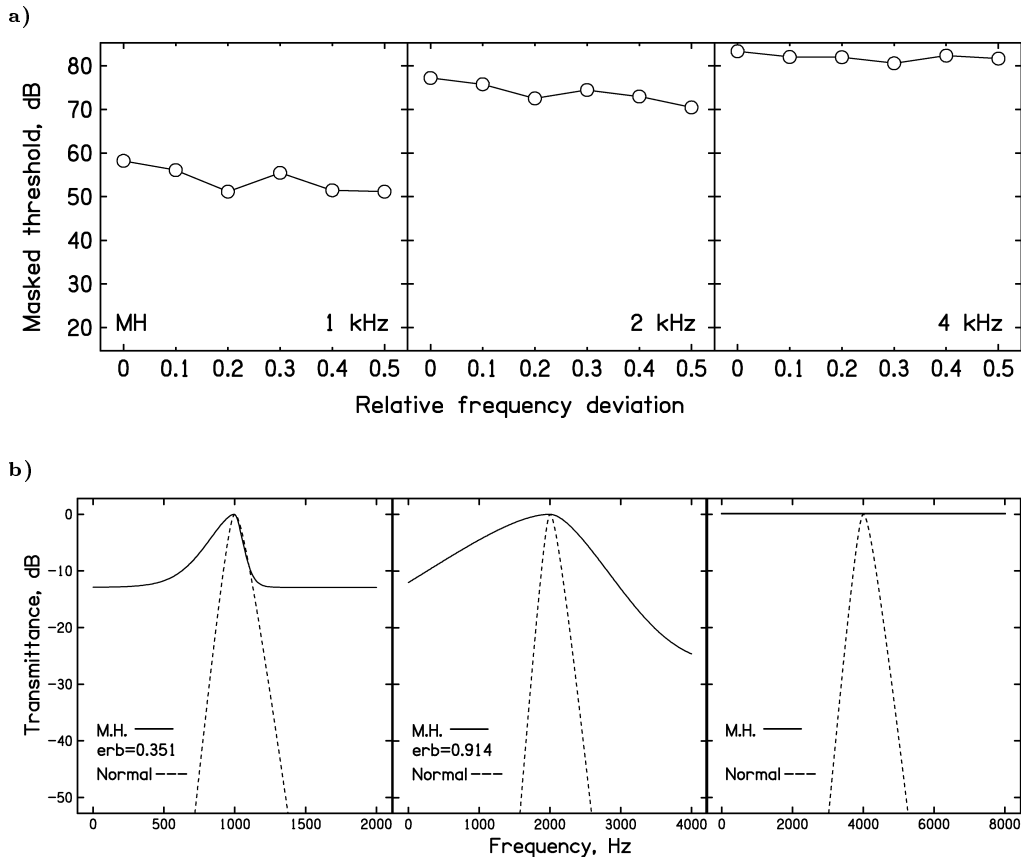


Fig. 5. The results for the subject MH: a – the masking threshold versus the relative frequency deviation, b – the auditory filters (solid line) and the auditory filters of a normal hearing subject (dashed line).

Figure 6 presents the results obtained for the subject TD. The shape of the filter of the centre frequency of 1 kHz is similar to those in normal hearing subjects. The other filters are much broader. The filter of the centre frequency of 2 kHz is asymmetric, with the high-frequency slope much smaller than that of the low-frequency side.

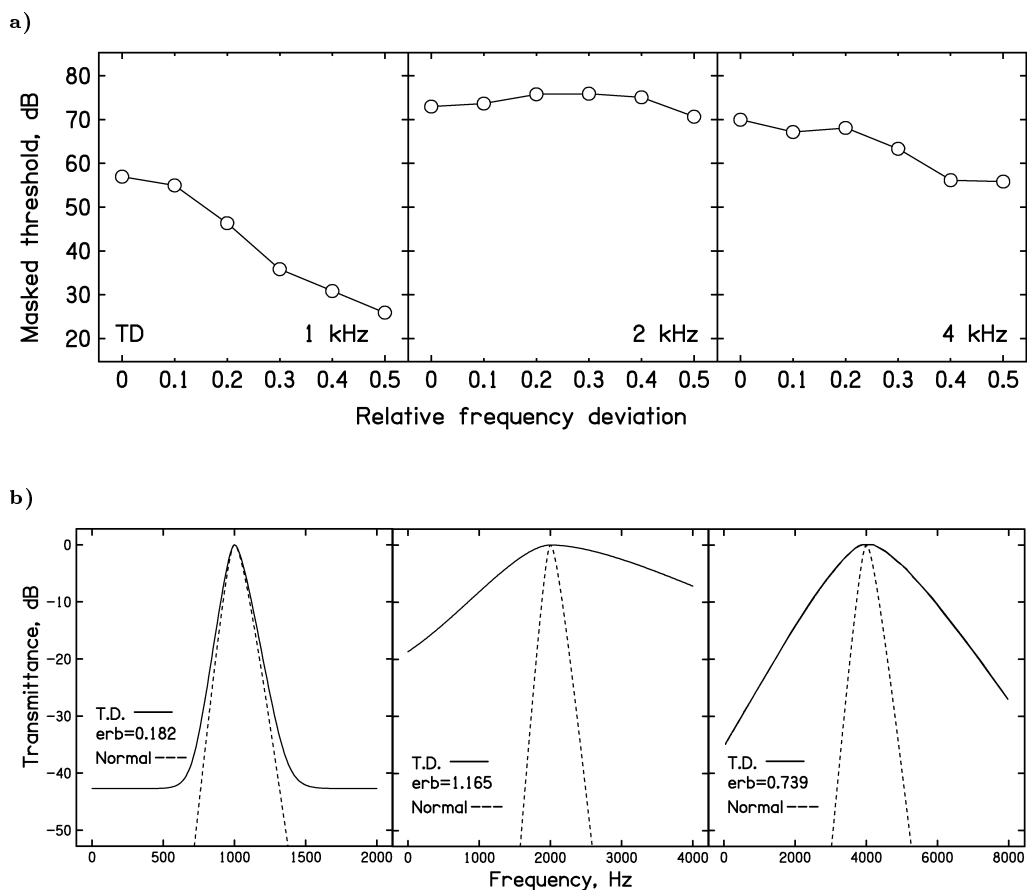


Fig. 6. The results for the subject TD: a – the masking threshold versus the relative frequency deviation, b – the auditory filters (solid line) and the auditory filters of a normal hearing subject (dashed line).

Analysis of Figs. 2-6 and Table 1 data shows that when the dynamic range of the masked thresholds is small (i.e. the absolute value of  $r$  is small), the values of  $p_u$  and  $p_l$  are not defined. Moreover, when a filter is significantly asymmetric, the fitting procedure does not give accurate results of the slope  $p_u$  on the high-frequency side. It is assumed that when the slope on one side is twice greater than on the other side, the higher slope value is inaccurate (GLASBERG and MOORE, [1]; GLASBERG and MOORE [2]). In Table 1 the inaccurate values of the parameters  $p_u$  and  $p_l$  are not given. The relative value of ERB given in Table 1 is referred to the centre frequency of a given filter. The ERB/ $f_0$  value determined experimentally for normal hearing subjects is 0.11 – 0.17. In Figs. 2-6 the value of ERB/ $f_0$  was assumed as 0.16.

It is well evident that in subjects with sensorineural hearing losses the auditory filters are much broader for the frequencies corresponding to those of the hearing losses. The shape of the filter is specific for a subject. In some subjects the filters remain symmetric despite the broadening, but in others they become asymmetric with the low or high-

**Table 1.** The auditory filter parameters determined by the notched noise method,  $p_l$  — low frequency slope,  $p_u$  — high frequency slope.

Subject	$f_0$ Hz	Ear	Absolute threshold dB HL	$p_l$	$p_u$	$r$ dB	ERB/ $f_0$
AS	1000	Left	20	24.1	20.1	-70.3	0.18
	2000		40	13.6	11.8	-16.5	0.32
	4000		50	-	-	-8.5	0.46
AK	1000	Right	55	8.8	16.5	-23.5	0.36
	2000		60	43.5	8.8	-28.8	0.28
	4000		65	-	-	-5.5	0.72
MS	1000	Left	20	34.8	17.5	-88.6	0.17
	2000		47	49.6	13.6	-28.4	0.19
	4000		40	18.5	15.2	-31.7	0.24
MH	1000	Right	55	-	-	-12.9	0.35
	2000		75	2.9	6.2	-27.0	0.91
	4000		75	-	-	0.0	$\infty$
TD	1000	Right	20	24.7	19.8	-42.7	0.18
	2000		60	< 3	< 3	-25.4	> 1.3
	4000		60	5.9	4.8	-53.2	0.74

frequency side of smaller slope. For the frequencies for which the absolute threshold does not exceed 30 dB HL, the auditory filters have parameters close to those of the filters in normal hearing subjects.

## 7. Conclusions

The obtained results of the study permit drawing the following conclusions:

- The auditory filters determined for subjects with sensorineural hearing loss for the frequencies for which no significant hearing losses were observed are symmetric, of high dynamics and parameters close to those of the corresponding filters in normal hearing subjects in the whole range of audible frequencies. For the frequencies for which significant hearing loss was noted, the auditory filters can be symmetric or asymmetric, have smaller slopes, lower dynamics and are a few times broader than the corresponding filters of normal hearing subjects.

- For the subject MH with a high-frequency dead region, whose border frequency was equal to the centre frequency of a given filter, the filter was infinitely broad.

- The broadening of the auditory filters, having a deteriorating effect on the frequency selectivity, can significantly impair the speech intelligibility, especially when the speech is presented in a masking noise. Amplification of the signal reaching the ear for a subject with broader filters cannot improve the speech intelligibility, because the signal to noise ratio remains the same. Improvement in the speech intelligibility can be achieved by conversion of the signal reaching the ear, e.g. by the frequency compression, enhancement of the spectral contrast or syllabic compression.

- The experimental results obtained do not suggest a relationship between the shape of the auditory filter and the course of the audiogram or the type of hearing loss. Thus, it seems unjustified and unreliable to infer about the auditory filter shape from the classical audiogram, when the audiogram indicates sensorineural hearing loss.

- The course of the masking curves as a function of the bandwidth of the notch brings approximate information on the bandwidth of the auditory filter. When the dynamics of the audiograms is low (lower than a few dB), a significant broadening of the filter can be expected.

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