[1] Basic principles
[2] The basic principle of the plateau method
[3] General expression for the plateau widths

[1] Basic principles

1.1 Transmission pathways

Air conduction (AC) signals are an AC test signal (**AT**) and AC noise (**N**). They reach a cochlea of the participant via its external and middle ear sound-conduction system, which is called an AC transmission pathway (hereafter, **AC pathway**) (**Fig. 1-1**). By contrast, bone vibrators vibrate the participant's skull to generate a bone conduction (BC) test signal (**BT**) that travels through the cranium and arrives at the cochlea directly. This is called a BC transmission pathway (hereafter, **BC pathway**). When a bone vibrator is placed at the mastoid of one ear, the pathway to that ear is termed **a direct BC pathway** and that to the opposite ear is termed **a cross BC pathway**.

Supra-aural earphones vibrate the participant's skull to generate a BC signal corresponding to the output level of the AC signal. The BC signal produced by the BC output of a supra-aural earphone is tentatively called a converted BC signal. The BC pathways of converted BC signals are termed converted BC pathways (the direct-converted and cross-converted BC pathway) in order to differentiate them from those of original BC signals.

Here, we stipulate the viewpoint that "the signals are heard by the inner ear or cochlea."

In response to the output level of a signal, the level of the signal that has reached the cochlea is called **a cochlear level** (dB HL).

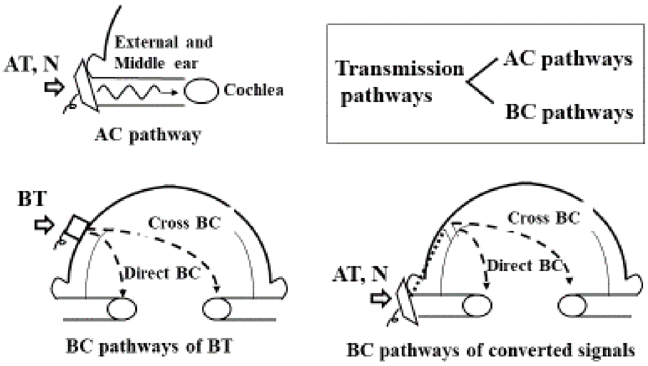

Figure 1-1 Transmission pathways

Signals reach each cochlea through five transmission pathways (**Fig. 1-2**).

1) The AC pathway (AT, N)
2) The direct-converted BC pathway (AT, N)
3) The direct BC pathway (BT)
4) The cross BC pathway (BT)
5) The cross-converted BC pathway (AT, N)

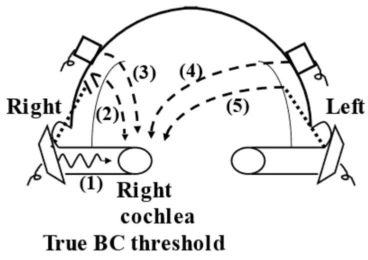

Figure 1-2 Five pathways

The AC signals reach the cochlea in one ear not only via the AC pathway but also via the direct-converted BC pathway in the form of converted BC signals. This direct-converted BC pathway creates the key used to open the black box of masking.

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1.2 The relative attenuation values in pure tone audiometry: IaA, IaB, CL

The relative amounts of sound pressure (SP) change in PTA (rY: IaA, IaB, and CL) all show relative attenuation values in transmission pathways in relation to standard pathways.

IaA: the interaural attenuation for AC signals is the relative amounts of SP change for AC signals in the cross-converted BC pathway in relation to the direct BC pathway.

IaB: the interaural attenuation for BC signals is the relative amounts of SP change for BC signals in the cross BC pathway in relation to the direct BC pathway.

CL: the amount of the air conduction loss is the relative amounts of SP change for AC signals in some AC pathway in relation to the normal AC pathway.

Since these relative attenuation values are equivalent, they can be managed in a unified form. Here, we hypothesize that the sound pressures of signals remain unchanged in the two standard pathways (**Fig. 1-3**):

The hypothetical amount of SP change in the normal AC pathway: hY0 = 0 dB,

The hypothetical amount of SP change in the direct BC pathway: hYd = 0 dB.

Under the virtual setting, it can be assumed that the signals are relatively attenuated by a certain amount (rY: IaA, IaB, or CL) in the transmission pathways before reaching a cochlea (**Fig. 1-4**). These relative attenuation values are customarily expressed as absolute values. The hypothetical cochlear levels of the test signals are as follows (**Fig. 1-5**):

Hypothetical cochlear level [AT] in the cross-converted BC pathway = AT − IaA, Hypothetical cochlear level [BT] in the cross BC pathway = BT − IaB, Hypothetical cochlear level [AT] in the AC pathway [n] = AT − CLn.

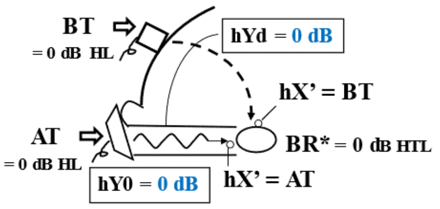


Figure 1-3 Assumptions

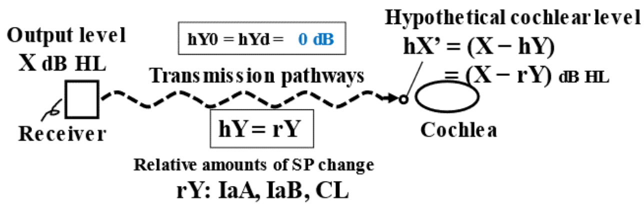


Figure 1-4 Hypothetical SP change (hY = rY)

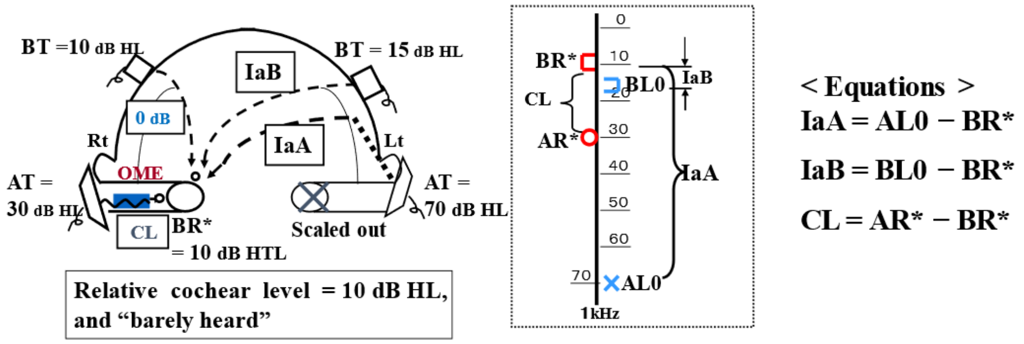


Figure 1-5 Relative attenuation values in pure tone audiometry

The three relative attenuation values (IaA, IaB, and CL) appear on an audiogram as the difference between measured thresholds. The AC and BC thresholds measured without masking in the left ear (AL0, BL0) are the shadow hearing thresholds.

BR*: True BC threshold in the right ear — AR*: True AC threshold in the right ear

BL0: Apparent BC threshold in the left ear — AL0: Apparent AC threshold in the left ear

It can be said that when the hypothetical cochlear level of the test signals in one ear is equal to the true BC threshold level of that ear, the signals are barely heard by the cochlea (**Fig. 1-5**).

Hypothetical cochlear level [the test signal] < the true BC threshold - - - 'not heard'

Hypothetical cochlear level [the test signal] = the true BC threshold - - - 'barely heard'

Hypothetical cochlear level [the test signal] > the true BC threshold - - - 'heard'

1.3 Masking Diagram

Although cross hearing (CH) and shadow hearing (SH) have been considered synonymous, they should be distinguished: CH is defined as hearing the signals (test signals or masking noises) presented to one ear by the opposite inner ear, regardless of whether they are heard by the ear to which they are presented or not. By contrast, SH is defined as hearing the test signals by the non-test inner ear, and not by the test inner ear.

To illustrate the concepts of CH, SH, and masking visually, a masking diagram is invented (**Fig. 1-6**). The vertical (frequency) axis on the audiogram at a given frequency is divided into the right and left axes. IaA and IaB are indicated by dashed lines between the axes. The AC and BC thresholds are indicated simply by 'A' and 'B', respectively. The subscripts 'R' and 'L' refer to right and left, respectively. The asterisk (*) denotes true thresholds, and zero (0) denotes thresholds measured without masking. For example, BL* is the true BC threshold in the left ear and AR0 is the AC threshold measured without masking in the right ear. Conventionally, an AC threshold measured without masking has been described as "an unmasked AC threshold." Here, however, the word "unmasked" is not used. Instead, we use the word "apparent" to describe an apparent AC threshold.

< Abbreviations >

AT: Air-conduction test signal (dB HL)
BT: Bone-conduction test signal (dB HL)

AR*: True AC threshold in the right ear
AL*: True AC threshold in the left ear
BR*: True BC threshold in the right ear
BL*: True BC threshold in the left ear

AR0: Apparent AC threshold in the right ear
AL0: Apparent AC threshold in the left ear
BR0: Apparent BC threshold in the right ear
BL0: Apparent BC threshold in the left ear
(The apparent threshold is the threshold measured without masking)

IaA: Interaural attenuation for AC signals
IaB: Interaural attenuation for BC signals

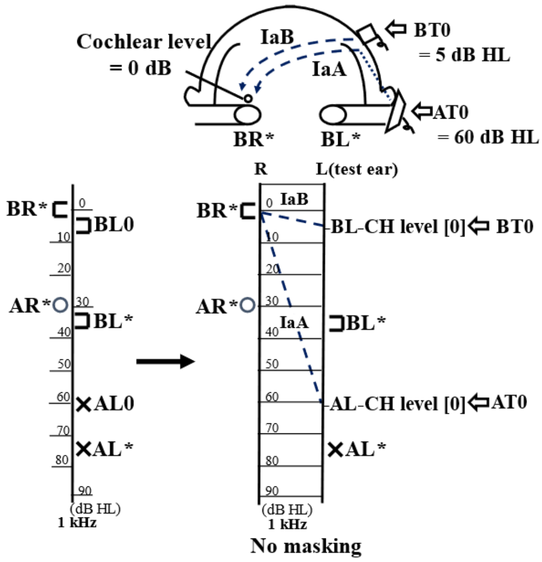


Figure 1-6 Masking Diagram

The minimum hearing level (dB HL) at which CH of the test signals occurs is referred to as a CH level. Without masking, the CH level for AC in the left ear (AL-CH level [0]) that corresponds to the true BC threshold in the right ear (BR* = 0 dB HTL) is given by

AL-CH level [0] = [BR*] + IaA

= 0 (dB HTL) + 60 (dB) = 60 dB HL.

When an AC test signal at a level that is equal to the AL-CH level [0] (AT0 = 60 dB HL) is presented to the left ear, the right cochlear level [AT0] becomes equal to the BR*. Therefore, the signal is barely heard by the right inner ear (BR*): the AC threshold of the left ear measured without masking (AL0 = 60 dB HTL) is an SH threshold. AT0 is the AC test signal that the participant barely hears without masking.

Similarly, the CH-level [0] for BC in the left ear (BL-CH level [0]) is given by

BL-CH level [0] = [BR*] + IaB

= 0 (dB HTL) + 5 (dB) = 5 dB HL.

When a BT0 of 5 dB HL is directed to the left ear, it is barely heard by the right inner ear.

cf. Masking theory **1.5**

Masking theory in pure tone audiometry – systematic lectures – (https://izumo-yaegaki.jp).

1.4 Effective masking and ineffective masking

Masking is a phenomenon that occurs when the minimum hearing threshold is elevated due to the presence of noise. Here, we stipulate that when masking noise is presented to the non-test ear, **effective masking** refers to elevation in the BC threshold of the non-test ear. If no BC threshold elevation occurs, the masking is ineffective. The masking noise is calibrated in terms of the effective masking level (EML), such that a given masking noise will shift the AC threshold in the non-test ear to a level equal to the masking noise level (ANSI, 2004).

For example, in **Fig. 1-8**, when the true AC threshold in the right (non-test) ear (AR*) is 50 dB HTL, the masking noise of 70 dB HL that is presented to the right ear will shift the AC threshold to 70 dB HTL. This means that the masked AC threshold in the right ear (mAR) is 70 dB HTL. At the same time, the BC threshold in the right ear is also elevated, thus the masking is effective. However, the AC threshold remains stable with the masking noise of 50 dB HL. Therefore, noises of levels that are higher than the AR* cause effective masking to occur.

Here, let the difference between the masking noise level (N) and AR* be "α:"

$$\alpha \text{ (dB)} = \text{N (dB HL)} - \text{AR* (dB HTL)}.$$

Although α has been termed an effective level, it is termed an effective amount of masking (**cf**. Masking theory **1.3**).

When N ≤ AR* (α ≤ 0 dB), the BC threshold in the non-test ear is not elevated: ineffective masking. When N > AR* (α > 0 dB), the BC threshold in the non-test ear is elevated: effective masking.

Furthermore, let α which corresponds to Nn (the n-th masking noise; n = 1, 2, 3, …) be αn, which can be written as follows:

$$\alpha n \text{ (dB)} = \text{Nn (dB HL)} - \text{AR* (dB HTL)}.$$

Then, the n-th masking noise is as follows:

$$\text{Nn} = (\text{AR*} + \alpha n) \text{ dB HL}.$$

The amount of BC threshold elevation of the non-test ear with Nn is equal to αn (> 0 dB) .

With a masking noise of Nn in the right ear, the masked and elevated BC threshold in the right (non-test) ear is referred to as the BC threshold of the right ear masked by Nn (mBR[n]), which can be represented as follows:

$$\text{mBR[n]} = (\text{BR*} + \alpha n) \text{ dB HTL},$$

For example (**Fig. 1-8**),
when N1 = 70 dB HL (α1 = 20 dB),
mBR[1] = BR* + α1
= 10 (dB HTL) + 20 (dB)
= 30 dB HTL.

The AC threshold in the right (non-test) ear is also elevated by the same amount. The AC threshold of the right ear masked by Nn (mAR[n]) is as follows:

$$\text{mAR[n]} = (\text{AR*} + \alpha n) \text{ dB HTL} = \text{[Nn] dB HTL}.$$

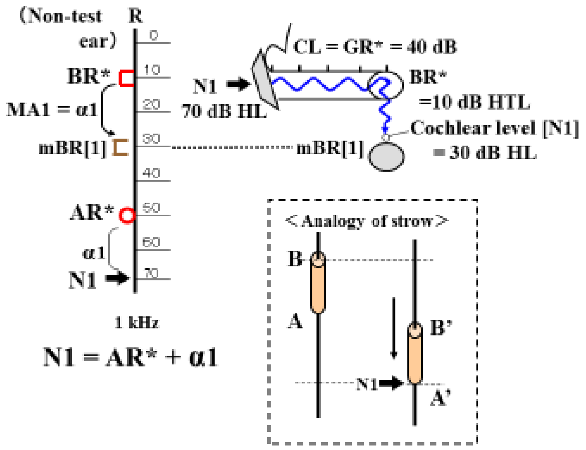


Figure 1-8 Effective masking

< An analogy of a straw >

Let the top edge of the straw be B, and the bottom edge be A. B is BR* and A is AR*. The length of the straw (i.e., AB) is the AB gap of the non-test ear.

Now, if the straw is moved downward to the position of the initial masking noise level (N1) along a string, B' is mBR[1], and A' is mAR[1].

1.5 A boundary condition

The condition for determining BC thresholds in effective masking must be the same as that in overmasking, which will be described later. Accordingly, we will first consider universal conditions that determine the BC thresholds in the test and non-test ear with masking.

> Let us consider the output levels of signals. In **Fig. 1-9**, when an N1 of 70 dB HL (α1 = 20 dB) is presented to the right (non-test) ear, the mBR[1] is 30 dB HTL. Therefore, if a BC test signal, BT1 of 30 dB HL, is presented to the right ear along with the N1, it reaches the right inner ear via the direct BC pathway and is barely heard by that inner ear.

Now, let us discuss this case example with attention to the cochlear levels of signals (**Fig. 1-9**). If the BC test signal delivered to the right (non-test) ear along with N1 is just audible in that inner ear, how many decibels is the cochlear level of the test signal?

The cochlear level of Nn in the AC pathway is termed a masking level [n] (**M level [n]**).
When N1 is 70 dB HL, the M level [1] is as follows (cf. **1.2**):

M level [1] = N1 − CL
= N1 − GR*
= 70 (dB HL) − 40 (dB)
= 30 dB HL.

At the same time, when the BC test signal is presented to the right ear, and its cochlear level in the right ear is lower than the M level [1], then the signal is not heard. By contrast, the signal is heard when it is higher. Therefore:

a) A BT of 20 dB HL is not heard by the right ear.
Rt cochlear level = 20 dB HL < M level [1].
b) A BT of 40 dB HL is heard by the right ear.
Rt cochlear level = 40 dB HL > M level [1].
c) Especially, when BT1 is 30 dB HL,
Rt cochlear level [BT1] = BT1
= 30 dB HL = M level [1].
At that point, BT1 is just audible in the right inner ear.

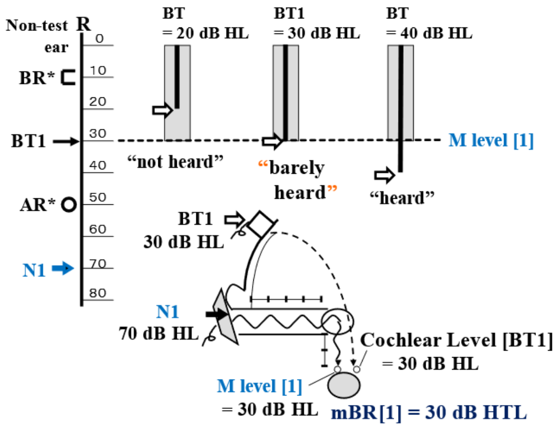


Figure 1-9 Boundary condition

Hence, the BC test signal (BTn) is barely heard by the non-test inner ear when the cochlear level of the non-test ear [BTn] is equal to the M level [n]. This is a condition that determines the border of the BC threshold in the non-test ear with masking (i.e., "heard" or "not heard") and is called a boundary condition.

> **The boundary condition for BC thresholds in the non-test ear:**
> In cases where the M level ≥ BR* (αn ≥ 0 dB), the test signal is barely heard if the cochlear level of the signal is equal to the M level.

This may be referred to as the boundary condition for effective masking.

When the M level = BR* (α = 0 dB, N = AR*), the non-test ear's BC threshold is not elevated.
When the M level > BR* (α > 0 dB, N > AR*), the non-test ear's BC threshold is elevated.
(i.e., mBR[n] = BR* + αn > BR*).

Furthermore, note that the masked BC and AC thresholds are usually calculated theoretically and almost never measured. However, as shown in **Fig. 1-9**, if the BC threshold measured in the non-test ear with N1 (BR1 = 30 dB HTL) can be obtained, it will be equal to the masked BC threshold (BR1 = mBR[1] = 30 dB HTL).

1.6 Overmasking

When the AC masking noises (Nn, n = 1, 2, 3, . . .) are introduced to the right (non-test) ear using supra-aural earphones, they reach the left (test) inner ear as converted BC noises via the cross-converted BC pathway (**Fig. 1-10**). At this time, Overmasking (OM) refers to elevation in the BC threshold of the test ear. In terms of BC threshold elevation, effective masking (i.e., the BC threshold elevation in the non-test ear) and OM (i.e., the BC threshold elevation in the test ear) are the same event or masking phenomenon. Therefore, the discussions related to effective masking are true in the same way as those related to OM (**Table 1-1**).

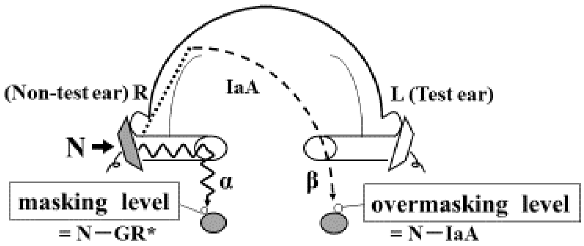


Figure 1-10 Effective masking and overmasking

Table 1-1 Effective masking and overmasking

	Effective masking The BC threshold elevation in the right, non-test ear	**Overmasking** The BC threshold elevation in the left, test ear
Requirements	M level [n] > BR*	OM level [n] > BL*
Amounts of the threshold elevation	the effective amount of masking αn = M level − BR* = Nn − AR*	the effective amount of overmasking βn = OM level − BL*
Elevated BC thresholds	mBR[n] = BR* + αn = M level [n] = Nn − GR*	omBL[n] = BL* + βn = OM level [n] = Nn − IaA

An overmasking level

The cochlear level of the masking noise (Nn) in the cross-converted BC pathway is referred to as an OM level [n]:

OM level [n] = (Nn − IaA) dB HL, (n = 1, 2, 3, …).

Let the difference between the OM level [n] and BL* be “βn”:

βn (dB) = OM level [n] (dB HL) − BL* (dB HTL).

On the model of α (the effective amount of masking), β is termed an effective amount of OM. The requirement for the test ear’s BC threshold to be determined is as follows:

The boundary condition for BC thresholds in the test ear: In cases where the OM level ≥ BL* (βn ≥ 0 dB), the test signal is barely heard if the cochlear level of the signal is equal to the OM level.

This may be referred to as the boundary condition for OM.
When the OM level = BL* (β = 0 dB), the test ear’s BC threshold is not elevated.
When the OM level > BL* (β > 0 dB), the test ear’s BC threshold is elevated.
(omBL[n] = BL* + βn > BL*)

In OM, βn (> 0 dB, n = 1, 2, 3, …) is equal to the amount of threshold elevation in the test ear with Nn. The masked and elevated BC threshold in the left (test) ear, which is referred to as the BC threshold of the left ear overmasked by Nn (omBL[n]), is represented as follows:

omBL[n] = (BL* + βn) dB HTL, (βn > 0 dB, n = 1, 2, 3…).

1.7 The relationship between an AB gap and IaA

When an AC test signal (AT) is introduced into one ear by supra-aural earphones, the BC output of the earphones generates a converted BC test signal that can reach the cochlea of the same ear via the direct-converted BC pathway. Here, the relative attenuation values in that pathway are assumed to be the same as the IaA value, and cannot be larger than the IaA value in any case. The hypothetical cochlear levels in the AC and direct-converted BC pathways are as follows:

Hypothetical cochlear level [AT] in the AC pathway = AT − CL,

Hypothetical cochlear level [AT] in the direct-converted BC pathway = AT − IaA.

Usually, since amounts of conduction loss are smaller than IaA values (CL < IaA), the hypothetical cochlear level [AT] in the AC pathway is higher than that in the direct-converted BC pathway (**Fig. 1-11 [a]**). As a result, the AC test signal is barely heard via the AC pathway, and the AB gap is equal to the CL value.

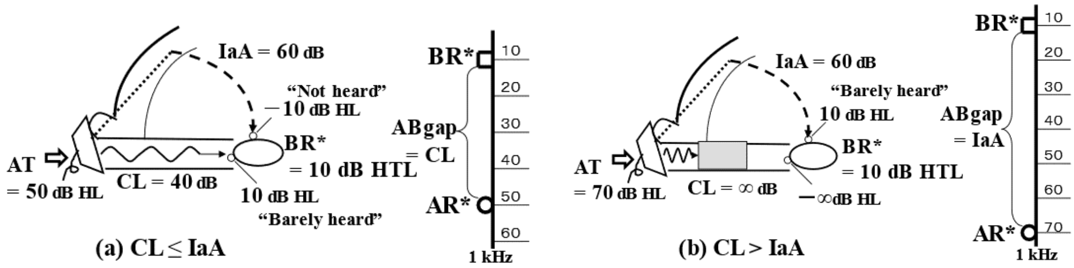


Figure 1-11 Relationship between AB gap and IaA

However, in the case of external ear canal atresia, for example, the CL value is so much larger than the IaA value (CL >> IaA) that the converted BC test signal will be heard via the direct-converted BC pathway (**Fig. 1-11 [b]**). Note that the participant will be unable to tell the difference between the converted BC test signal and the original AC test signal. Therefore, at this time the AB gap is equal to the IaA value. It is because AB gaps are limited to IaA values that the maximum limit of conductive hearing loss is considered approximately 60 dB HTL. Consequently, however severe an air conductive disorder may be, the AB gap at any one frequency is never larger than the IaA value at the same frequency:

AB gap ≤ IaA.

1.8 Requirements for apparent thresholds to be the SH thresholds

Let us consider the requirements for apparent AC and BC thresholds to be the SH thresholds, according to the relationship AB gap ≤ IaA.
It is assumed that the IaB value and measurement error are 0 dB.

1) The requirement for the apparent BC threshold to be the SH threshold is that bilateral true BC thresholds differ (i.e., a necessary and sufficient condition). The apparent BC threshold in the poorer ear by BC is always the SH threshold.

2) The requirements for the apparent AC threshold to be the SH threshold are that bilateral true BC thresholds differ (i.e., a necessary condition) and that the true AC threshold in the poorer ear by BC is higher than the CH level [0] for AC in the same ear (i.e., a sufficient condition). Then, the apparent AC threshold in the poorer ear by BC is always the SH threshold.

3) Importantly, in a clinical situation, if the apparent AC threshold in one ear is the SH threshold, the apparent BC threshold in the same ear is always the SH threshold. That is, the side at which SH for AC and BC occurs is always the same.

4) When the true BC thresholds differ (e.g., BR* < BL*), the apparent AC and BC thresholds in the better ear by BC (AR0, BR0) are always the true thresholds.

5) When the apparent AC thresholds differ significantly (e.g., AR0 + 15 dB ≤ AL0), the apparent AC threshold in the better ear by AC (AR0) is always the true threshold (AR0 = AR*).

When bilateral true BC thresholds are equal (BR* = BL*), all apparent AC and BC thresholds are not the SH thresholds.

1.9 Patterns of audiometric configurations at a given frequency

According to the requirements for SH thresholds, audiometric configurations at a given frequency are classified into 12 patterns, as described below (**Fig. 1-12**, **1-13**). For simplicity, it is supposed that IaB = 0 dB and that the left ear is the poorer ear by AC and the right ear is the better ear by AC. The difference between the apparent AC threshold in one ear (e.g., AL0) and the apparent BC threshold in the opposite ear (i.e., BR0) at some frequency is called air and opposite bone gap (AOB gap) (Gelfand, 2009):

Lt AOB gap = AL0 − BR0, **Rt AOB gap = AR0 − BL0**.

Here, the Lt and RT represent left and right, respectively. Moreover, the difference between bilateral apparent AC thresholds at some frequency is termed air and air gap (AA gap ≥ 0 dB):

Rt AA gap = AL0 − AR0 ≥ 0 dB, (AL0 ≥ AR0),

Lt AA gap = AR0 − AL0 ≥ 0 dB, (AR0 ≥ AL0).

It is supposed that clinically significant AA gaps are larger than or equal to 15 dB (AA gap ≥ 15 dB).

The difference between BL* and BR* is termed a relative amount of sensorineural component of the left ear compared to the right ear (Lt SNC) (**cf**. Masking theory **6.3-1**):

Lt SNC = BL* − BR* ≥ 0 dB, (BL* ≥ BR*),

Rt SNC = BR* − BL* ≥ 0 dB, (BR* ≥ BL*).

(1) Patterns where bilateral apparent AC thresholds differ significantly

Audiometric configurations are classified into seven patterns, as follows (**Fig. 1-12**):

Lt AOB gap = AL0 − BR0 = IaA (= 60 dB) and Rt AA gap = 20 dB.

[1]: all apparent thresholds are not SH but true thresholds;
[2]: only BR0 in the better ear by AC is the SH threshold (BR0 < BR*);
[3]: only BL0 in the poorer ear by AC is the SH threshold (BL0 < BL*); or
[4]: both BL0 and AL0 in the poorer ear by AC are SH thresholds (BL0 < BL*, AL0 < AL*).

Lt AOB gap = AL0 − BR0 < IaA’ (= 70 dB) and Rt AA gap = 20 dB.

[1’]: all apparent thresholds are not SH but true thresholds;
[2’]: only BR0 in the better ear by AC is the SH threshold (BR0 < BR*); or
[3’]: only BL0 in the poorer ear by AC is the SH threshold (BL0 < BL*).

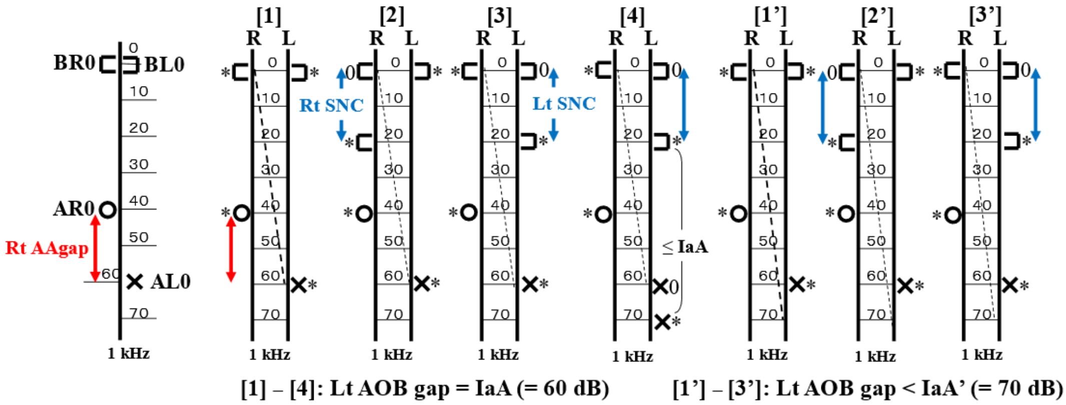


Figure 1-12 Audiometric patterns with Rt AA gap of 20 dB (AR0 < AL0)

Findings of these patterns above are as follows:

1) The apparent AC threshold in the better ear by AC (AR0) is always the true threshold.

2) The apparent AC threshold in the poorer ear by AC (AL0) is either the true or SH threshold. Only in pattern [4] can AL0 be the SH threshold, in which case the apparent BC threshold in the same ear (BL0) is also the SH threshold. Since BL0 < BL*, automatically BR0 = BR*. Furthermore, the IaA value can be calculated as follows: **IaA = Lt AOB gap** = AL0 − BR0.

3) In all patterns except for pattern [4], we only know that IaA ≥ (AL0 − BL0) dB.

4) Evidently, the Lt AOB gap is never larger than IaA (**Lt AOB gap ≤ IaA**) and the apparent AB gaps (GR0 and GL0) are never larger than IaA (**GR0, GL0 ≤ IaA**).

Since the right and left are symmetric, the patterns are the same as the left-right reversal configurations. When AB gaps in these patterns are larger or smaller at variable proportions and/or the BC threshold levels are higher, the configurations fall under those in a clinical setting. Unilateral sensorineural and complete hearing impairments are included in patterns [4] or [7].

(2) Patterns where bilateral apparent AC thresholds do not differ significantly

Clinically, insignificant AA gaps are smaller than or equal to 10 dB (0 dB, 5dB, 10 dB). For simplicity, the cases with an AA gap of 0 dB (i.e., AR0 = AL0) are shown below.

Audiometric configurations are classified into five patterns as follows (**Fig. 1-13**):

Lt AOB gap = AL0 − BR0 = IaA (= 60 dB) and Rt AA gap = 0 dB.

[5]: all apparent thresholds are not SH but true thresholds;
[6]: only BL0 in the poorer ear by AC is the SH threshold (BL0 < BL*); or
[7]: both BL0 and AL0 in the poorer ear by AC are SH thresholds (BL0 < BL*, AL0 < AL*).

Lt AOB gap = AL0 − BR0 < IaA' (= 70 dB) and Rt AA gap = 0 dB.

[5']: all apparent thresholds are not SH but true thresholds; or
[6']: only BL0 in the poorer ear by AC is the SH threshold (BL0 < BL*).

In patterns [6] and [6'], since the AA gaps is insignificant, the poorer ear by BC may be either ear.

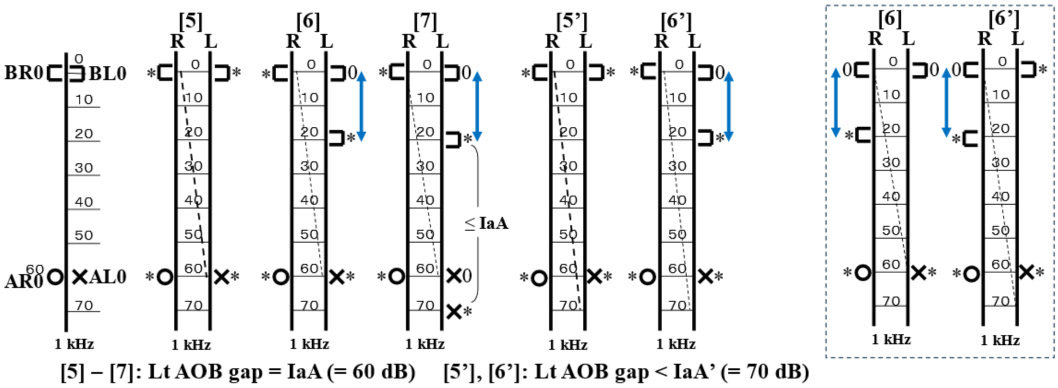


Figure 1-13 Audiometric patterns with an AA gap of 0 dB (AR0 = AL0)

Findings of all patterns are as follows (**Fig. 1-12**, **1-13**):

1) The apparent AC and BC thresholds in at least one ear are the true thresholds.
2) Only in patterns [4] and [7] can the apparent AC threshold in one ear (e.g., AL0) be the SH threshold, in which case the apparent BC threshold in the same ear (i.e., BL0) is also the SH threshold. Then, the IaA value can be calculated as follows: IaA = Lt AOB gap = AL0 − BR0.
3) In all patterns except for patterns [4] and [7], we only know that IaA ≥ (AL0 − BR0) dB.
4) The following gaps are never larger than IaA values.

True AB gaps:	AL* − BL* = GL* ≤ IaA,	or AR* − BR* = GR* ≤ IaA.
Apparent AB gaps:	AL0 − BL0 = GL0 ≤ IaA,	or AR0 − BR0 = GR0 ≤ IaA.
AOB gaps:	AL0 − BR0 = Lt AOB gap ≤ IaA,	or AR0 − BL0 = Rt AOB gap ≤ IaA.

Subdivided patterns of patterns [4] and [7] (**Fig. 1-14**) Lt AOB gap = IaA.

Pattern [4-0]: GR* < IaA, GL* < IaA Pattern [7-0]: GR* ≤ IaA, GL* < IaA
Pattern [4-1]: GR* < IaA, GL* = IaA Pattern [7-1]: GR* ≤ IaA, GL* = IaA
Pattern [4-2]: GR* < IaA, Lt ear is CHL Pattern [7-2]: GR* ≤ IaA, Lt ear is CHL

where CHL is the complete hearing loss.

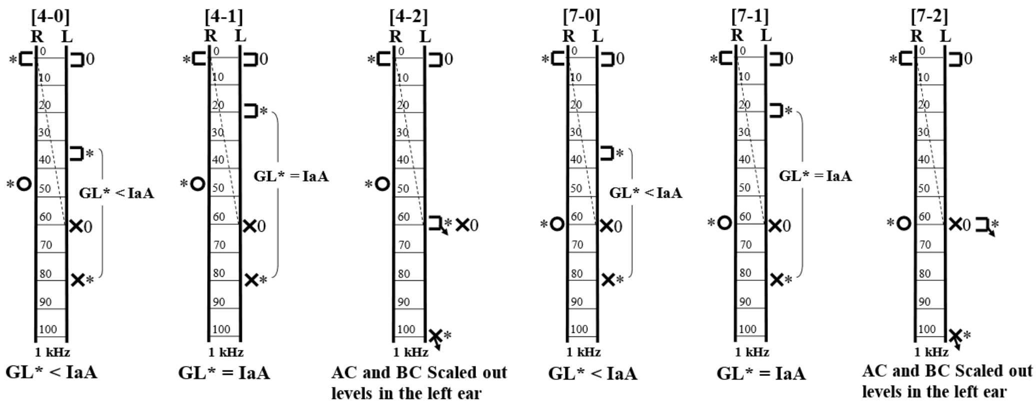


Figure 1-14 Subdivided patterns of patterns [4] and [7]

[2] The basic principle of the plateau method

The plateau method is the basic principle that forms the backbone of all masking methods.

2.1 Air-conduction audiometry

2.1-1 An audiometric configuration without masking

Let us consider the following audiometric configuration at 1000 Hz (**Fig. 2-1 [a]**). It is assumed that the non-test ear is the right, better ear by AC and the test ear is the left, poorer ear by AC.

	Non-test (right) ear	Test (left) ear	Interaural attenuation
Bone conduction (BC)	BR* = 0 dB HTL	BL* = 30 dB HTL	IaB = 0 dB
Air conduction (AC)	AR* = 40 dB HTL	AL* = 80 dB HTL	IaA = 60 dB
Air-Bone gap (AB gap)	GR* = 40 dB	GL* = 50 dB	

The configuration presented in **Fig. 2-1 (b)** is obtained without masking. The apparent AC threshold in the left ear (AL0) is a shadow-hearing (SH) threshold because the participant barely hears the AC test signal, which is at the same level as the AL-CH level [0] (i.e., AT0 = 60 dB HL) (**Fig. 2-1 [c]**). The same holds true for BC (i.e., BT0 = 0 dB HL).

In this configuration, typical AC and BC plateaus are obtained.

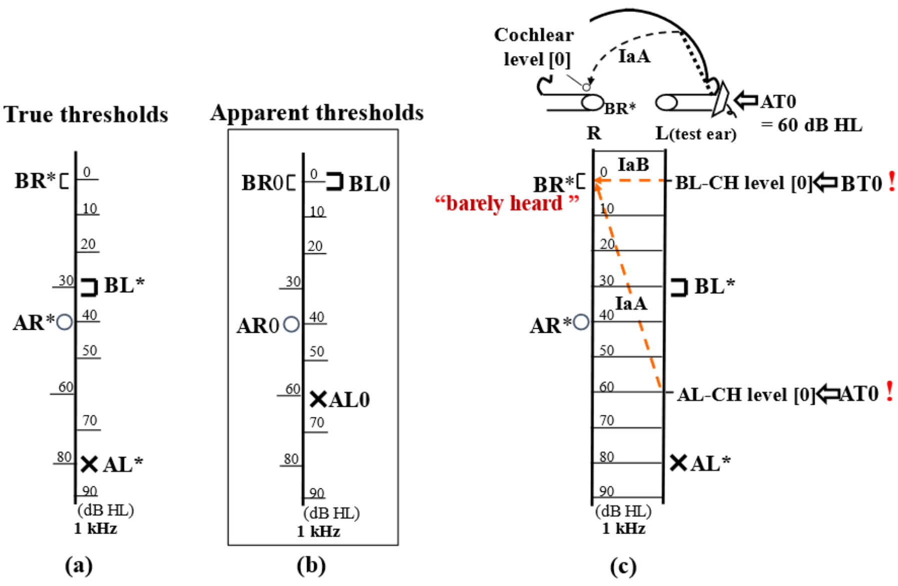


Figure 2-1 Audiometric configuration at 1000 Hz without masking

< Findings of the configuration without masking >

1) The apparent BC thresholds (BR0, BL0) are the true thresholds for at least one ear.
   Both BR0 and BL0 cannot be SH thresholds at the same time.
2) When the difference between the left and right apparent AC thresholds is significant (AL0 − AR0 ≥ 15dB), the apparent AC threshold in the better ear (AR0) is the true threshold because it cannot be the SH threshold.
3) The apparent AC threshold in the poorer ear (AL0) is either the true or SH threshold.

Therefore, considering the possibility that AL0 could be the SH threshold, we should retest the AC threshold in the left (test) ear with masking in the right ear.

Noises higher than 40 dB HL (N > [AR*]) elevate the BC threshold in the right (non-test) ear; i.e., **effective masking**, while masking noises lower than or equal to 40 dB HL (N ≤ [AR*]) do not elevate that BC threshold; i.e., **ineffective masking**.

Here, the right and left sides are represented as **Rt** and **Lt**, respectively. For example, **Rt N** is noise presented to the right ear.

The hypothetical cochlear level is referred to as simply ‘the cochlear level’ from here on out.

2.1-2 The plateau method: a masking procedure for air conduction

(1) 40 dB HL < Rt N < 60 dB HL [Undermasking]

As shown in **Fig. 2-2**, when the masking noise level in the right ear (Rt Nn) is increased from 45 dB HL (= [AR*] + 5) in 5 dB-steps, the AC threshold levels measured in the left ear are likewise increased in direct proportion to the noise levels. Accordingly, we will now consider what happens at the level of the cochleae.

When **Rt N1 = 50 dB HL** (α1 = 10 dB), let us check the following three key points.

First, **a)** Consider whether N1 causes overmasking (OM) (**Fig. 2-3 [a]**). The OM level of N1 (OM level [1]) is as follows:

OM level [1] = N1 − IaA = 50 (dB HL) − 60 (dB)

= −10 dB HL (< BL* = 30 dB HTL).

Since the OM level [1] is lower than the true BC threshold level in the test ear (BL* of 30 dB HTL), N1 does not cause OM.

Second, **b)** Consider how many decibels of the test signal will be barely heard by the participant (**Fig. 2-3 [b]**). The BC threshold of the right ear masked by N1 (mBR[1]) and its AL-CH level [1] are determined as follows:

mBR[1] = BR* + α1 = 0 (dB HTL) + 10 (dB)

= 10 dB THL.

AL-CH level [1] = mBR[1] + IaA = 10 (dB THL) + 60 (dB)

= 70 dB HL (< AL* = 80 dB HTL).

When AT1 of 70 dB HL is delivered to the left ear, it is not heard by the left inner ear because the AT1 level is lower than the true AC threshold level in the left ear (AL* of 80 dB HTL).

In contrast, the AT1 cochlear level in the right ear is as follows:

Rt cochlear level [AT1] = AT1 − IaA = 70 (dB HL) − 60 (dB)

= 10 dB HL (= mBR[1] = 10 dB HTL).

In this case, the AT1 is just audible in the non-test, right inner ear (mBR[1]) and is not heard by the test, left inner ear (BL*). Hence, the AT1 hearing is SH and the AC threshold measured in the test ear with N1 (AL1) of 70 dB HTL is the SH threshold (SHT) for AC.

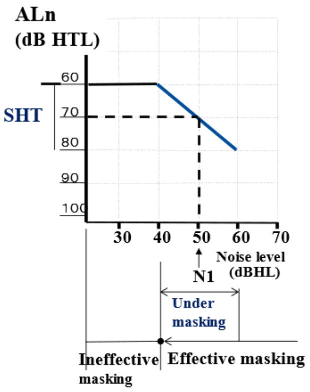


Figure 2-2 Undermasking 1

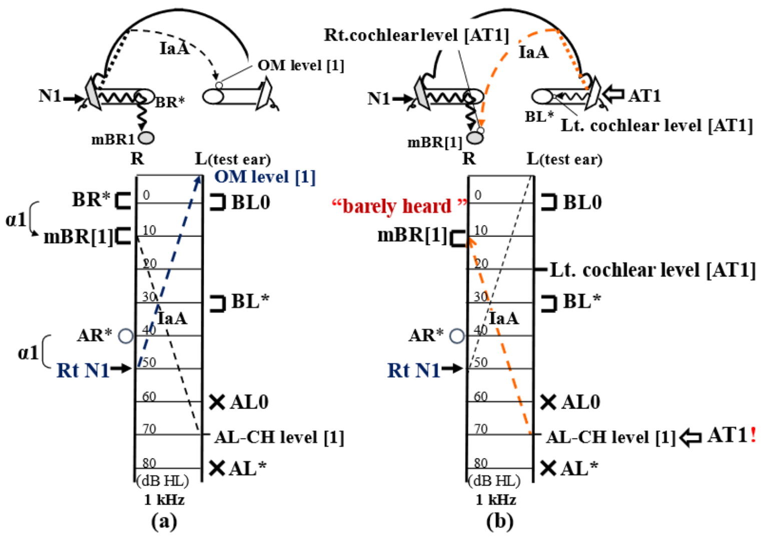


Figure 2-3 Undermasking 2

Third, c) Since the noises at these levels (40 dB HL < Rt N < 60 dB HL) are insufficient to prevent SH of the AC test signals, masking with these noises is termed **undermasking**. At that point, the test signals (60 dB HL < AT < 80 dB HL) are received by the masked BC threshold in the non-test, right ear (mBR[n]). As a result, if the noise level is increased by 5 dB, mBR[n] is also elevated by the same amount. This means that the AC threshold measured in the test, left ear is also elevated by 5 dB, exhibiting a direct proportional relationship to the noise levels (**Fig. 2-2**).

(2) 60 dB HL ≤ Rt N ≤ 90 dB HL [Adequate masking]

As in **Fig. 2-4**, when noises at levels from 60 to 90 dB HL are introduced to the right (non-test) ear, the AC thresholds measured in the left (test) ear with masking remain the same at 80 dB HTL, thus indicating a masking plateau. When N2 is 60 dB HL and N4 is 90 dB HL, masking with these noise levels will produce interesting results, as will be described later.

When **Rt N3 = 75 dB HL** (α3 = 35 dB) (**Fig. 2-5 [a]**),

OM level [3] = N3 − IaA

= 75 (dB HL) − 60 (dB)

= 15 dB HL (< BL* = 30 dB HTL).

a) Since the OM level [3] is lower than the true BC threshold level in the test ear (BL*), N3 does not cause OM. Then, the BC threshold of the non-test ear masked by N3 (mBR[3]) and its AL-CH level are as follows:

mBR[3] = BR* + α3 = 0 (dB HTL) + 35 (dB)

= 35 dB THL.

AL-CH level [3] = mBR[3] + IaA

= 35 (dB THL) + 60 (dB)

= 95 dB HL

(> AL* = 80 dB HTL).

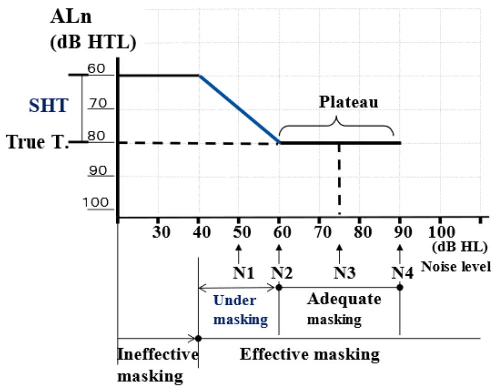


Figure 2-4 Adequate masking 1

b) When AT3 of 80 dB HL is presented to the test ear (**Fig. 2-5 [b]**),

Lt cochlear level [AT3] = AT3 − GL* = 80 (dB HL) − 50 (dB)

= 30 dB HL (= BL* = 30 dB HTL).

Therefore, the test signal is barely heard by the test, left inner ear (BL*). In contrast,

Rt cochlear level [AT3] = AT3 − IaA = 80 (dB HL) − 60 (dB)

= 20 dB HL (< mBR[3] = 35 dB HTL).

It is not heard by the non-test inner ear (mBR[3]). Hence, the AT3 hearing is true hearing, and then the AC threshold measured in the test ear with N3 (AL3) of 80 dB HTL is a true AC hearing threshold (i.e., AL3 = AL*).

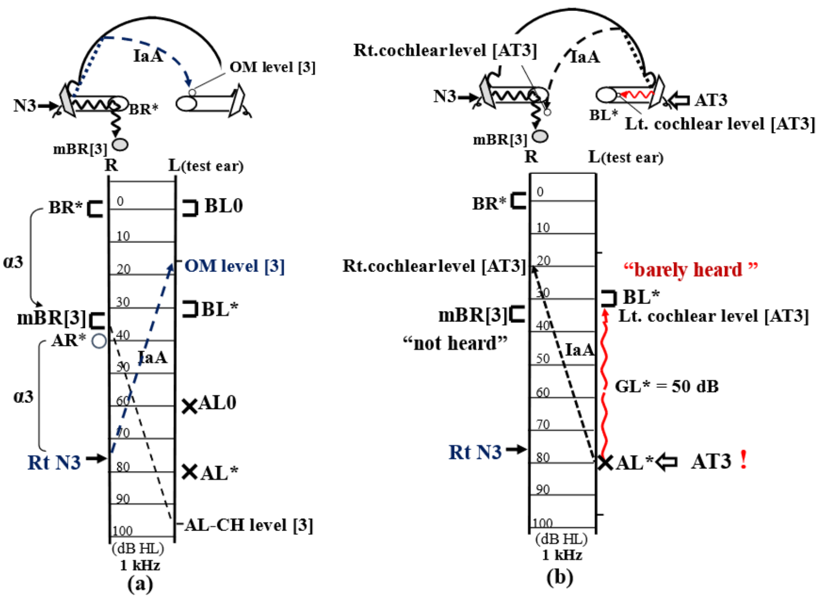


Figure 2-5 Adequate masking 2

c) Since noises at these levels (60 dB HL ≤ Rt N ≤ 90 dB HL) are sufficient to prevent SH of AC test signals and do not cause OM, this is termed **adequate masking** (**Fig. 2-4**).

In adequate masking, the AC test signal of 80 dB HL is heard by the test ear's true BC threshold (BL*), therefore, the AC thresholds measured in the test ear remain stable even if the noise levels are increased or decreased within these levels (60 dB HL ≤ Rt N ≤ 90 dB HL).

(3) 90 dB HL < Rt N [Overmasking]

When noise levels are higher than 90 dB HL, the AC thresholds measured in the test ear are elevated again in direct proportional manner (**Fig. 2-6**).

When **Rt N5 = 100 dB HL** (α5 = 60 dB) (**Fig. 2-7**),

OM level [5] = N5 − IaA = 100 (dB HL) − 60 (dB)

= 40 dB HL (> BL* = 30 dB HTL).

a) Since the OM level [5] is higher than BL*, N5 causes OM. That is, the BC threshold in the test ear is elevated. Depending on the boundary condition for OM (cf. **1.6**), the BC threshold level of the test ear overmasked by N5 (omBL[5]) is equal to the OM level [5]:

omBL[5] = 40 dB HTL = (OM level [5] = 40 dB HL).

The effective amount of OM with N5 (β5) is the difference between the OM level [5] and BL*, (cf. **1.6**):

β5 = OM level [5] − BL* = 40 (dB HL) − 30 (dB HTL)

= 10 dB

Therefore, omBL[5] is as follows:

omBL[5] = BL* + β5 = 30 (dB HTL) + 10 (dB)

= 40 dB HTL.

The AC threshold of the test ear overmasked by N5 (omAL[5]) is as follows:

omAL[5] = AL* + β5 = 90 dB HTL.

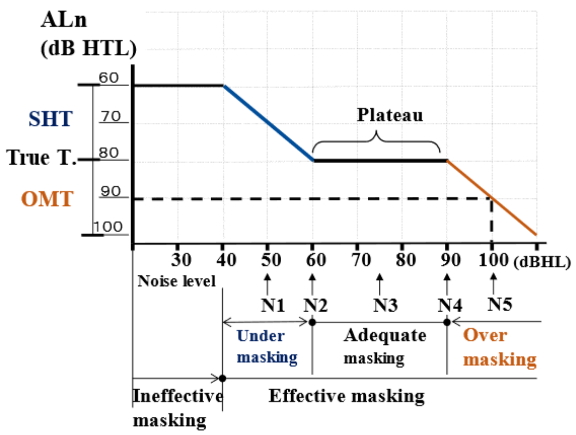


Figure 2-6 Overmasking 1

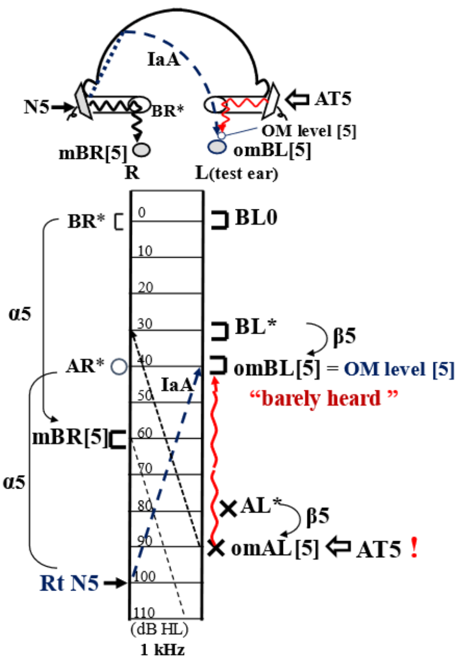


Figure 2-7 Overmasking 2

b) When AT5 of 90 dB HL is presented to the test ear (**Fig. 2-7**),

Lt cochlear level [AT5] = AT5 − GL* = 90 (dB HL) − 50 (dB)

= 40 dB HL (= omBL[5] = 40 dB HTL).

The AT5 is barely heard by the test inner ear (omBL[5]). Hence, the AT5 hearing is overmasked hearing, and the AC threshold measured in the test ear with N5 (AL5) of 90 dB HTL is equal to the test ear's AC threshold overmasked by N5 (i.e., AL5 = omAL[5]). AL5 is an overmasked hearing threshold (OMT). By contrast,

Rt cochlear level [AT5] = AT5 − IaA = 90 (dB HL) − 60 (dB)

= 30 dB HL (< mBR[5] = 60 dB HTL).

It is not received by the non-test inner ear (mBR[5]). In overmasking, it does not matter whether the test signal is heard by the non-test ear.

c) Since noises at these levels (90 dB HL < Rt N ≤ 110 dB HL) elevate the BC threshold in the test ear, OM occurs. In OM, the AC test signals (80 dB HL < AT ≤ 100 dB HL) are heard by the test ear's BC threshold overmasked by Nn (omBL[n]). Therefore, the shift amounts of the AC threshold levels measured in the test ear are proportional to those of noise levels in the same manner as in undermasking.

(4) The minimum and maximum adequate masking noise levels

The minimum noise level for adequate masking is referred to as the minimum adequate masking noise level (**Nmin**). Nmin for AC is described as **ANmim**. The maximum noise level for adequate masking is referred to as the maximum adequate masking noise level (**Nmax**). In cases where masking plateaus are present, Nmax is equal to the maximum level of masking noise at which OM does not occur (**MN**). Nmax and MN are the same level for both AC and BC.

When **Rt N2 = 60 dB HL** (α2 = 20 dB) **[Minimum adequate masking]** (Fig. 2-8),

OM level [2] = N2 − IaA
= 60 (dB HL) − 60 (dB)
= 0 dB HL
(< BL* = 30 dB HTL).

a) N2 does not cause OM to occur. Then,

mBR[2] = BR* + α2 = 0 (dB HTL) + 20 (dB)
= 20 dB THL.

AL-CH level [2] = mBR[2] + IaA
= 20 (dB THL) + 60 (dB)
= 80 dB HL
(= AL* = 80 dB HTL).

b) When AT2 of 80 dB HL is presented to the test ear,

Lt cochlear level [AT2] = AT2 − GL*
= 80 (dB HL) − 50 (dB)
= 30 dB HL
(= BL* = 30 dB HTL).

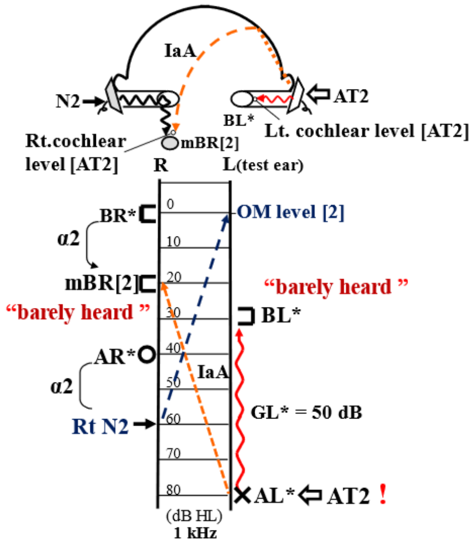


Figure 2-8 Minimum adequate masking for AC

Therefore, the AT2 is barely heard by the test inner ear (BL*). In contrast,

Rt cochlear level [AT2] = AT2 − IaA = 80 (dB HL) − 60 (dB)
= 20 dB HL (= mBR[2] = 20 dB HTL).

Note that AT2 is also barely heard by the right (non-test) inner ear (mBR[2]). Thus, the test signal is barely being heard by both the test and non-test inner ears at the same time. Then, is this hearing true, shadow, or cross hearing?

Since AT2 is heard by the true BC threshold in the test ear, it is true hearing **and** the AC threshold measured in the test ear with N2 (AL2) of 80 dB HTL is the true AC threshold. It should be noted that the AT2 hearing by the non-test ear is cross hearing, not SH (cf. 1.3). N2 is the minimum adequate masking noise level for AC (ANmim).

When **Rt N4 = 90 dB HL**, (α4 = 50 dB); **[Maximum adequate masking]** (Fig. 2-9)

OM level [4] = N4 − IaA
= 90 (dB HL) − 60 (dB)
= 30 dB HL
(= BL* = 30 dB HTL).

N4 is barely heard by the left (test) inner ear (BL*).
Here, when AT4 of 80 dB HL (= AL*) is presented to the test ear,

Lt cochlear level [AT4] = AT4 − GL*
= 80 (dB HL) − 50 (dB)
= 30 dB HL
(= OM level [4]).

Depending on the boundary condition for OM, the AT4 is barely heard by the test inner ear (BL*): N4 does not cause OM. N4 is the maximum adequate masking noise level (Nmax) and is equal to the maximum level of masking noise at which OM does not occur (MN):

Rt N4 = **Rt Nmax** = **Rt MN** = **BL* + IaA**.

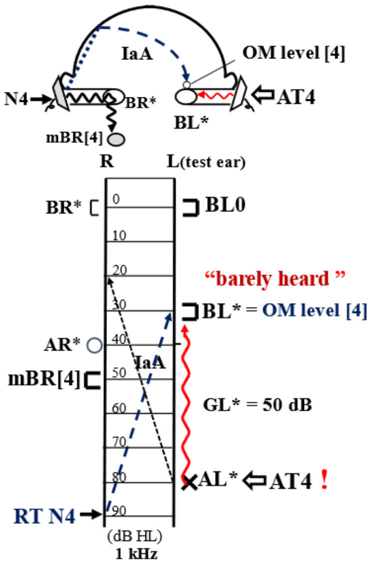


Figure 2-9 Maximum adequate masking for AC

(5) The air-conduction plateau width

Fig. 2-10 shows a case in which the typical plateau for AC is present.

When masking is adequate, test signals are audible by the true BC threshold in the test ear (BL*), therefore, the measured AC thresholds remain stable even if the noise levels are increased or decreased within the range from 60 to 90 dB HL. That is, the plateau has been reached.

A plateau width (PW) is defined as the difference between the maximum adequate masking noise level in the right ear (Rt Nmax) and the minimum adequate masking noise level in the right ear (Rt Nmin). In other words, the PW is the noise level range in which adequate masking can be performed. The AC plateau width of the left ear (Lt APW) is described in **Fig. 2-10** and through the following formula: **Lt APW = Rt Nmax – Rt ANmin**.

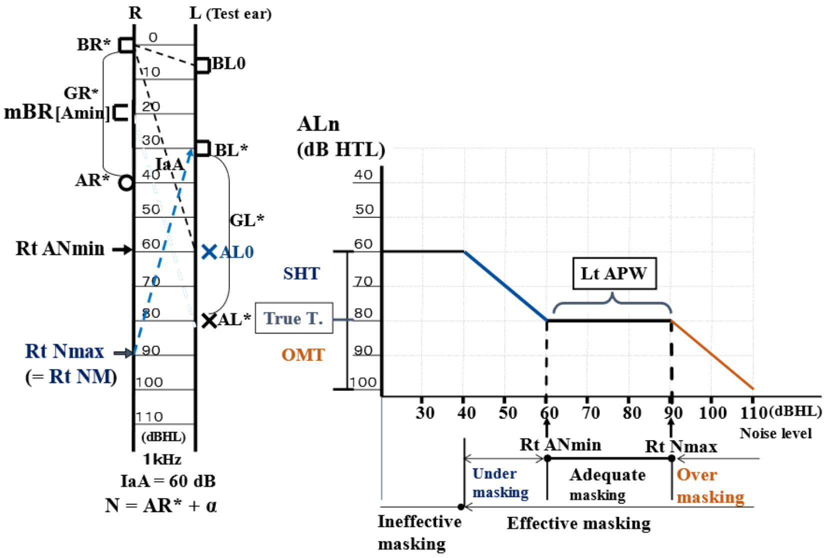


Figure 2-10 Typical AC plateau width

In cases with typical plateaus, the Nmax presented to the right, non-test ear (**Rt Nmax**) is equal to **Rt MN** (the maximum level of masking noise at which OM does not occur in the right ear). Note that Rt Nmax and Rt MN are the same level for both AC and BC (**Fig. 2-11**).

Rt Nmax = Rt MN = BL* + IaA --- (1)

When the minimum adequate masking noise for AC (ANmin) is introduced to the right ear, its CH level for AC in the left ear (AL-CH level [Amin]) is as follows:

AL-CH level [Amin] = mBR[Amin] + IaA

= (Rt ANmin − GR*) + IaA

This level is equal to the true AC threshold level in the left ear (AL*):

(Rt ANmin − GR*) + IaA = AL*

∴ Rt ANmin = AL* − IaA + GR* --- (2)

Subtract equation (2) from equation (1).

Lt APW = Rt Nmax – Rt ANmin

= (BL* + IaA) − (AL* − IaA + GR*)

= IaA − GR* + IaA − (AL* − BL*)

∴ Lt APW = (IaA − GR*) + (IaA − GL*)

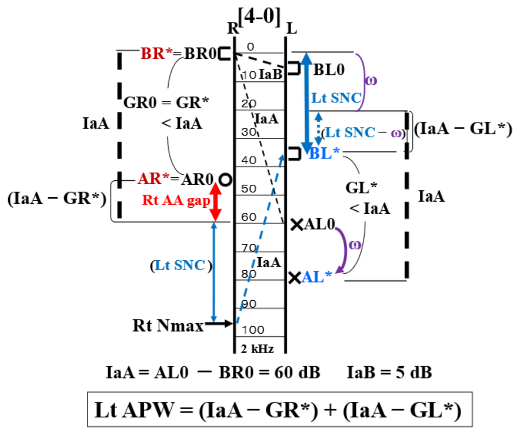


Figure 2-11 Lt APW

The Lt APW is always larger than or equal to 0 dB because AB gaps ≤ IaA. The Rt ANmin never exceeds the Rt Nmax (Rt ANmin ≤ Rt Nmax). If the Rt ANmin exceeded the Rt Nmax, the Lt APW would be minus (Lt APW < 0 dB) and the true AB gaps in at least one ear would be larger than IaA (AB gap > IaA). Such an audiometric configuration is not present.

2.2 Bone-conduction audiometry

The plateau method for BC audiometry is fundamentally the same as the one used for AC. The difference lies in the amount of the interaural attenuation. In order to comprehend masking systematically, AC and BC should be treated equally in both theoretical and clinical environments.

The BC plateau width of the left ear (Lt BPW) is described below:

Lt BPW = Rt Nmax – Rt BNmin.

Let us consider the audiometric configuration at 1000 Hz as follows:

	Non-test (right) ear	Test (left) ear	Interaural attenuation
Bone conduction	BR* = 0 dB HTL	BL* = 30 dB HTL	IaB = 0 dB or 5 dB
Air conduction	AR* = 40 dB HTL	AL* = 80 dB HTL	IaA = 60 dB
Air-bone gap	GR* = 40 dB	GL* = 50 dB	

(1) Lt BPW with the IaB value of 0 dB

Figure 2-12 shows the typical BPW with the IaB value of 0 dB.

When **Rt N1 = 50 dB HL** (α1 = 10 dB), the BC threshold measured in the left ear with N1 (BL1) of 10 dB HTL is the SH threshold.

When **Rt N2 = 80 dB HL** (α2 = 40 dB), BL2 of 30 dB HTL is the true threshold.

When **Rt N3 = 100 dB HL** (α3 = 60 dB), BL3 of 40 dB HTL is the OM threshold.

As shown in **Fig.2-13**, Rt N of 70 dB HL (α = 30 dB) is the minimum adequate masking noise level for BC in the right ear (Rt BNmin) because the CH level of Rt BNmin in the left ear (BL-CH level [Bmin]) is the same level as BL* shown as follows:

BL-CH level [Bmin] = mBR[BNmin] + IaB = 30 dB HL (= BL* = 30 dB HTL).

Since Rt Nmax is 90 dB HL,

Lt BPW = Rt Nmax − Rt BNmin = 90 (dB HL) − 70 (dB HL) = 20 dB.

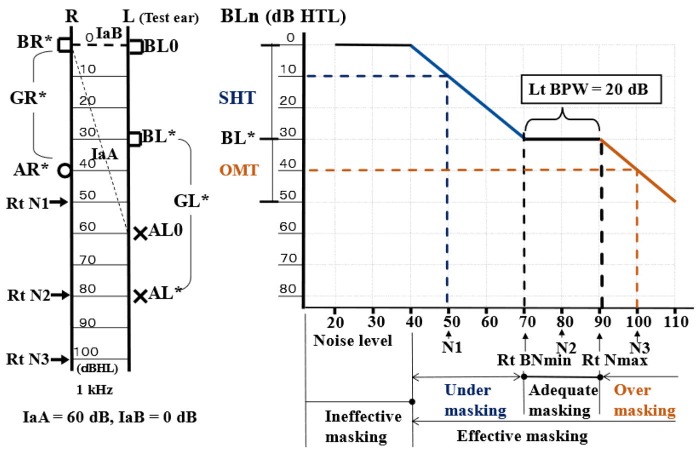


Figure 2-12 Typical BC plateau width with IaB of 0 dB

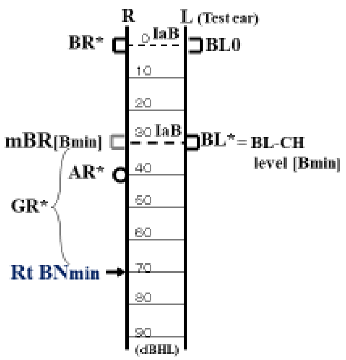


Figure 2-13 Rt BNmin

(2) The true AB gap of the non-test ear and a singular level (cf. Masking theory 5.7)

When the true AB gap of the non-test ear (GR*) is equal to IaA (GR* = IaA) and the IaB value is 0 dB, with masking noise of Nn (n = 1,2,3…), the OM level [n] and BL-CH level [n] become the same level. It is termed a singular level. At this situation, the BC plateau width of the test ear cannot be found (Lt BPW = 0 dB) (**Fig. 2-14)**.

OM level [n]
= Nn – IaA

BL-CH level [n]
= Nn – GR*

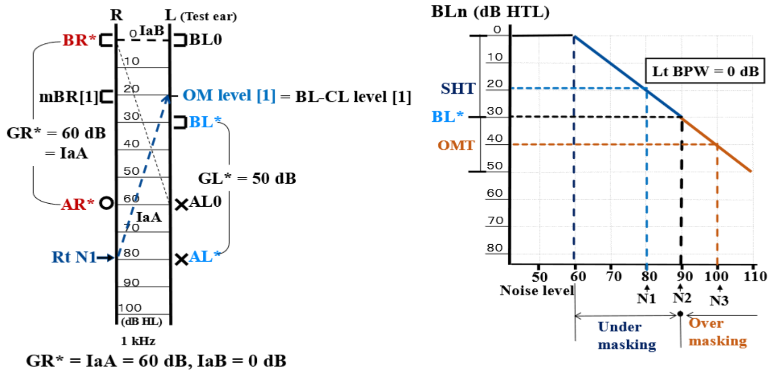


Fig. 2-14 A singular level

(3) Lt BPW with the IaB value of 5 dB

Fig. 2-15 shows the typical PW for BC with the IaB value of 5 dB. As in **Fig. 2-16**, when the IaB value is 5 dB, Rt BNmin is 65 dB HL (α = 25 dB). The CH level of Rt BNmin in the left ear is the same level as BL* as follows:

mBR[Bmin] = BR* + α = 0 (dB HTL) + 25 (dB) = 25 dB THL.

BL-CH level [Bmin] = mBR[BNmin] + IaB = 25 (dB HTL) + 5 (dB)

= 30 dB HL (= BL* = 30 dB HTL).

Since Rt Nmax is 90 dB HL,

Lt BPW = Rt Nmax − Rt BNmin = 90 (dB HL) − 65 (dB HL) = 25 dB.

Note that the Lt BPW becomes wider by the amount of the IaB value.

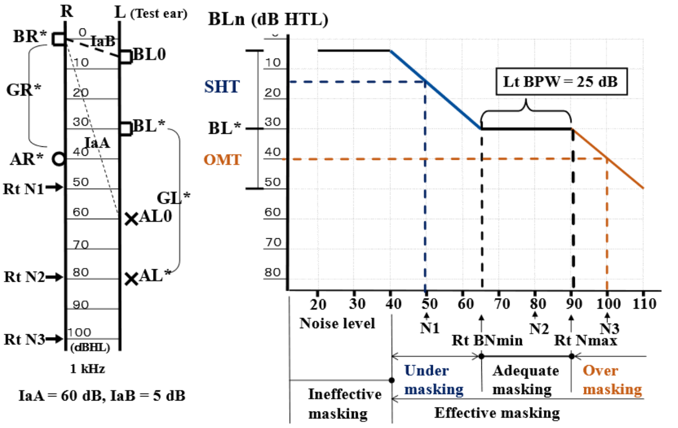


Figure 2-15 Typical BC plateau width with IaB of 5 dB

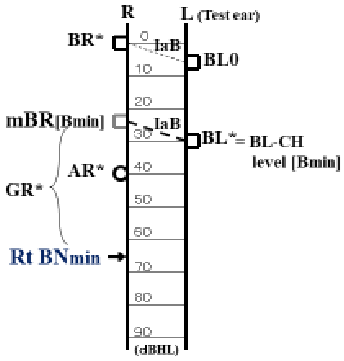


Figure 2-16 Rt BNmin

(4) The bone-conduction plateau width of the left ear: Lt BPW

Lt BPW = Rt Nmax – Rt BNmin.

Lt BPW can be treated equally with AC. When the minimum adequate masking noise for BC (BNmin) is introduced to the right ear, its BL-CH level is as follows (**Fig. 2-16**):

BL-CH level [Bmin] = mBR[Bmin] + IaB = (Rt BNmin − GR*) + IaB

This level is equal to the true BC threshold level in the left ear (BL*):

(Rt BNmin − GR*) + IaB = BL*

∴ Rt BNmin = BL* − IaB + GR*

Since Rt Nmax = BL* + IaA,

Lt BPW = Rt Nmax − Rt BNmin

= (BL* + IaA) − (BL* − IaB + GR*)

∴ Lt BPW = (IaA − GR*) + IaB.

It should be noted that the BNmin never exceeds the Nmax (Rt BNmin ≤ Rt Nmax).
The minimum effective masking level never exceeds the maximum effective masking level.

(5) Clinically significant plateau widths

Although a PW of 5 dB is theoretically significant (**Fig. 2-17 [a]**), clinically we are unable to detect such a narrow plateau as 5-dB in width. We assume that the PWs of ≥ 15 dB for both AC and BC are clinically significant to ensure a wide safety margin (**Fig. 2-17 [c]**). However, a PW of 10 dB might be significant if it could be obtained with high measurement accuracy (**Fig. 2-17 [b]**).

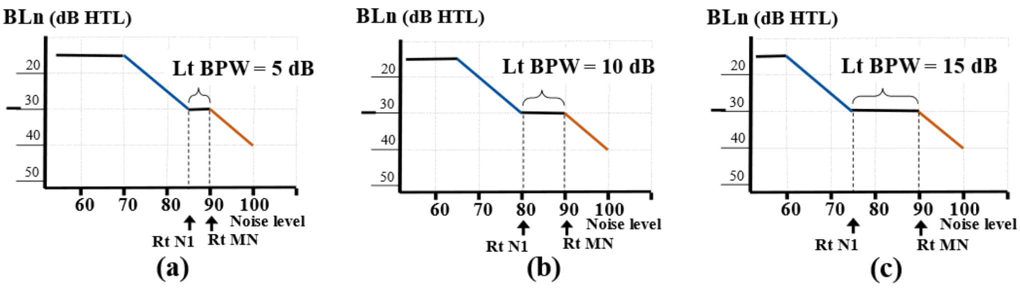


Figure 2-17 Significant BC plateau widths

2.3 Atypical plateau cases

Fig. 2-18 shows atypical plateau cases for AC and BC in which noise levels of undermasking are not present. First, the right ear is masked.

When Rt N > 40 dB HL (= [AR*]), these noise levels provide **effective masking**. A noise of 60 dB HL presented to the right ear is the maximum level of masking noise at which OM does not occur (**Rt MN** = 60 dB HL) and is likewise the maximum adequate masking noise level (**Rt Nmax**):

Rt MN = Rt Nmax = 60 dB HL.

Therefore, when 40 dB HL < Rt N ≤ 60 dB HL, **adequate masking** is provided.

In this case, the minimum adequate masking noise level for AC in the right ear (Rt ANmin) is either not present or cannot be defined because masking with a noise of 40 dB HL is ineffective. Therefore, in atypical plateau cases, the noise level equal to the true AC threshold level in the non-test ear (AR*) is used instead of Rt ANmin to represent the AC plateau widths. An alternative noise in the right ear (Rt N0) is written by

Rt N0 = [AR*] = 40 dB HL.

An atypical plateau width for AC of the left ear (Lt APW) is as follows:

Lt APW = Rt Nmax − Rt N0 = Rt MN − [AR*] = 60 (dB HL) − 40 (dB HL) = 20 dB.

Subsequently, for BC, Rt BNmin is also not present and Lt BPW is as follows:

Lt BPW = Rt Nmax − Rt N0 = Rt NM − [AR*] = 60 (dB HL) − 40 (dB HL) = 20 dB.

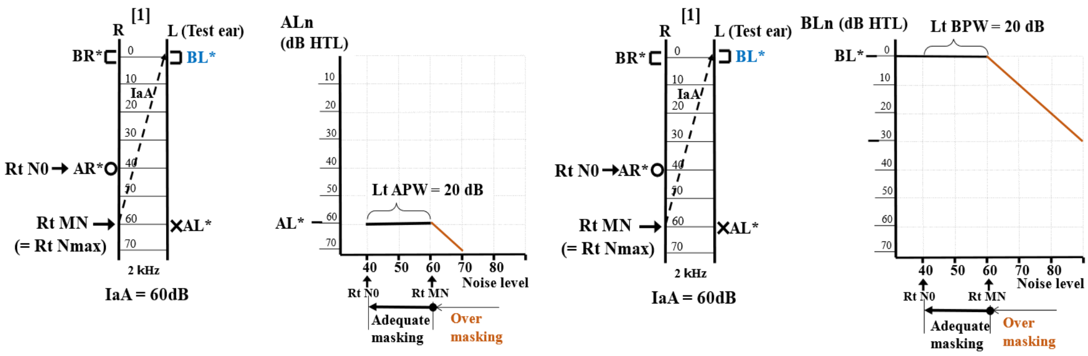


Figure 2-18 Atypical BC plateaus

2.4 No plateau cases

(1) Overmasking In the pattern [5] (**Fig.2-19 [a]**), when Rt N > 60 dB HL (effective masking), the noises of these levels always cause OM, and the AC and BC thresholds measured in the left ear with Nn (ALn, BLn) are the OM thresholds. Therefore, no AC or BC plateaus are present.

(2) Undermasking In the pattern [7-2] (**Fig.2-19 [b]**), when Rt N > 60 dB HL, noises at these levels always cause undermasking to occur and the AC and BC thresholds measured in the left ear with masking are always the SH thresholds. Therefore, AC and BC plateaus are not present.

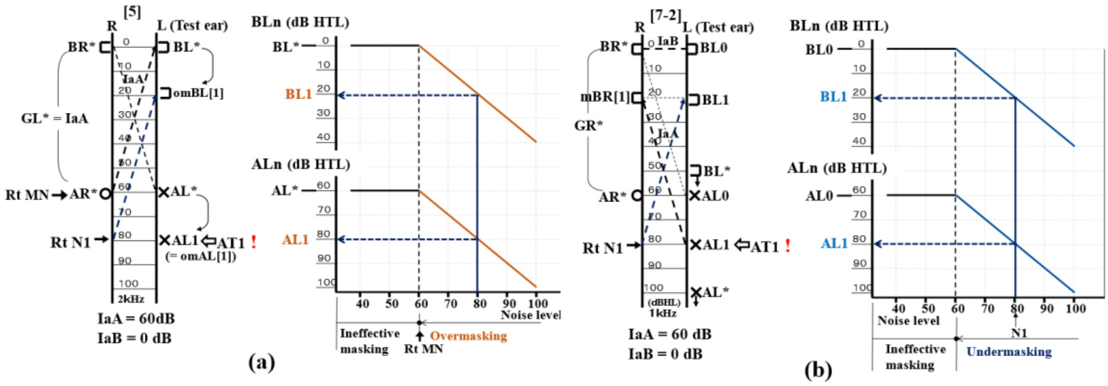


Figure 2-19 No plateau cases

Cases in which "the clinically significant plateau cannot be identified" includes the following: 1) Cases in which the plateaus are not present (**Fig. 2-19**) 2) Cases in which, even if a 0 dB plateau is present, it cannot be identified (cf. **Fig. 3-6**) 3) Cases in which, even if the plateaus are present (i.e., PW = 5 dB), they are clinically difficult to identify (cf. **Fig. 3-11**)

2.5 The true BC threshold which is the first cause of shadow hearing

When the apparent AC thresholds in both ears differ significantly at frequencies except for 4000 Hz as shown in **Fig. 2-20**, we need to consider whether the AC thresholds in the left ear (AL0s) can be the SH thresholds or not. For example, the criterion for AC masking at 1000 Hz, is as follows:

Lt AOB gap = AL0 − BR0 = 60 (dB HTL) − 0 (dB HTL) = 60 dB > 40 dB.

Thus, AL0 of 60 dB HTL at 1000 Hz is possible to be the SH threshold (SHT). Therefore, the AC threshold in the left ear needs to be retested with masking in the right ear. Then, there are three combinations of the true BC thresholds in the configuration at 1000 Hz. **Fig. 2-20 (a)** shows that both apparent BC thresholds are the true thresholds. **Fig. 2-20 (b)**, **(c)** represents that one ear's apparent BC threshold is the true threshold and the other is the SH threshold (SHT). Understandably, both ears' apparent BC thresholds cannot be the SH thresholds at the same time.

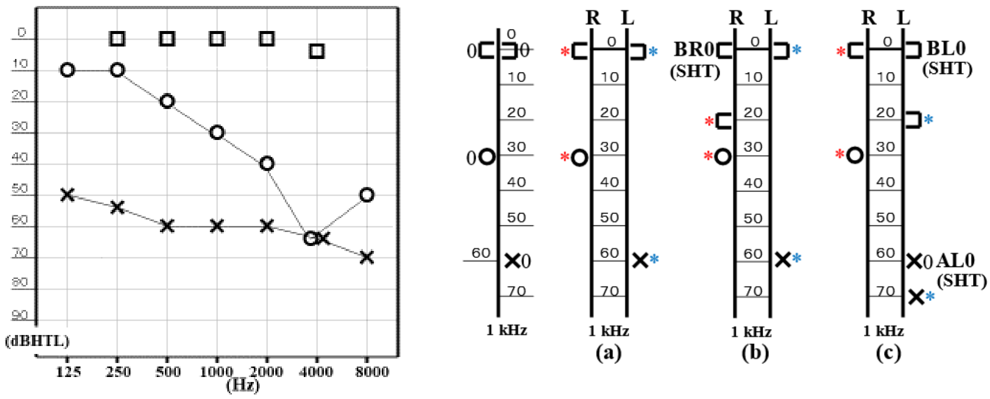


Figure 2-20 Audiogram without masking and three combinations of the true BC thresholds

The case in which the apparent AC threshold in the left ear (AL0) is the SH threshold is exclusively limited to the pattern [4] (**Fig. 2-21**). Then, the apparent BC threshold in the right ear (BR0) is the true threshold (BR0 = BR*), and BR* is the first cause of SH. When BR0 is the SH threshold as in patterns [2] and [2'], both AL0 and BL0 are always the true thresholds (AL0 = AL*, BL0 = BL*). Namely, when we consider that AL0 might be the SH threshold, we will mask the right ear assuming that BR0 is the true threshold (i.e., the pattern [4]). However, even if BR0 is the true threshold, AL0 cannot be the SH threshold in patterns [1], [3], [1'], and [3']. Therefore, that BR0 is the true threshold is a necessary (not sufficient) condition for AL0 to be the SH threshold. The same holds true for BC.

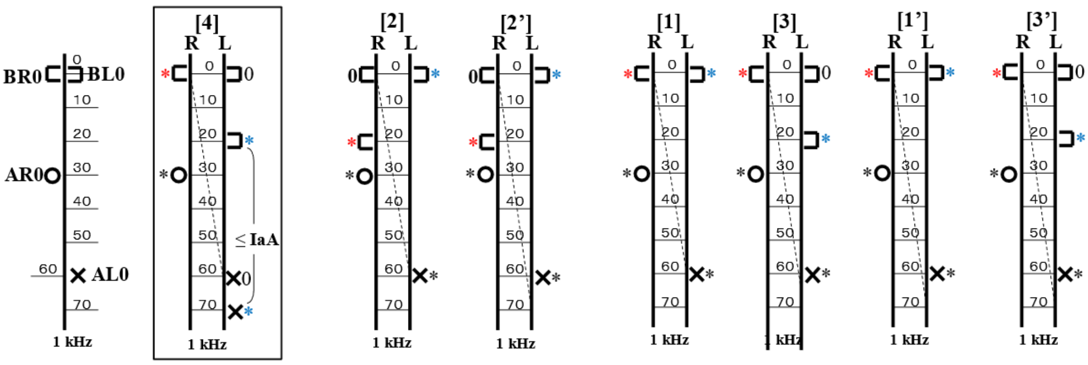


Figure 2-21 the right ear's true BC threshold: the first cause for shadow hearing

To consider that AL0 might be the SH threshold is to assume that its audiometric configuration might be the pattern [4].

If AL0 is the SH threshold (AL0 < AL*),

1) BR0 is the true threshold (BR0 = BR*): the first cause of SH.
2) BL0 is also the SH threshold (BL0 < BL*): AB gap ≤ IaA.
3) IaA = Lt AOB gap = AL0 – BR0 = (AL0 − BR*) dB.

[3] General expression for the plateau widths

3.1 The plateau widths of pattern [4-0]

In the pattern [4-0], typical plateaus for both AC and BC are obtained (**Fig. 3-1**). The apparent AC threshold in the left ear (AL0) is the SH threshold, and the true AC threshold in the left ear (AL*) is AL0 plus **ω** (AL* = AL0 + **ω**).

The APW of the left, poorer ear by AC (Lt APW) is described below (cf. **Fig. 2-11**):

Lt APW = Rt Nmax − Rt ANmin = (IaA − GR*) + (IaA − GL*)

Then, with attention to Rt AA gap, **ω** and Lt SNC, let the formula change into more general form below. When masking in the right ear, adequate masking for AC is detected in the noise range where 65 dB HL ≤ N ≤ 95 dB HL.

Rt ANmin = [AR0] + ω = 45 (dB HTL) + 20 dB = 65 dB HL.

Rt Nmax = [AR0] + Rt AAgap + Lt SNC = 45 (dB HTL) + 15 dB + 35 dB = 95 dB HL.

Lt APW can be expressed as follows:

Lt APW = Rt Nmax − Rt ANmin = {[AR0] + Rt AAgap + Lt SNC} – { [AR0] + ω}

∴ **Lt APW = Rt AAgap + Lt SNC – ω,**

where Rt AA gap = AL0 − AR0 ≥ 0 dB, Lt SNC = BL* − BR* ≥ 0 dB, **ω** = AL* − AL0 ≥ 0 dB.

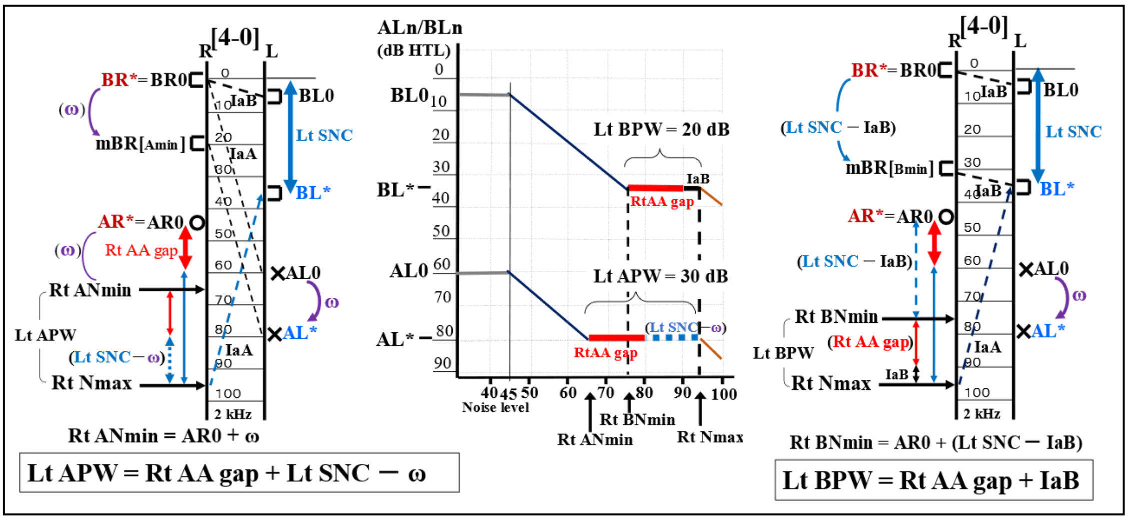


Figure 3-1 Typical plateaus for AC and BC in Pattern [4-0]

Adequate masking for BC is detected in the noise range where 75 dB HL ≤ N ≤ 95 dB HL.

The BPW of the left ear (Lt BPW) is written as follows:

Lt BPW = Rt Nmax − Rt BNmin = **(IaA − GR*) + IaB**

= {[AR0] + Rt AAgap + Lt SNC} − { [AR0] + (Lt SNC − IaB)}

∴ **Lt BPW = Rt AAgap + IaB.**

Lt APW = (IaA − GR*) + (IaA − GL*) **= Rt AAgap + Lt SNC – ω.**	**Lt BPW = (IaA − GR*) + IaB** **= Rt AAgap + IaB.**

The difference between BL* and BR* is termed a relative amount of sensorineural component of the left ear compared to the right ear (Lt SNC):

Lt SNC = BL* − BR* ≥ 0 dB. BL* ≥ BR*.

In the case that AR0 > AL0 and BR* > BL* (**Fig.3-2**),

Rt SNC = BR* − BL* = 35 dB.

Rt APW and Rt BPW are as follows:

Rt APW = Lt AAgap + Rt SNC – ω = 30 dB,

Rt BPW = Lt AAgap + IaB = 20 dB,

where Lt AA gap = AR0 − AL0 = 15 dB,

ω = AR* − AR0 = 20 dB.

In this case, Rt AA gap = 0 dB.

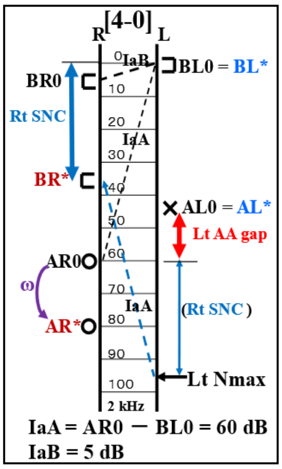


Figure 3-2 AR0 > AL0

3.2 Patterns of the audiometric configurations with significant AA gaps (≥ 15dB)

(1) Pattern [1] is the configuration in which the apparent AC and BC thresholds are all the true ones and Lt AOB gap = IaA. Atypical plateaus for AC and BC are obtained in the left ear (**Fig. 3-3**).

According to the requirements for the SH threshold (**cf. 1.8**), when the AA gap is significant, the apparent AC threshold in the right, better ear by AC (AR0) is the true threshold (AR0 = AR*).

In this case, instead of ANmin and BNmin, the noise level equal to the apparent AC threshold level in the right ear (AR0) is used: **Rt N0 = [AR0 = AR*]** = 45 dB HL.

When the right, better ear by AC is masked (**Fig. 3-3**),

Air conduction: AC adequate masking occurs, when 45 dB HL< Rt N < 60 dB HL.

Rt Nmax = [AR0] + Rt AAgap = 60 dB HL、Rt N0 =[AR0] = 45 dB HL. Lt APW is as follows:

Lt APW = Rt Nmax − Rt N0 = ([AR0] + Rt Aagap) − [AR0]
= Rt AA gap = 15 dB. ∴ AL* = AL0 = 60 dB HTL.

Bone conduction: BC adequate masking occurs, when 45 dB HL< Rt N < 60 dB HL.

Lt BPW = Rt Nmax − Rt N0 = Rt AA gap = 15 dB. ∴ BL* = BL0 = 0 dB HTL.

Masking in the right ear.

Lt APW = Rt AA gap
= 15 dB

Lt BPW = Rt AA gap
= 15 dB

AL* = AL0 = 60 dB HTL
BL* = BL0 = 0 dB HTL

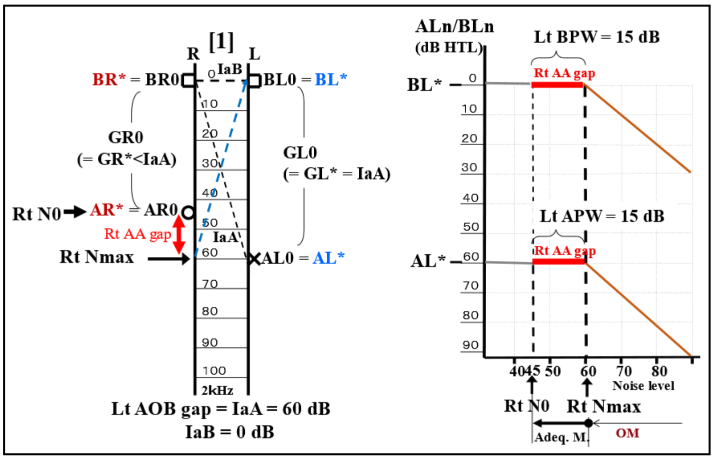


Figure 3-3 Lt plateau graph in Pattern [1]

When the left, poorer ear by AC is masked (**Fig. 3-4**),

The masking noise levels (Lt N > 60 dB HL) always cause overmasking, so the AC and BC plateaus in the right ear are not present. Lt MN is 60 dB HL. However, Lt Nmax is not present (cf. Masking theory **5-7**). As the AC and BC plateaus are not present, the true BC threshold in the right ear (BR*) cannot be determined using the plateau method.

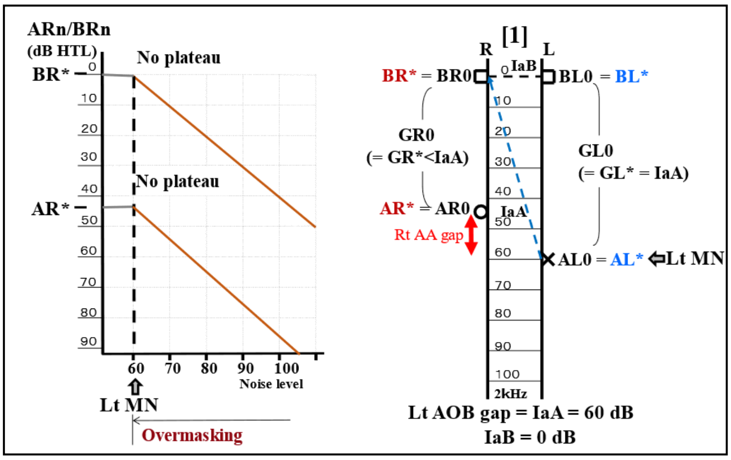


Figure 3-4 Rt plateau graph in Pattern [1]

Masking in the left ear.

The right ear's AC and BC plateaus are not present.

Rt APW (–)
Rt BPW (–)

AR0 = AR*
BR0 (undetermined)

Estimated level
BR* = BL0 = 0 dB HTL

Since AR0 = AR*, the AC threshold measured in the right ear is elevated in direct proportion to the noise level (Lt N > 60 dB HL). We find that it is not undermasking but overmasking. Therefore we can estimate BR* = BR0 = 0 dB HTL

(2) Pattern [2] is the configuration in which the true BC threshold in the right, better ear by AC is higher than the apparent BC threshold in that ear (BR* > BR0) and Lt AOB gap = IaA.

When the right, better ear by AC is masked (**Fig. 3-5**),
As with the pattern [1], atypical plateaus for AC and BC are obtained in the left ear.

Lt APW = Rt Nmax − Rt N0 = Rt AA gap = 15 dB. ∴ AL* = AL0 = 60 dB HTL.
Lt BPW = RT Nmax − Rt N0 = Rt AA gap = 15 dB. ∴ BL* = BL0 = 0 dB HTL.

Masking in the right ear.

Lt APW = Rt AA gap
= 15 dB

Lt BPW = Rt AA gap
= 15 dB

AL* = AL0 = 60 dB HTL
BL* = BL0 = 0 dB HTL

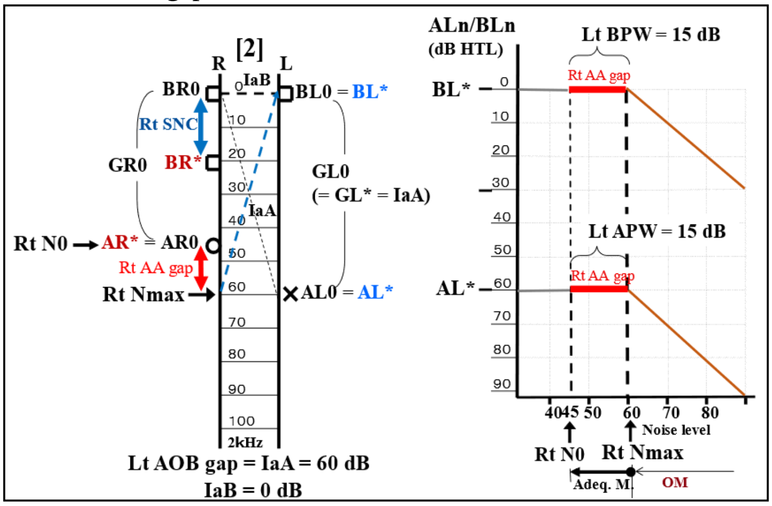


Figure 3-5 Lt plateau graph in Pattern [2]

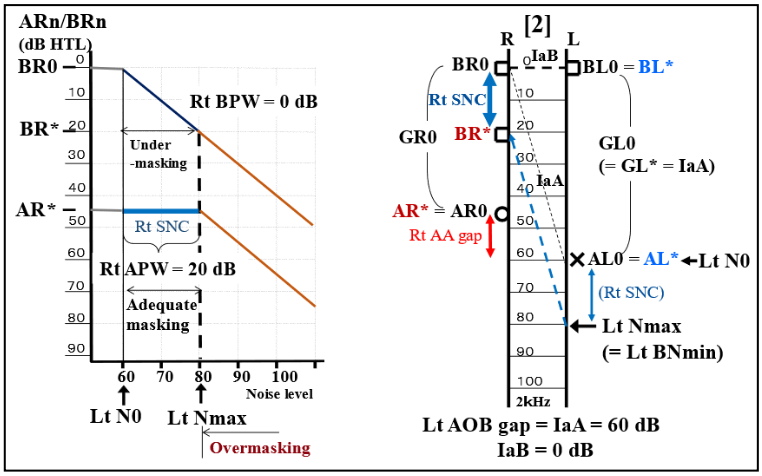
When the left, poorer ear by AC is masked (**Fig. 3-6**),
Air conduction: AC adequate masking occurs, when 60 dB HL < Lt N < 80 dB HL.
Lt Nmax = [AL0] + Rt SNC = 80 dB HL, Lt N0 = [AL0] = 60 dB HL. Rt APW is as follows:

Rt APW = Lt Nmax − Lt N0 = {[AL0] + Rt SNC} − [AL0]
= Rt SNC = 20 dB. ∴ AR* = AR0 = 45 dB HTL.

Bone conduction: BC undermasking occurs, when 60 dB HL < Lt N < 80 dB HL.
When Lt N > 80 dB HL, BC overmasking occurs. Therefore, Lt Nmax of 80 dB HL is equal to the minimum adequate masking noise level for BC: **Lt Nmax** = **Lt BNmin =** 80 dB HL.

∴ Rt BPW = Lt Nmax − Lt BNmin = 0 dB.

The true BC threshold in the right ear (BR*) is not able to be determined because the plateau of 0 dB cannot be detected. Note that the singular level is occurred in the right ear because BL* = IaA (cf. **2-2 (2)**).



Masking in the left ear.

Rt APW = Rt SNC
= 20 dB

Rt BPW = 0 dB

AR* = AR0 = 45 dB HTL
BR*(undetermined)

estimated level
BR* > BR0
BR* = 20 dB HTL

Figure 3-6 Rt plateau graph in Pattern [2]

When an atypical plateau for AC is obtained in the better ear by AC (Rt APW = Rt SNC), we can estimate that BR* > BR0 and find that this configuration is either pattern [2] or [2'].
Using the OM method, BR* can be calculated from the following equation (cf. Masking theory **6.3-1**.): BR* = BL* + (Lt Nmax − Rt Nmax) = 0 dB HTL + (80 − 60) dB HL = 20 dB HTL.

(3) Pattern [3] is the configuration in which the true BC threshold in the left, poorer ear by AC is higher than the apparent BC threshold in that ear (BL* > BL0) and Lt AOB gap = IaA.

When the right, better ear by AC is masked (**Fig. 3-7**),
Air conduction: AC adequate masking occurs, when 45 dB HL< Rt N < 80 dB HL.
An atypical plateau for AC is obtained in the left ear.
Rt Nmax = [AR0] + Rt AAgap + Lt SNC = 80 dB HL,   Rt N0 = [AR0] = 45 dB HL,
Lt APW = Rt Nmax − Rt N0 = {[AR0] + Rt AAgap + Lt SNC}− [AR0]
= Rt AA gap + Lt SNC = 35 dB HL.   ∴ AL* = AL0 = 60 dB HTL.

Bone conduction: BC adequate masking occurs, when 65 dB HL< Rt N < 80 dB HL.
A typical plateau for BC is obtained in the left ear.
Rt BNmin = [AR0] + Lt SNC = 65 dB HL   (IaB = 0 dB)
Lt BPW = Rt Nmax − Rt BNmin= {[AR0] + Rt AAgap + Lt SNC}− {[AR0] + Lt SNC}
= Rt AA gap = 15 dB.   ∴ BL* = 20 dB HTL> BL0.

Masking in the right ear.

Lt APW = Rt AA gap + Lt SNC
= 35 dB

Lt BPW = Rt AA gap
= 15 dB

AL* = AL0 = 60 dB HTL
BL* = 20 dB HTL > BL0

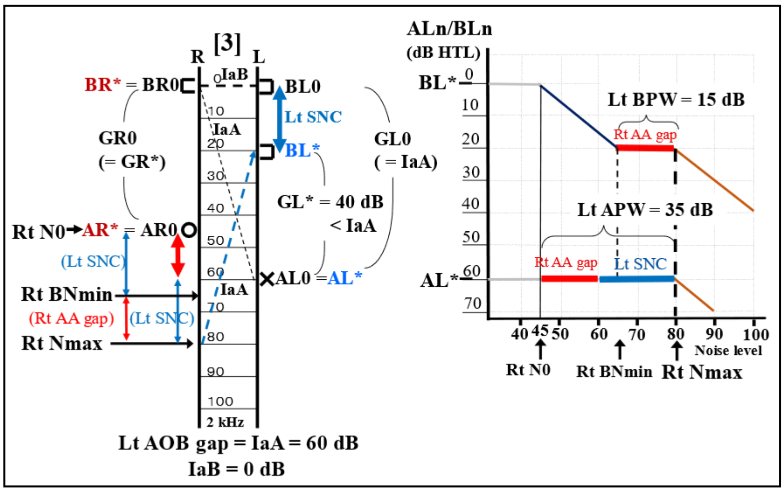
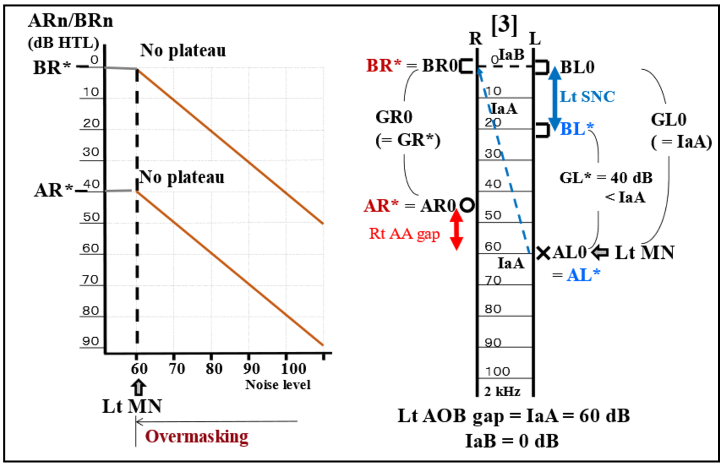


Figure 3-7 Lt plateau graph in Pattern [3]

When the left, poorer ear by AC is masked (**Fig. 3-8**),
The AC and BC plateaus in the right ear are not present because the masking noise levels (Lt N > 60 dBHL) always cause overmasking. Lt MN is 60 dB HL.



Masking in the left ear.

The right ear's AC and BC plateaus are not present.
Rt APW (–)
Rt BPW (–)

AR0 = AR*
BL0 = SHT
BR0 is not SHT.
BR0 = BR*

Figure 3-8 Rt plateau graph in Pattern [3]

The BL0 is found to be the SH threshold at the point that BL* = 20 dB HL > BL0 are determined. So we find that the BR0 is not the SH threshold but the true one (BR0 = BR*). Furthermore, the AR0 cannot be the SH threshold: AR0 = AR*. Therefore, masking in the left ear is not needed.

(4) Patterns [1], [2], [3]: Lt AOB gap = IaA = 60 dB, δ = 0 dB (**Fig. 3-9**).

	Lt APW	Lt BPW
Pattern [1]: GL* = IaA, BR* = BL* (Lt SNC = 0 dB)	Rt AAgap	Rt AAgap + IaB
Pattern [2]: GL* = IaA, BR* = BL* (Lt SNC = 0 dB)	Rt AAgap	Rt AAgap + IaB
Pattern [3]: GL* < IaA, BR* < BL* (Lt SNC > 0 dB)	Rt AAgap + **Lt SNC**	Rt AAgap + IaB

If the clinical plateau contraction of 10 dB occurs, the Lt APW, BPW may be 5 dB (insignificant) and the AC and BC plateau cannot be detected (**cf**. Masking theory **8.2-2 (3)**).

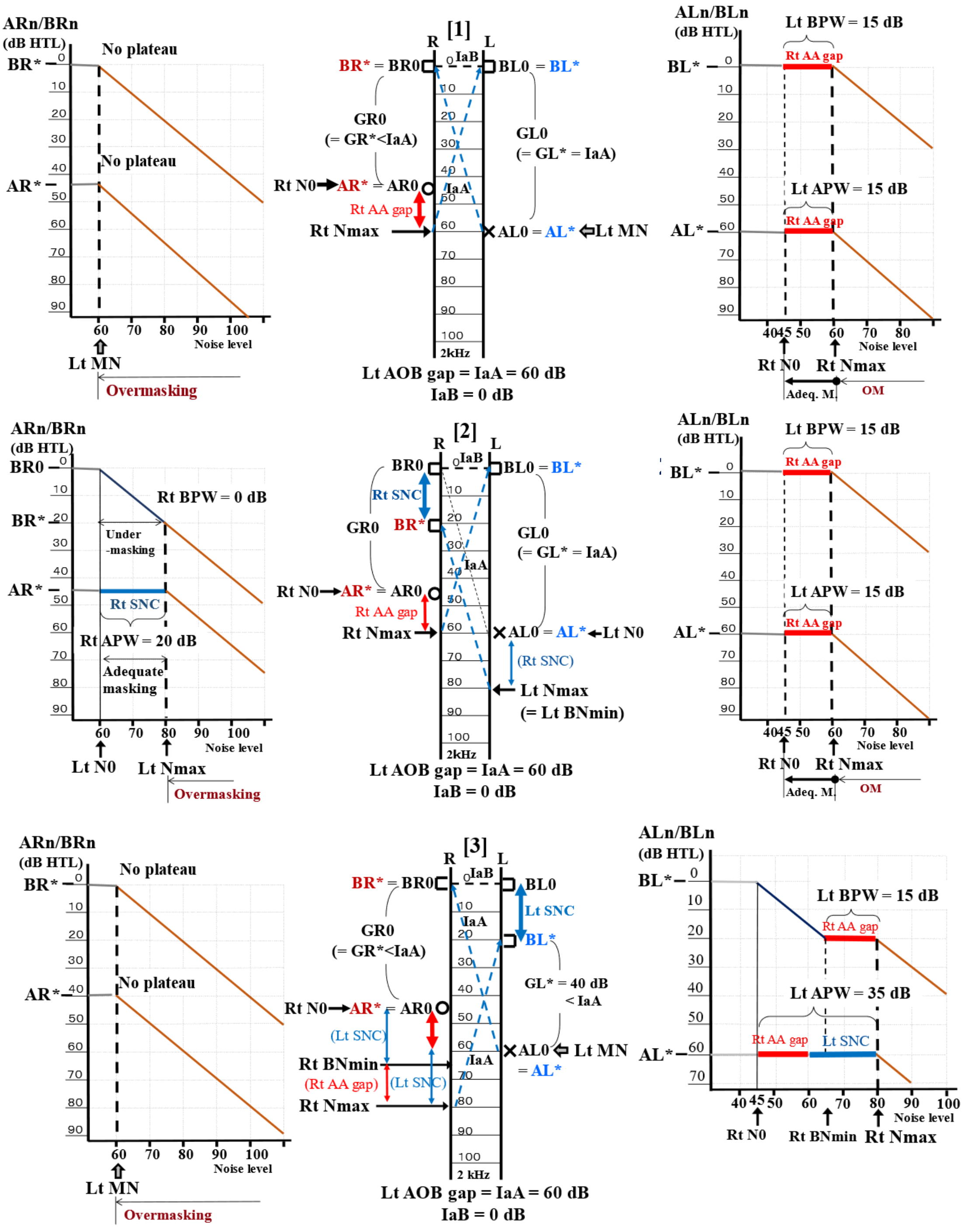


Figure 3-9 Plateau graphs in Patterns [1], [2], [3]

(5) Patterns [1'], [2'], [3']: Lt AOB gap < IaA = 70 dB, δ = IaA − Lt AOB gap = 10 dB. (**Fig. 3-10**)

	Lt APW	Lt BPW
Pattern [1']: GL* = IaA, BR* = BL* (Lt SNC = 0 dB)	Rt AAgap + **δ**	Rt AAgap + IaB + **δ**
Pattern [2']: GL* = IaA, BR* = BL* (Lt SNC = 0 dB)	Rt AAgap + **δ**	Rt AAgap + IaB + **δ**
Pattern [3']: GL* < IaA, BR* < BL* (Lt SNC > 0 dB)	Rt AAgap + **δ** + **Lt SNC**	Rt AAgap + IaB + **δ**

The plateau widths of both ears in P. [1'], [2'], [3'] are δ dB larger than those in P. [1], [2], [3].

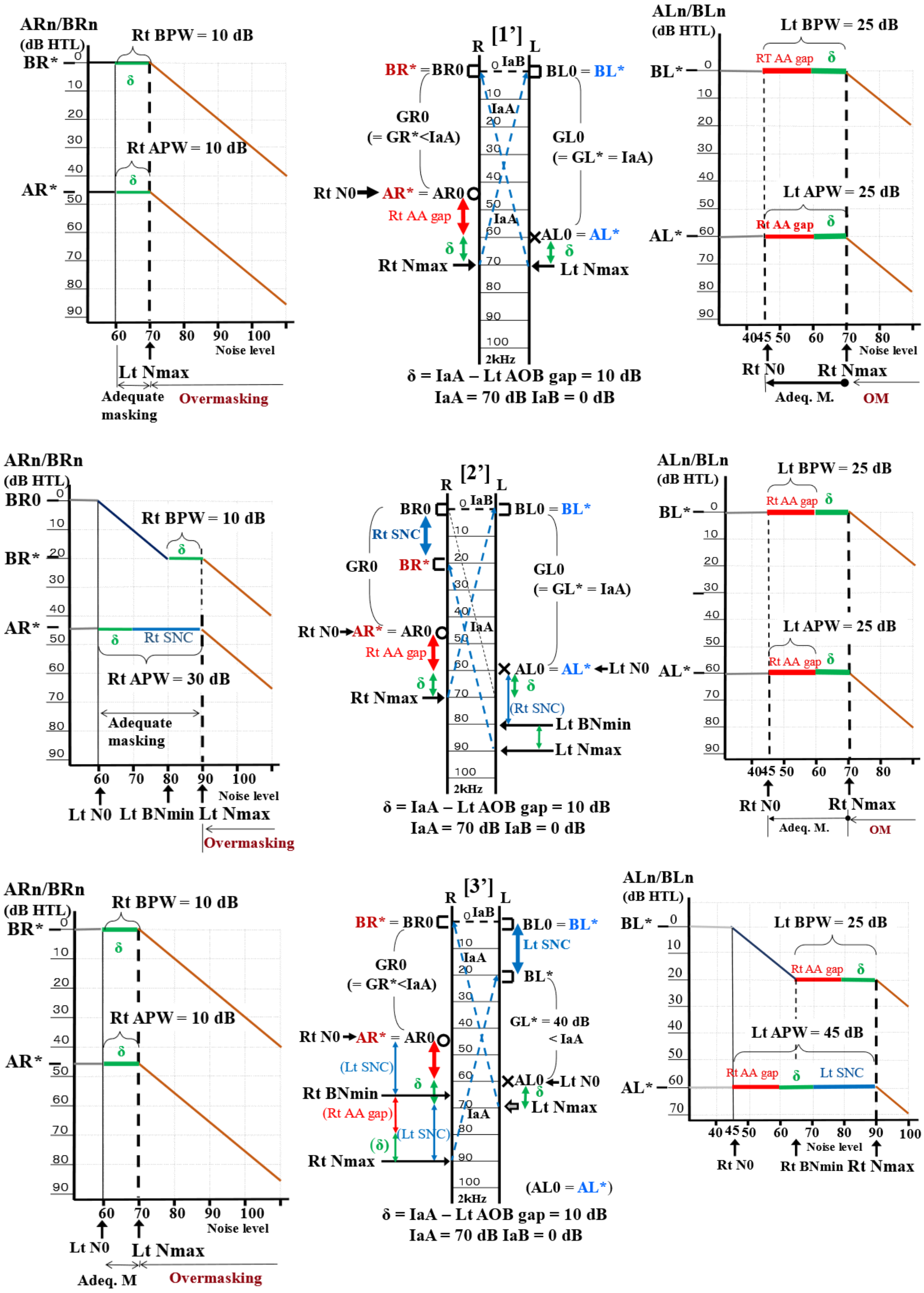


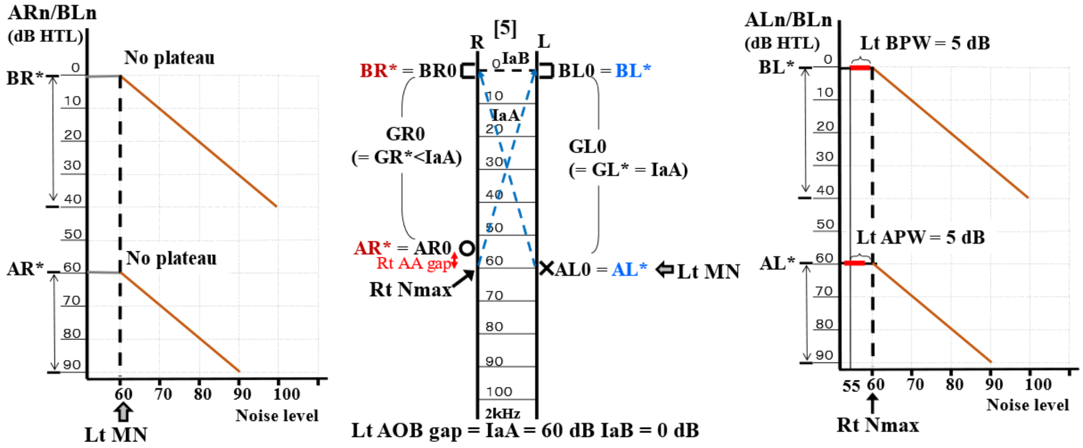
Figure 3-10 Plateau graphs in Patterns [1'], [2'], [3']

3.3 Patterns of the audiometric configurations with insignificant AA gaps (≤ 10dB)

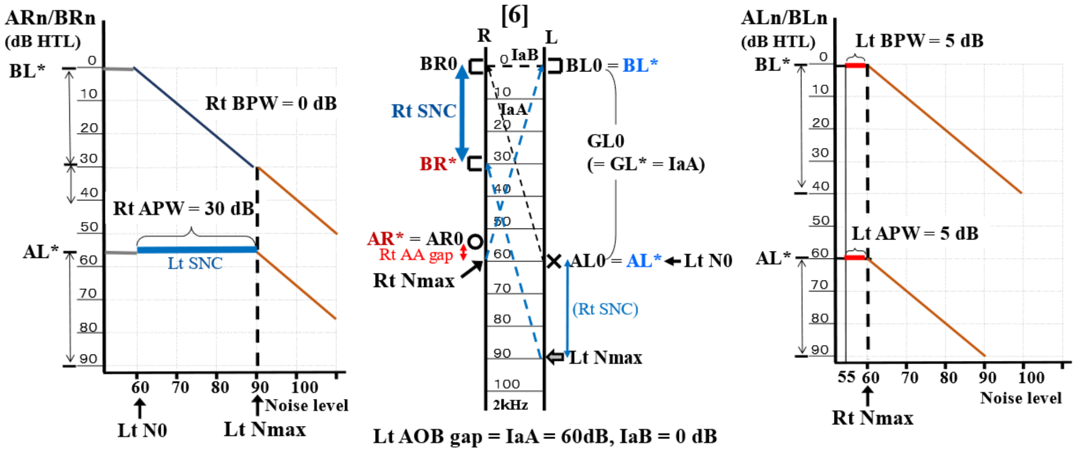
(1) Patterns [5], [6]: Lt AOB gap = IaA = 60 dB, δ = IaA − Lt AOB gap = 0 dB.

Pattern [5] (Rt AAgap = 5 dB) belongs to the pattern [1] series. Lt APW and BPW are only 5 dB: insignificant and the true thresholds cannot be determined, i.e., the clinical masking dilemma.

Pattern [6] (Rt AAgap = 5 dB) belongs to the pattern [2] or [3] series.). The true BC threshold in one ear is higher than the apparent BC threshold in that ear (ex; BR* > BR0). When the Rt AAgap is insignificant, the apparent AC threshold in the better ear by AC (ex; AR0) can be the SH threshold, considering measurement errors and is not determined to be the true one.

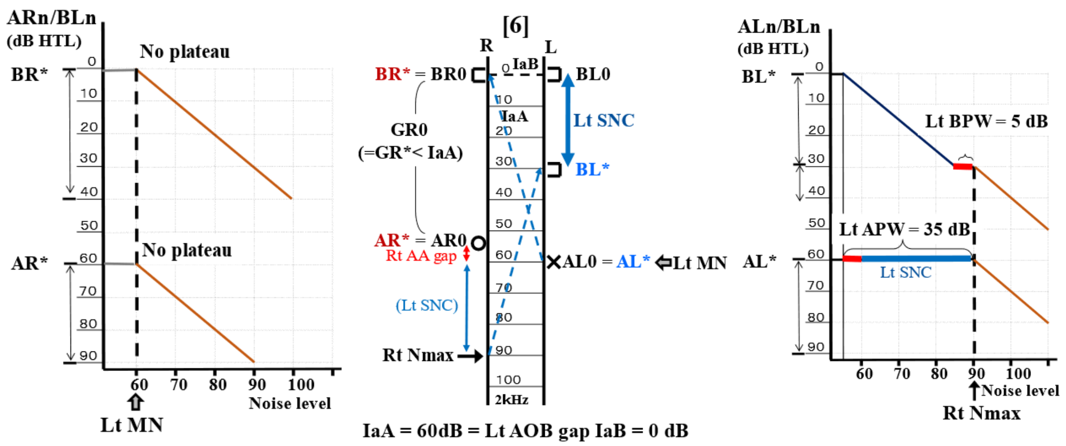


Pattern [1](Rt AAgap = 15 dB, δ = 0 dB) → **Pattern [5]** (Rt AAgap = 5 dB, δ = 0 dB)



Pattern [2](Rt AAgap = 15 dB, δ = 0 dB) → **Pattern [6]** (Rt AAgap = 5 dB, δ = 0 dB)

BR* can be estimated as well as the pattern [2]. The BL0 and AL0 can be found to be the true thresholds.



Pattern [3](Rt AAgap = 15 dB, δ = 0 dB) → **Pattern [6]** (Rt AAgap = 5 dB, δ = 0 dB)

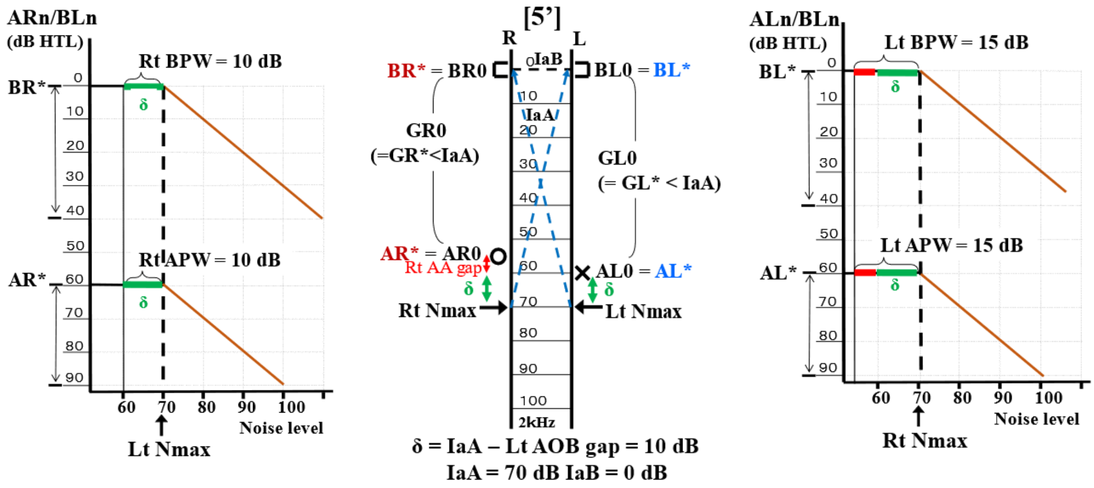
BL* can be estimated as well as the pattern [3]. The BR0 and AR0 can be found to be the true thresholds

Figure 3-11 Plateau graphs in Patterns [5], [6]

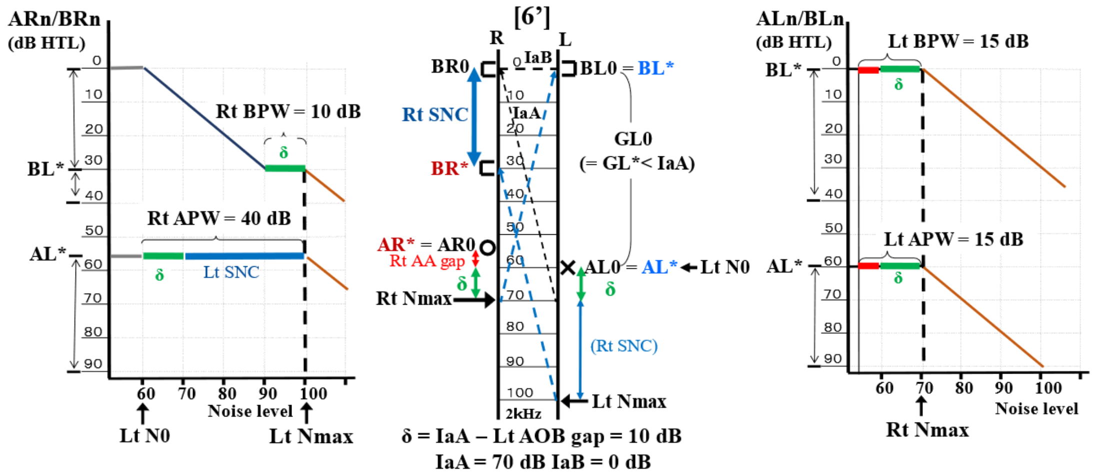
(2) Patterns [5’], [6’]: Lt AOB gap < IaA = 70 dB, δ = IaA − Lt AOB gap = 10 dB.

	Lt APW	Lt BPW
Pattern [5’]: GL* = IaA, BR* = BL*	Rt AAgap + δ	Rt AAgap + IaB + δ
Pattern [6’]: GL* < IaA, BR* < BL*	Rt AAgap + δ + Lt SNC	Rt AAgap + IaB + δ

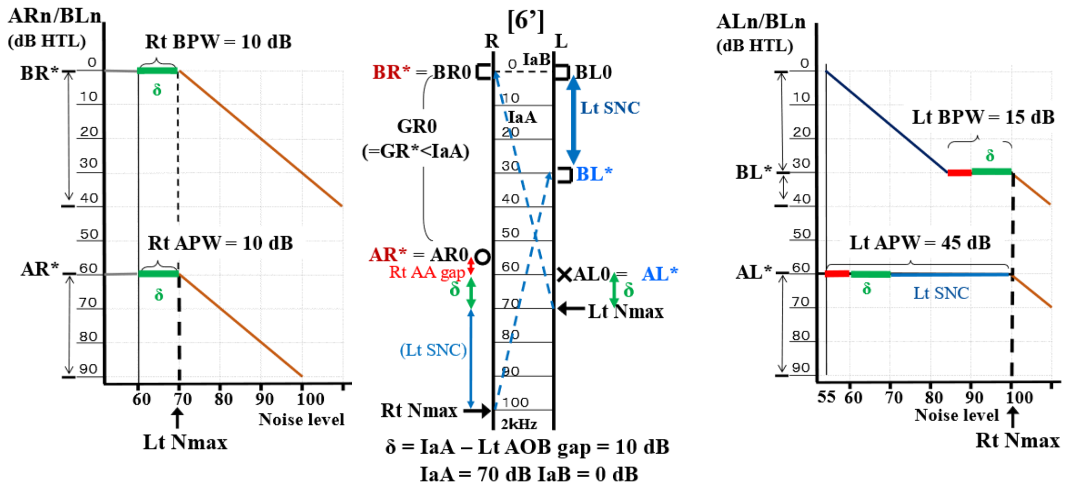
The plateau widths of both ears in P. [5’], [6’] are δ dB larger than those in P. [5], [6].



Pattern [1’](Rt AAgap = 15 dB, δ > 0 dB) → **Pattern [5’]** (Rt AAgap = 5 dB, δ > 0 dB)



Pattern [2’](Rt AAgap = 15 dB, δ > 0 dB) → **Pattern [6’]** (Rt AAgap = 5 dB, δ > 0 dB)



Pattern [3’](Rt AAgap = 15 dB, δ > 0 dB) → **Pattern [6’]** (Rt AAgap = 5 dB, δ > 0 dB)

Figure 3-12 Plateau graphs in Patterns [5’], [6’]

3.4 The audiometric configurations with the typical AC plateau

(1) Patterns of the audiometric configurations with significant AA gaps (≥ 15dB)

In the pattern [4-0] (Rt AAgap = 15 dB, AL0 < AL*, GL* < IaA), the apparent AC threshold in the left ear (AL0) is the SH threshold, and the true AC threshold in the left ear (AL*) is **ω** dB higher than AL0 (AL* = AL0 + **ω**) (**Fig. 3-13**). Typical plateaus for both AC and BC are obtained (**Fig. 3-14**).

Lt APW = Rt Nmax − Rt ANmin
= **Rt AAgap + Lt SNC** − **ω** = 30 dB.
∴ AL* = 80 dB HTL = AL0 + **ω**

Lt BPW = Rt Nmax − Rt BNmin
= **Rt AAgap + IaB** = 15 dB, IaB = 0 dB.
∴ BL* = 35 dB HTL = BL0 + Lt SNC

When the left ear is masked, the masking noise levels (Lt N > 60 dB HL) always cause overmasking, so the AC and BC plateaus in the right ear are not present.

We can estimate that this configuration is either the pattern [4-0] or [4-1], at the point that the AL0 is determined to be the SH threshold (AL0 < AL*). Therefore, the apparent AC and BC thresholds in the right ear (AR0 and BR0) are determined to be the true thresholds without masking. Since GL* = 45 dB < IaA, we find that it is the pattern [4-0].

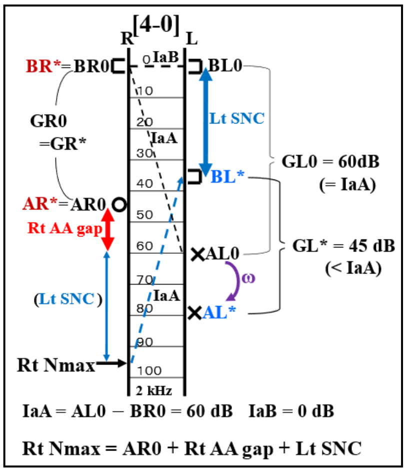


Figure 3-13 Pattern [4-0]

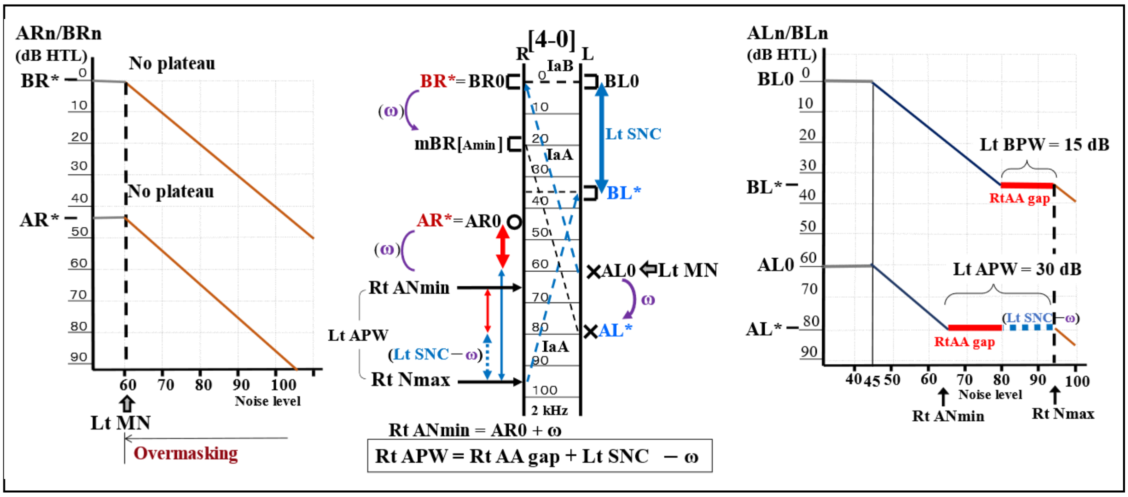


Figure 3-14 Plateau graphs in pattern [4-0]: GL* < IaA

For bone conduction, when IaB is 0 dB, Lt BPW = Rt AA gap + 0 dB = 15 dB (**Fig. 3-14**).
When IaB is 5 dB, Lt BPW is 5 dB (= IaB) wider: Lt BPW = Rt AAgap + 5 dB = 20 dB (**Fig. 3-15**).

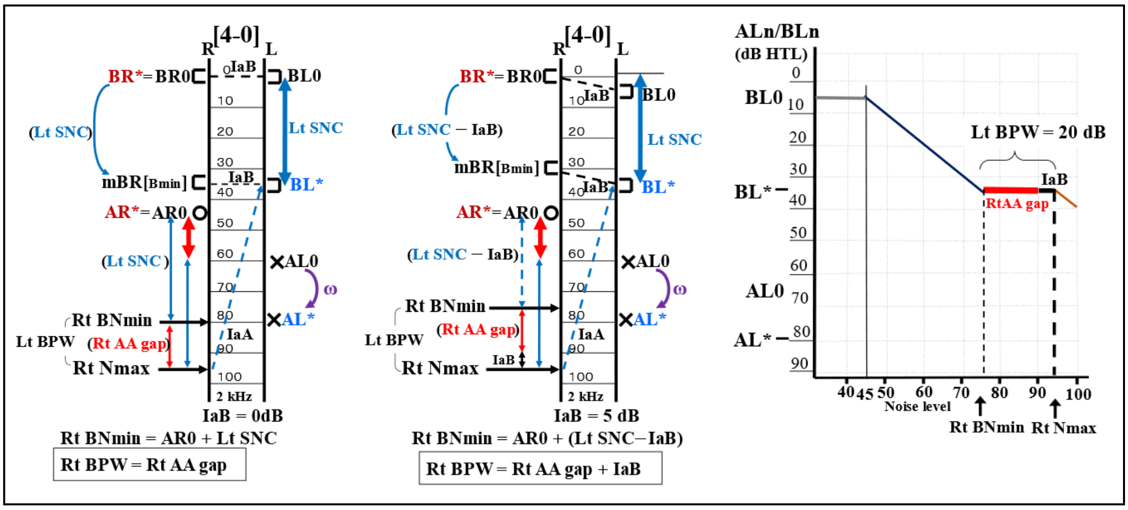


Figure 3-15 Lt BPW: IaB = 0 dB, IaB = 5 dB

Pattern [4-1] (Rt AAgap = 15 dB, AL0 < AL*, GL* = IaA) is the configuration in which the true AB gap in the left ear (GL*) is equal to IaA (GL* = IaA) (**Fig. 3-16**). Then, ω of 20 dB is equal to Lt SNC of 20 dB and (Lt SNC − ω) is 0 dB.

Lt APW = Rt AAgap + (Lt SNC − ω) **= Rt AA gap** = 15 dB.

∴ AL* = AL0 + **ω** = 80 dB HTL. ω = 20 dB

Lt BPW = **Rt AAgap** = 15 dB. IaB = 0 dB

∴ BL* = BL0 + Lt SNC = 20 dB HTL.

Since GL* = 60 dB = IaA, we find that this configuration is the pattern [4-1]. Therefore, the apparent thresholds in the right ear (AR0, BR0) are determined to be the true thresholds without masking. However, if the clinical plateau contraction of 10 dB occurs, the Lt APW may be 5 dB (insignificant) and the AC plateau cannot be detected. Thus, it is difficult to distinguish from the pattern [4-2], as described next. However, when Rt AA gap is larger than or equal to 25 dB, even if the contraction may occur, Lt APW is at least 15 dB (significant) and the true AC threshold in the left ear can be determined (**cf**. Masking theory **8.2-2, 8-6**).

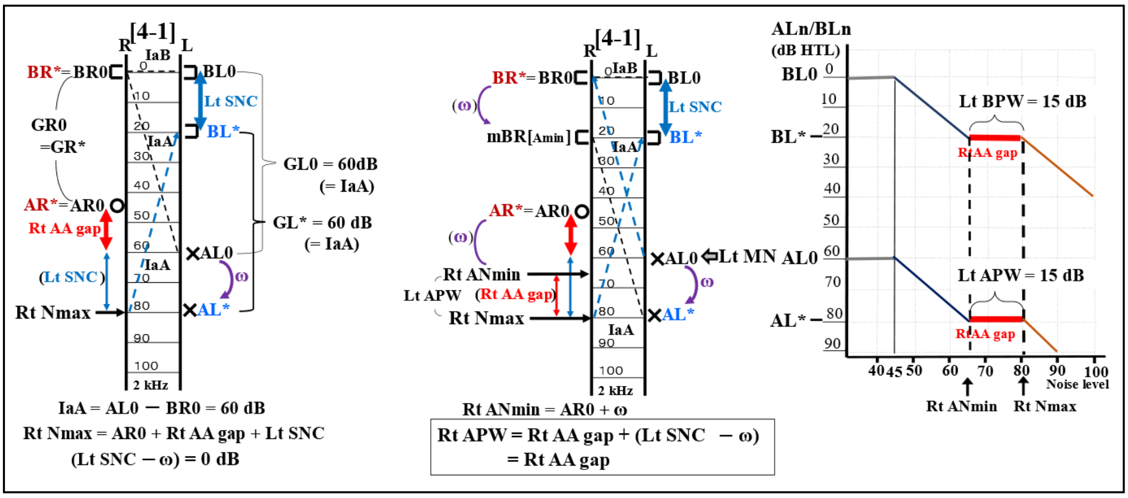


Figure 3-16 Lt plateau graph in Pattern [4-1]: GL* = IaA

Pattern [4-2] (Rt AAgap = 15 dB) is the configuration in which the true AC and BC thresholds in the left ear are the scaled-out levels (**Fig. 3-17**). When the right is masked, the effective masking noise levels (Rt N > 45 dB HL) always cause undermasking and the AC and BC plateaus in the left ear are not present.

As stated above, when Rt AA gap is 15 dB, the pattern [4-2] with no plateau cannot be distinguished from the pattern [4-1] with insignificant plateaus (= 5 dB).

When Rt AA gaps are ≥ 25 dB, if significant plateaus in the left ear are not present, we may consider that it is not overmasking but undermasking and that the true AC and BC thresholds in the left ear are the scaled-out levels . Hence, the apparent thresholds in the right ear (AR0, BR0) are found to be the true ones.

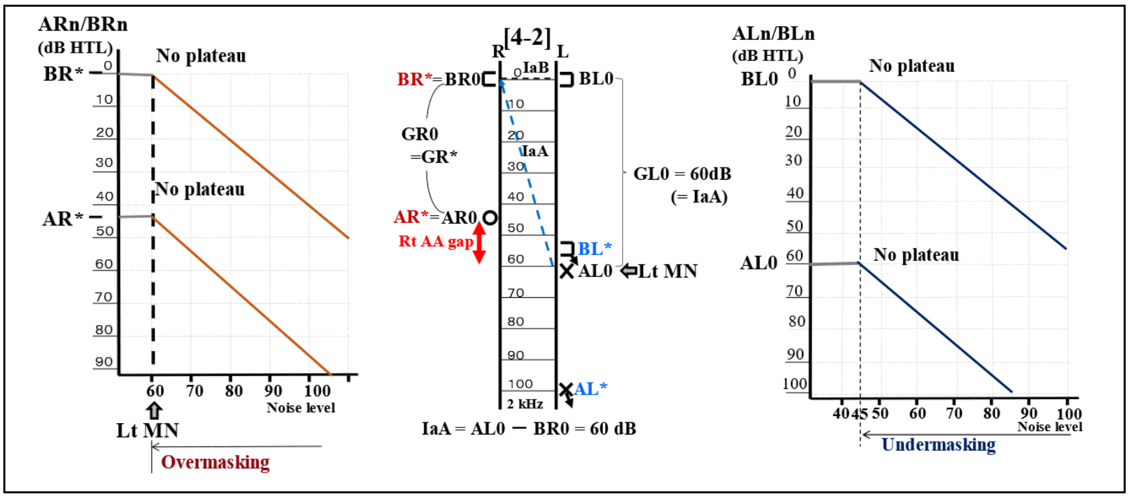


Figure 3-17 Plateau graphs in Pattern [4-2]

(2) Patterns of the audiometric configurations with insignificant AAgaps (≤ 10dB)

Pattern [7] (Rt AAgap = 5 dB) belongs to the pattern [4] series (Rt AAgap = 15 dB) (**Fig. 3-18**). The plateau widths of patterns [7-0] and [7-1] are the same as the patterns [4-0] and [4-1] (**Fig. 3-19**).

Lt APW = **Rt AAgap + Lt SNC** − **ω** = 20 dB.

Lt BPW = **Rt AAgap + IaB** = 5 dB, IaB = 0 dB.

The plateau width of the pattern [7] is narrower than that of the pattern [4].

In the pattern [7-0] (Rt AAgap = 5 dB, AL0 < AL*, GL* < IaA), at the point that the AL0 is determined to be the SH threshold (AL0 < AL*), we can find that the apparent thresholds in the right ear (AR0 and BR0) are the true thresholds (**Fig. 3-19**). Therefore, masking in the left ear is not needed.

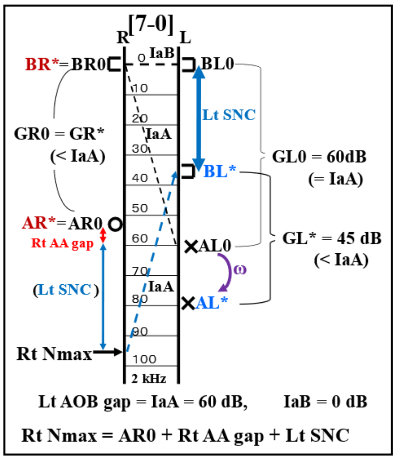


Figure 3-18 Pattern [7-0]

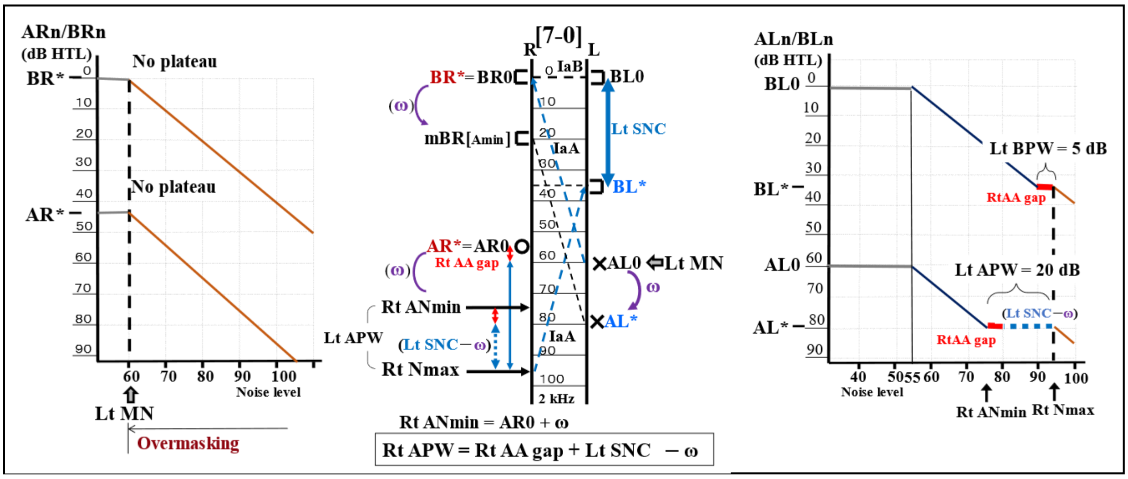


Figure 3-19 Plateau graphs in pattern [7-0]: GL* < IaA

For bone conduction, when IaB is 0 dB, the true BC threshold in the left ear cannot be determined since Lt BPW of 5 dB is insignificant (**Fig. 3-19**).

When IaB is 5 dB (**Fig. 3-20**), although the Lt BPW (Rt AA gap + IaA) of 10 dB is insignificant, the true BC threshold in the left ear (BL*) might be determined if it is obtained with high measurement accuracy (ΔA = 0 dB). The BL* can be calculated with the following equation:

BL* = **Rt Nmax** − **IaA** = Rt Nmax − (AL0 − BR0)

= 95 (dB HL) – 60 (dB) = 35 dB HTL.

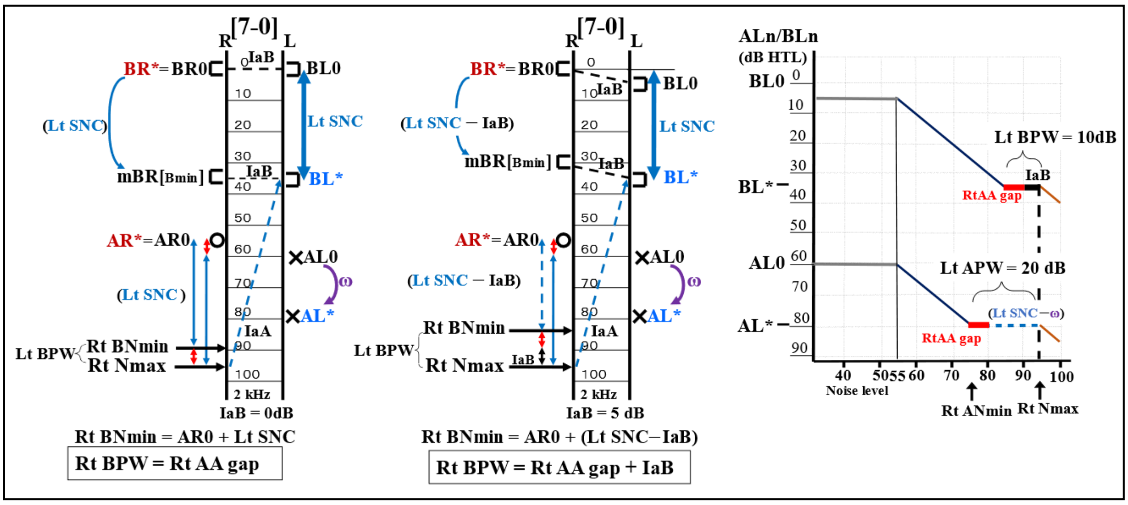


Figure 3-20 Lt BPW: IaB = 0 dB, IaB = 5 dB

Pattern [7-1] (Rt AAgap = 5 dB, AL0 < AL*, GL* = IaA) is the configuration in which the true AB gap in the left ear (GL*) is equal to IaA (GL* = IaA). Then, ω of 20 dB is equal to Lt SNC of 20 dB and (Lt SNC − ω) is 0 dB (**Fig. 3-21**).

Lt APW = Rt AA gap + (Lt SNC − ω)

= **Rt AA gap** = 5 dB.

Lt BPW = **Rt AA gap** = 5 dB, IaB = 0 dB

Since the plateau width of 5 dB is insignificant, the true AC and BC thresholds in the left ear cannot be determined. When the left ear is masked, the masking noise levels (Lt N > 60 dBHL) always cause overmasking, so the AC and BC plateaus in the right ear are not present (**Fig. 3-22**). The true AC and BC thresholds in the right ear cannot be determined. Therefore, the pattern [7-1] is a clinical masking dilemma .

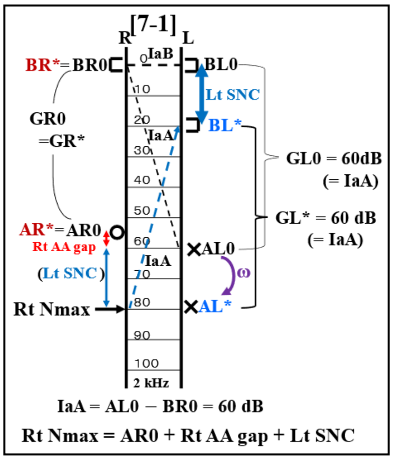


Figure 3-21 Pattern [7-1]

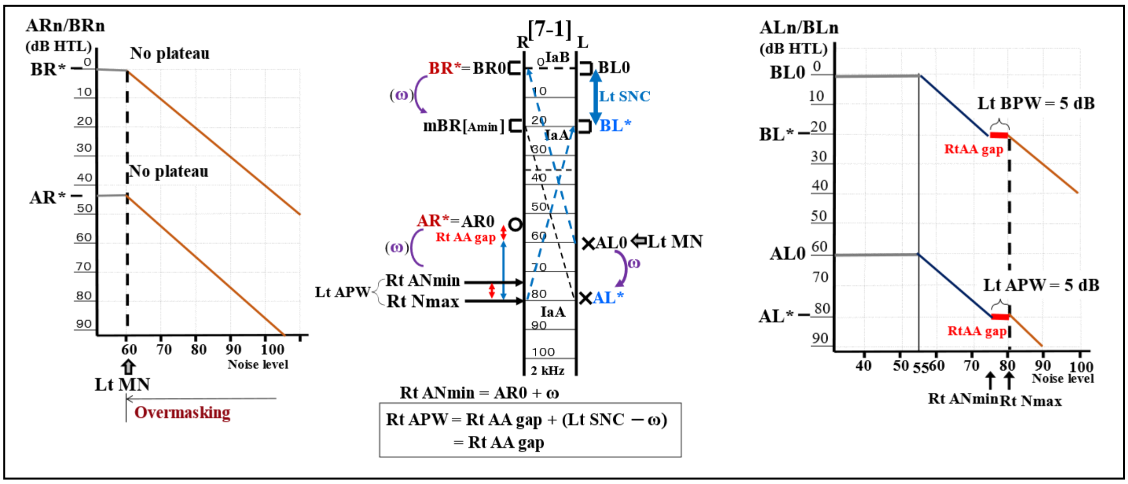


Figure 3-22 Plateau graphs in pattern [7-1]: GL* = IaA

Pattern [7-2] (Rt AAgap = 5 dB) is the configuration in which the true AC and BC thresholds in the left ear are the scaled-out levels (**Fig. 3-23**). When the right ear is masked, the effective masking noise levels (Rt N > 55 dBHL) always cause undermasking and the AC and BC plateaus in the left ear are not present. When the left ear is masked, the AC and BC plateaus in the right ear are not present due to overmasking. Since the Rt AA gap of 5 dB is insignificant, the significant plateau width cannot be obtained. It is impossible to distinguish undermasking from overmasking (**cf.** pattern [4-2] **Fig. 3-17**). The pattern [7-2] is also the masking dilemma.

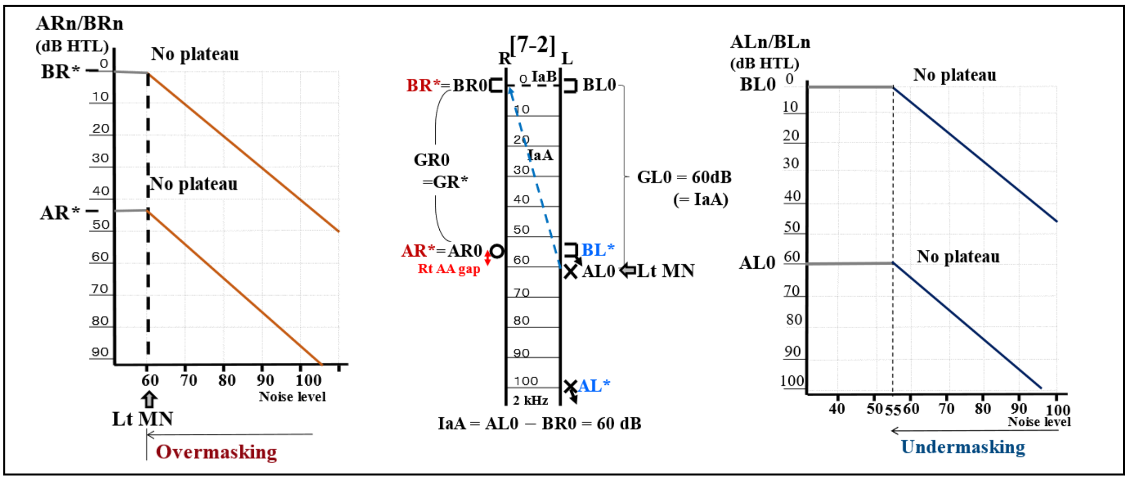
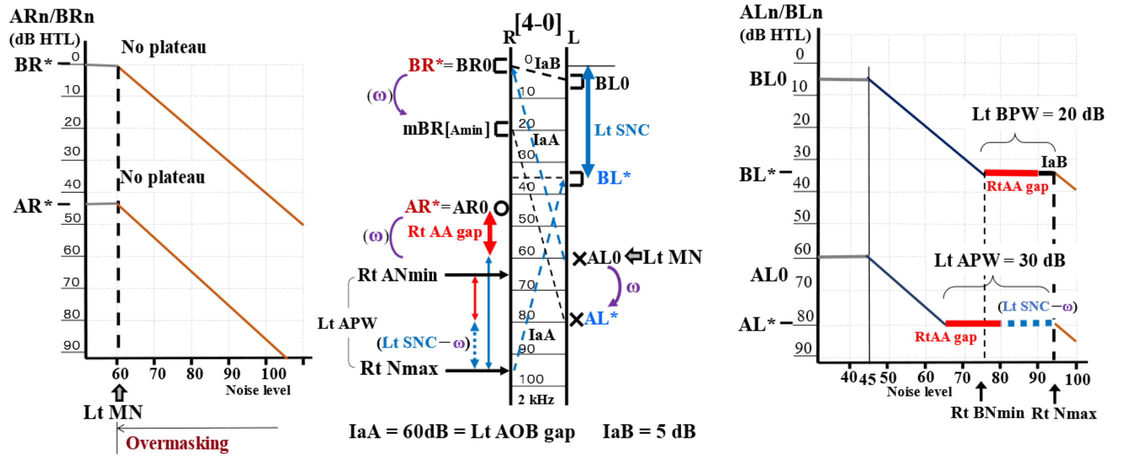


Figure 3-23 Plateau graphs in pattern [7-2]

(3) Patterns [4-0], [4-1], [4-2]: Rt AA gap ≥ 15 dB, Lt AOB gap = IaA = 60 dB, δ = 0 dB.

	Lt APW	Lt BPW
Pattern [4-0]: GL* < IaA, BR* < BL* (Lt SNC = 35 dB)	Rt AAgap + **Lt SNC** − **ω**	Rt AAgap + IaB
Pattern [4-1]: GL* = IaA, BR* < BL* (Lt SNC = 20 dB)	Rt AAgap	Rt AAgap + IaB
Pattern [4-2]:	No APW	No BPW

In patterns [4-0] and [4-1], typical plateaus for both AC and BC are obtained (**Fig. 3-24**).
It should be noted that if the IaB value > 0 dB, Lt BPWs are larger by the IaA value.



At the point that the AL0 is determined to be the SH threshold (AL0 < AL*), we can estimate that this configuration is either the pattern [4-0] or [4-1]. Therefore, the apparent AC and BC thresholds in the right ear (AR0 and BR0) are determined to be the true thresholds without masking.

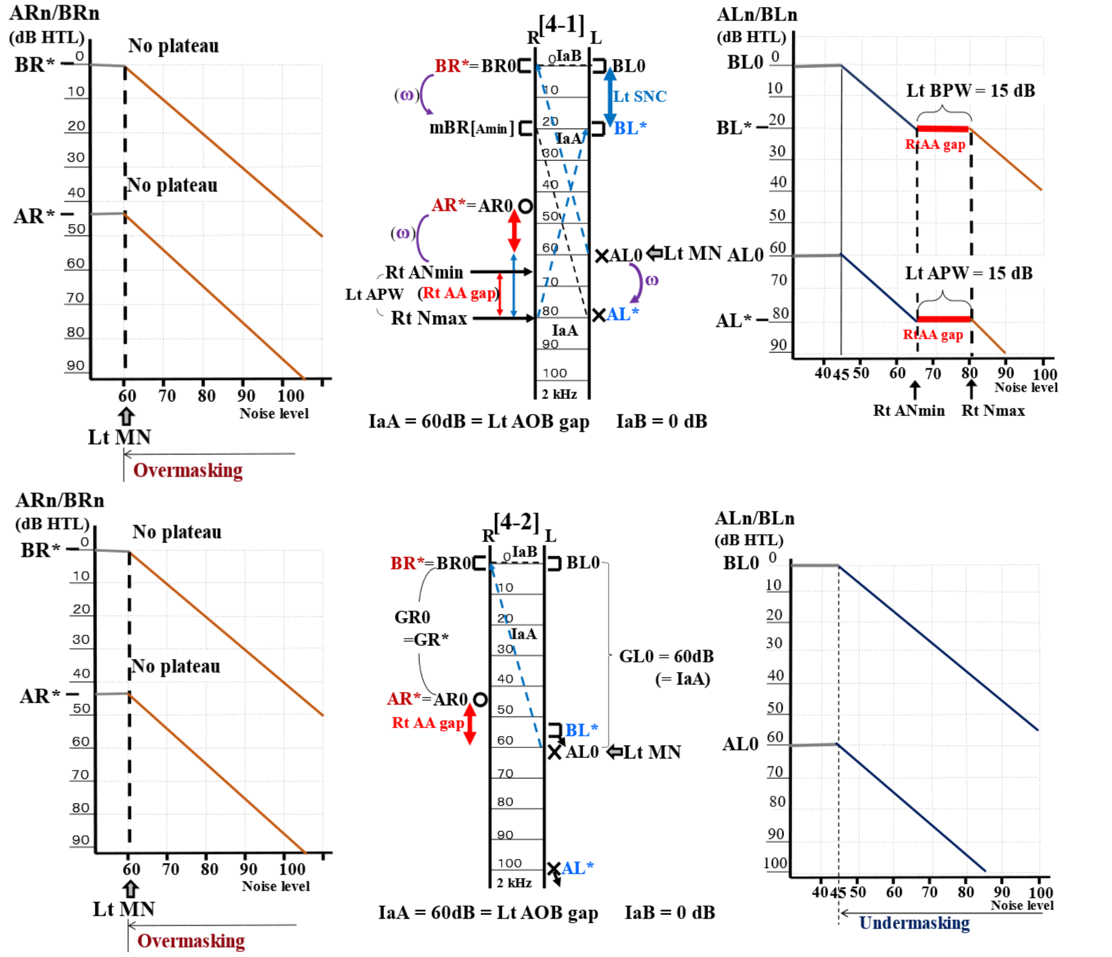
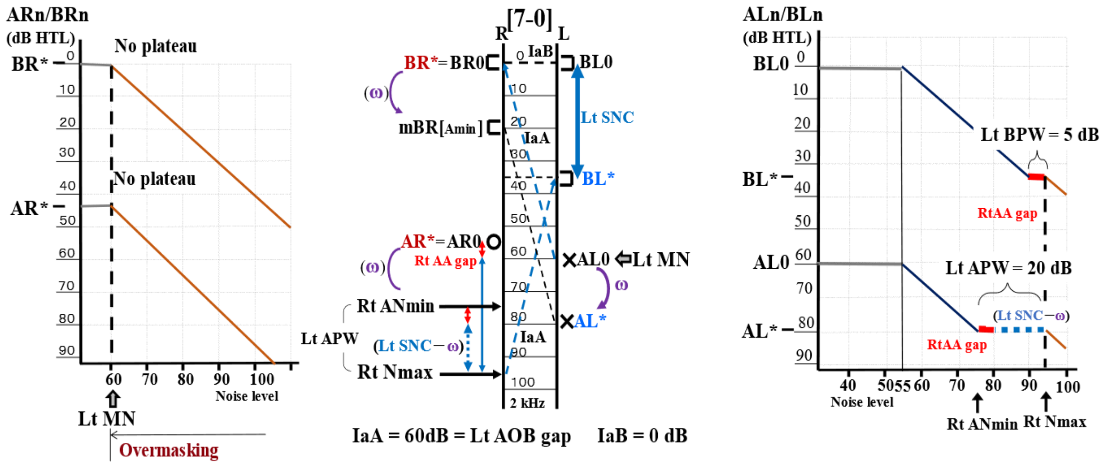


Figure 3-24 Plateau graphs in pattern [4]

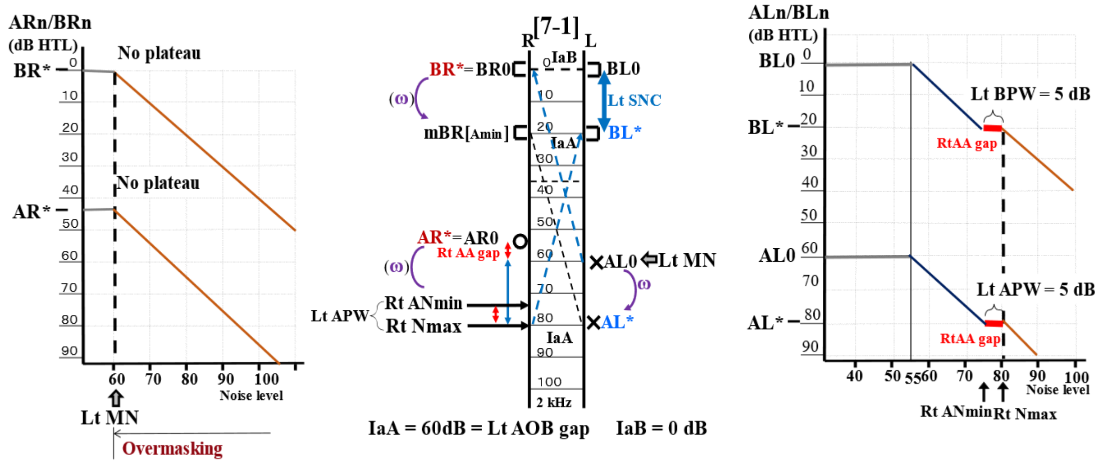
(4) Patterns [7-0], [7-1], [7-2]: Rt AA gap ≤ 10 dB, Lt AOB gap = IaA = 60 dB, δ = 0 dB).

	Lt APW	Lt BPW
Pattern [7-0]: GL* < IaA, BR* < BL* (Lt SNC = 35 dB)	Rt AAgap + Lt SNC − ω	Rt AAgap + IaB
Pattern [7-1]: GL* = IaA, BR* < BL* (Lt SNC = 20 dB)	Rt AAgap	Rt AAgap + IaB
Pattern [7-2]:	No APW	No BPW

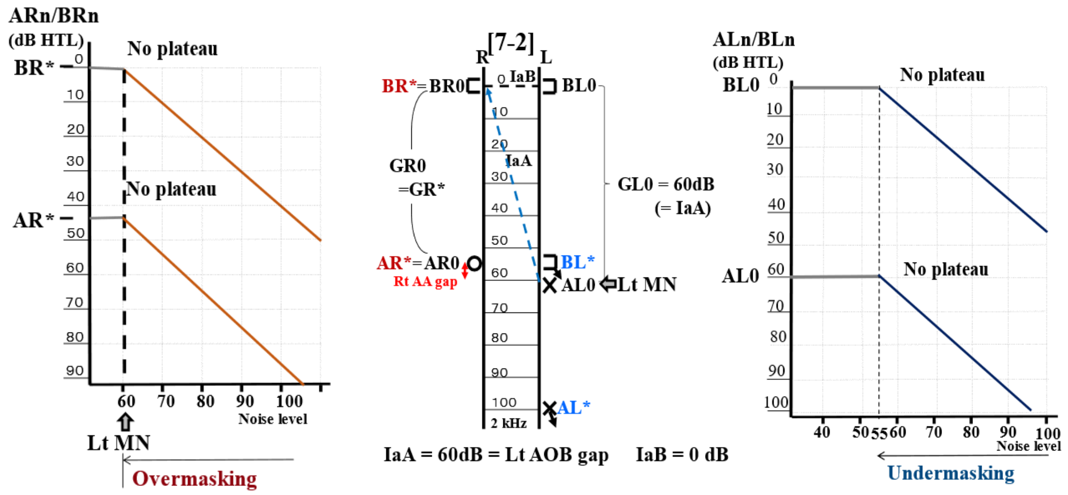
Pattern [7] series belongs to the pattern [4] series (**Fig. 3-25**).



Pattern [4-0](Rt AAgap = 15 dB, GL* < IaA) → **Pattern [7-0]** (Rt AAgap = 5 dB, GL* < IaA)



Pattern [4-1](Rt AAgap = 15 dB, GL* = IaA) → **Pattern [7-0]** (Rt AAgap = 5 dB, GL* = IaA)



Pattern [4-0](Rt AAgap = 5 dB, Lt: scaled out) → **Pattern [7-2]** (Rt AAgap = 5 dB, Lt: scaled out)

Figure 3-25 Plateau graphs in pattern [7]

3.5 Series of the audiometric patterns and their utmost limits

All patterns of audiometric configurations at some frequency are grouped into four series.

(1) Pattern [1] series (Fig. 3-26)

In pattern [1'], Lt PWs = Rt AA gap + δ = 70 dB. When δ = 0 dB (IaA = Lt AOB gap), Lt PWs = Rt AA gap; i.e., pattern [1]. The two patterns are termed pattern [1] series. Furthermore, if the Rt AA gap becomes smaller and insignificant (Rt AA gap ≤ 10 dB), the patterns shift to patterns [5'] and [5] (i.e., pattern [5] series). The utmost limit of pattern [1] series is pattern [5] series.

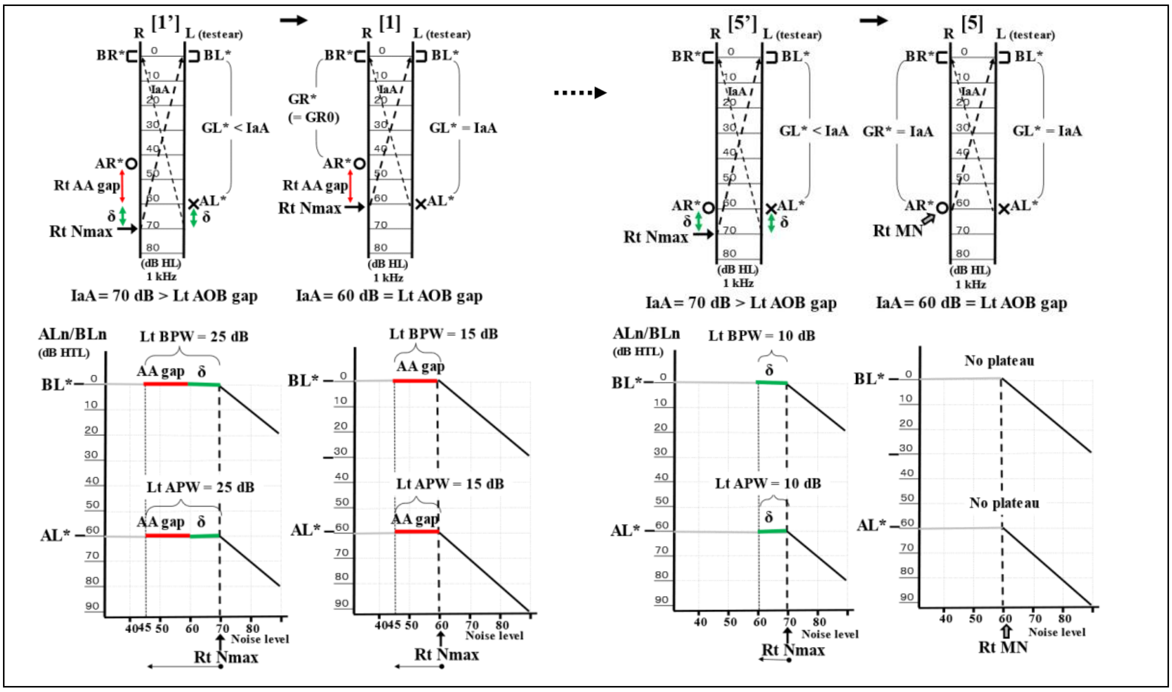


Figure 3-26 Pattern [1] series and its utmost limit

(2) Pattern [2] series (Fig. 3-27)

Pattern [2] series consists of pattern [2'] (IaA = Lt AOB gap + δ) and pattern [2] (IaA = Lt AOB gap). The utmost limit of the pattern [2] series is the pattern [6] series (pattern [6] and [6']).
The Lt PWs of the pattern [2] series are the same as those of the pattern [1] series.

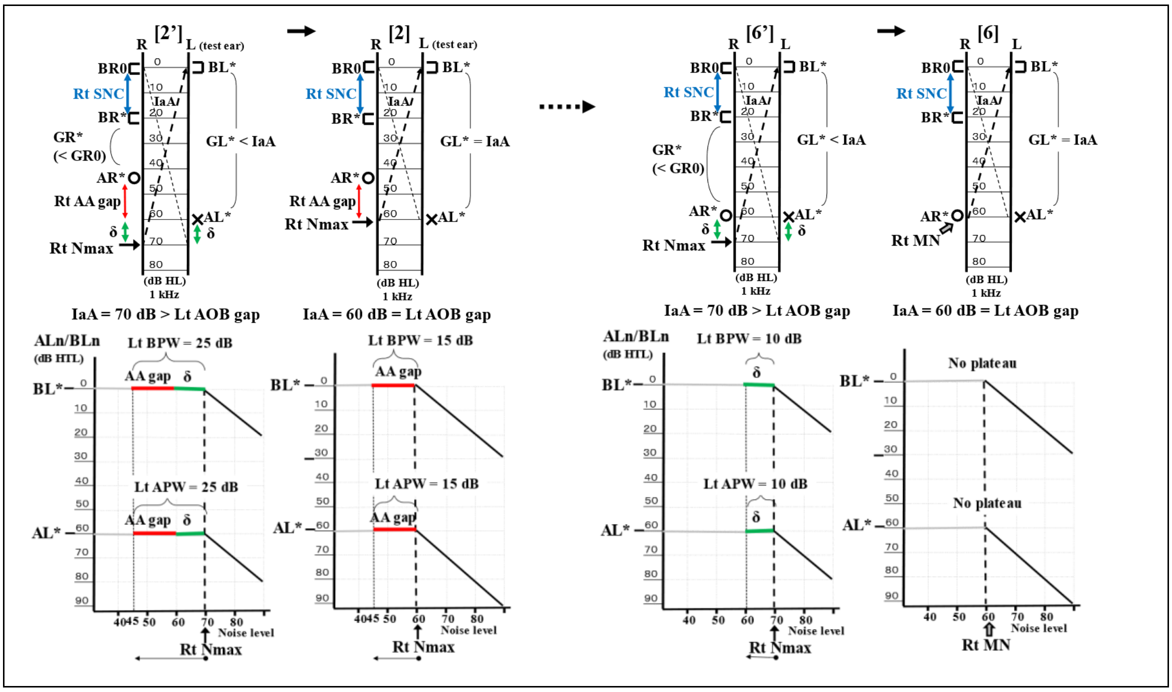


Figure 3-27 Pattern [2] series and its utmost limit

(3) Pattern [3] series (Fig. 3-28)

Pattern [3] series consists of pattern [3'] (IaA = Lt AOB gap + δ) and pattern [3] (IaA = Lt AOG gap). The utmost limit of the pattern [3] series is the pattern [6] series (pattern [6] and [6']).

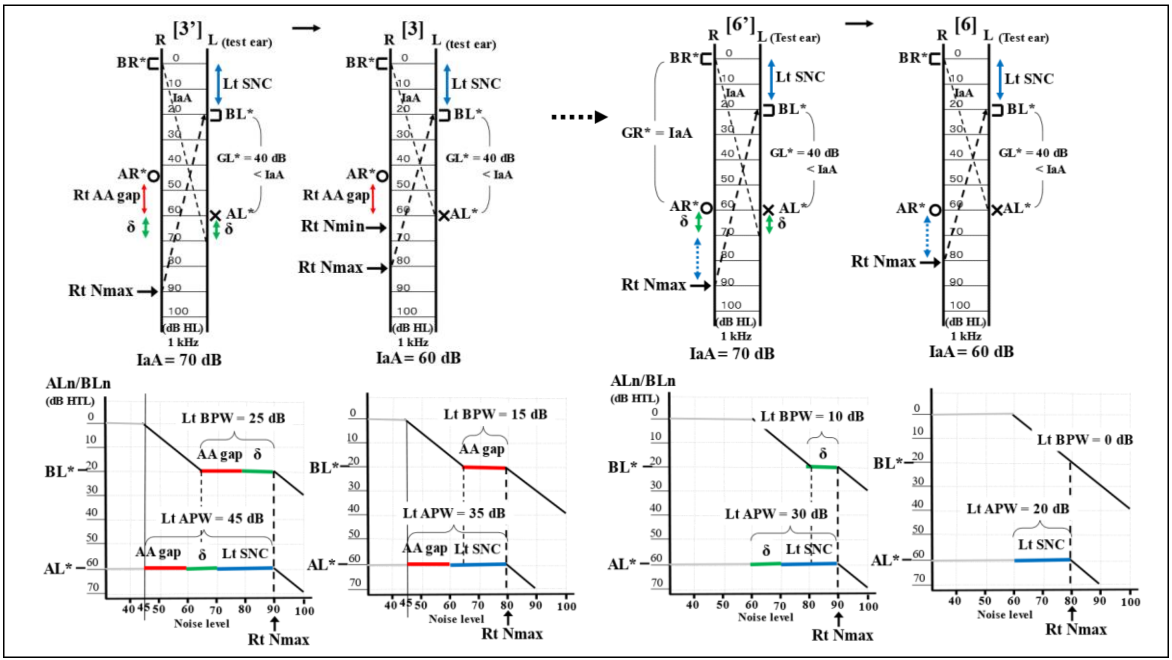


Figure 3-28 Pattern [3] series and its utmost limit

(4) Pattern [4] series (Fig. 3-29)

In pattern [4-0], the true AB gap of the left, poorer ear by AC is smaller than IaA (GL* < IaA). In pattern [4-1], GL* = IaA. In pattern [4-2], the left ear is a complete hearing loss. Furthermore, if the Rt AA gap becomes smaller and insignificant (Rt AA gap ≤ 10 dB), each pattern [4] series shifts to patterns [7-0], [7-1], and [7-2]. The utmost limit of the pattern [4] series is the pattern [7] series.

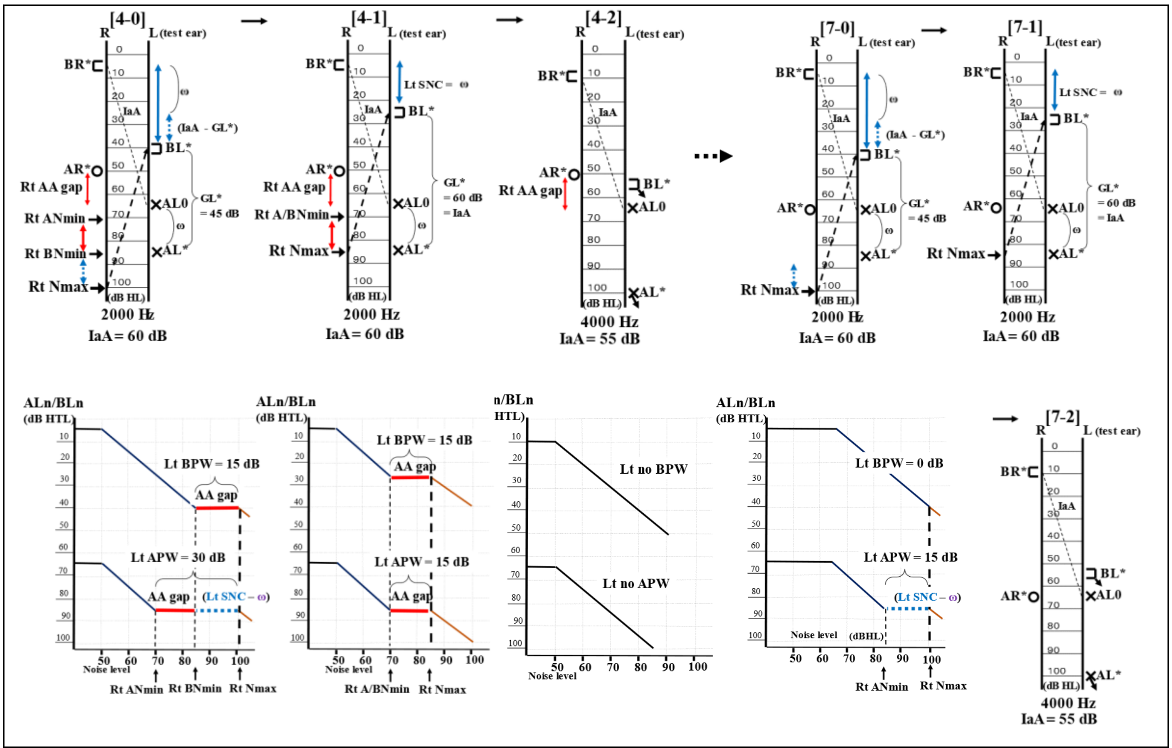


Figure 3-29 Pattern [4] series and its utmost limit

3.6 Factors that determine the difficulty level of masking

When Rt AA gap = AL0 − AR0 ≥ 0 dB, the plateau widths may be reduced to formulas including the Rt AA gap (**Fig. 3-30**). The PWs in both ears consist of five elements as follows:

1) Rt AA gap = AL0 − AR0 ≥ 0 dB 2) δ = IaA − Lt AOB gap ≥ 0 dB
3) Rt SNC = BR* − BL* ≥ 0 dB 4) Lt SNC = BL* − BR* ≥ 0 dB
5) ω = AL* − AL0 > 0 dB; only in patterns [4] and [7].

Here, the case with no plateau is indicated using the symbol (–).

The IaB value is supposed to be 0 dB (IaB = 0 dB). Lt AA gap = 0 dB.

Patterns		Rt APW	Rt BPW	Lt APW	Lt BPW
[1], [5]:	δ = 0 dB	(−)	(−)	Rt AA gap	Rt AA gap
[2], [6]:	δ = 0 dB	**Rt SNC**	0 dB	Rt AA gap	Rt AA gap
[3], [6]:	δ = 0 dB	(−)	(−)	Rt AA gap + **Lt SNC**	Rt AA gap
[4-0], [7-0]:	δ = 0 dB	(−)	(−)	Rt AA gap + **Lt SNC** − **ω**	Rt AA gap
[4-1], [7-1]:	δ = 0 dB	(−)	(−)	Rt AA gap	Rt AA gap
[4-2], [7-2]:	δ = 0 dB	(−)	(−)	(−)	(−)
[1'], [5']:	δ ≥ 5 dB	**δ**	**δ**	Rt AA gap + **δ**	Rt AA gap + **δ**
[2'], [6']:	δ ≥ 5 dB	**δ** + **Rt SNC**	**δ**	Rt AA gap + **δ**	Rt AA gap + **δ**
[3'], [6']:	δ ≥ 5 dB	**δ**	**δ**	Rt AA gap + **δ** + **Lt SNC**	Rt AA gap + **δ**

When Rt AA gap ≥ 15 dB, the configurations are patterns [1], [2], [3], [4], [1'], [2'], or [3'].
When Rt AA gap ≤ 10 dB, those are patterns [5], [6], [7], [5'], or [6'].

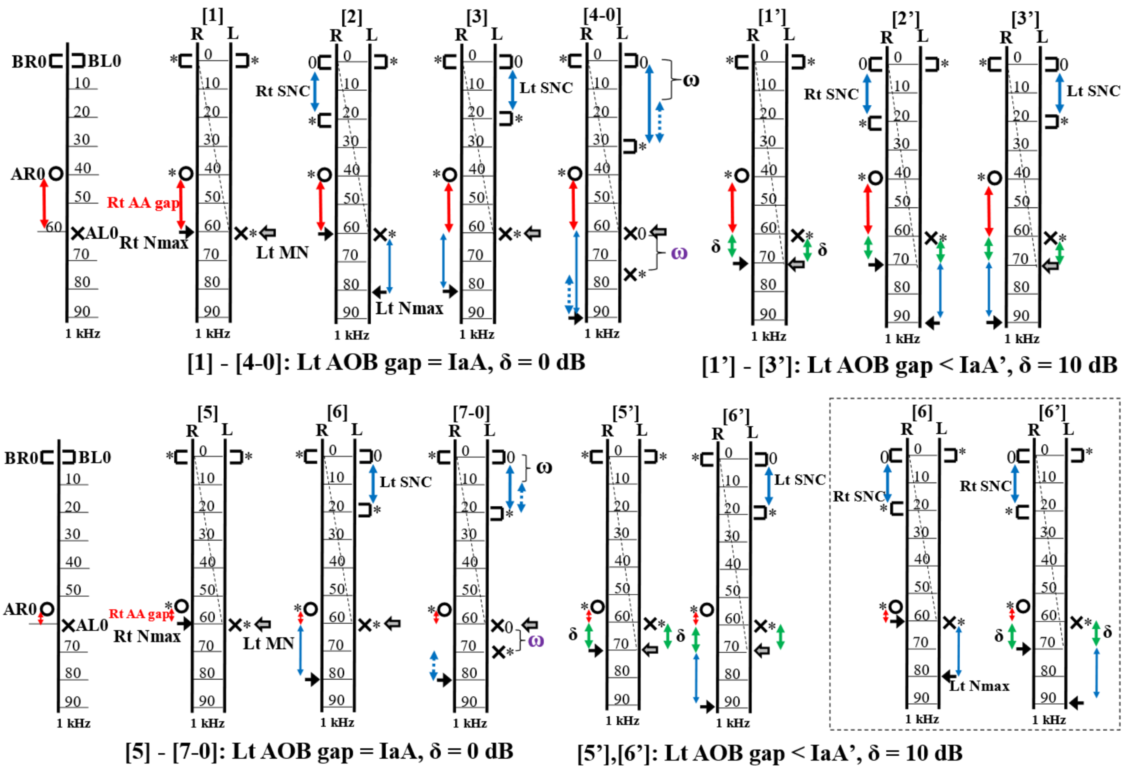


Figure 3-30 Audiometric configurations including Rt AA gaps

General expression for the plateau widths

Lt APW = (Rt AA gap + **δ**) + (**Lt SNC** – **ω**).	Lt BPW = (Rt AA gap + **δ**).

When **ω ≥ 0 dB** (AL* < AL0), **δ** = 0 dB, the configuration is the pattern [4] series.

Lt APW = Rt AA gap + (**Lt SNC** – **ω**).	Lt BPW = Rt AA gap.	P. [4-0], [4-1], [7-0]

When **ω = 0 dB** (AL* = AL0), **δ** ≥ 0 dB, the configuration is one of the patterns [1], [2] or [3] series.

Lt APW = (Rt AA gap + **δ**) + **Lt SNC**.	Lt BPW = (Rt AA gap + **δ**).	P.[3'], [6']

Lt APW = Rt AA gap + **Lt SNC**.	Lt BPW = Rt AA gap.	P.[3], [6]
Lt APW = Rt AA gap + **δ**.	Lt BPW = Rt AA gap + **δ**.	P.[1'], [5'], [2'], [6']
Lt APW = Rt AA gap.	Lt BPW = Rt AA gap.	P.[1], [5], [2], [6]

Lt APW = (Rt AA gap + δ) + (**Lt SNC**).	Lt BPW = (Rt AA gap + δ).	P.[1],[2].[3] series
Lt APW = (Rt AA gap) + (**Lt SNC** – ω).	Lt BPW = (Rt AA gap).	P.[4] series

Among the five elements of PWs, only AA gaps can be determined without masking. The other elements (δ, Rt SNC, Lt SNC and ω) are unknown. Furthermore, as the Lt AOB gap is larger, δ becomes smaller and the plateau width becomes narrower. The reverse is also true. Namely, the Rt AA gap and Lt AOB gap may be indicators for estimating the difficulty level of masking.

Rt AA gap = AL0 − AR0 ≥ 0 dB   **δ** = IaA − **Lt AOB gap** ≥ 0 dB

Using the two factors AA gap and AOB gap, we may estimate the difficulty level of masking to some extent before masking.

When Rt AA gap = AL0 − AR0 ≥ 15 dB, the minimum plateau width is equal to the Rt AA gap:

Lt APW ≥ Lt BPW ≥ Rt AA gap ≥ 15 dB.

Lt BPW and Lt APW are guaranteed to be significant (≥ 15 dB). Even if the Lt AOB gap is large (i.e., δ is small), masking for the left AC and BC is easy.

As shown in **Fig. 3-31 (a)**, when Rt AA gap = AL0 − AR0 ≤ 10 dB and Lt AOB gap is small (< 40 dB), masking for AC is not needed. Even if Rt AA gap is small (5 dB), since Lt AOB gap is small (i.e., δ is large), we can predict Lt BPW would be wide.

In **Fig. 3-31 (b), (c)**, when Lt AOB gap is large (≥ 40 dB) (i.e., δ is large), Lt BW may be narrow. Thus, we can expect that masking for both the BC may be difficult or impossible. At this time, although masking for AC might also be difficult. However, if either Rt SNC or Lt SNC is large, the APW can be detected in one ear. We cannot predict the SNC value and masking for AC should be done.

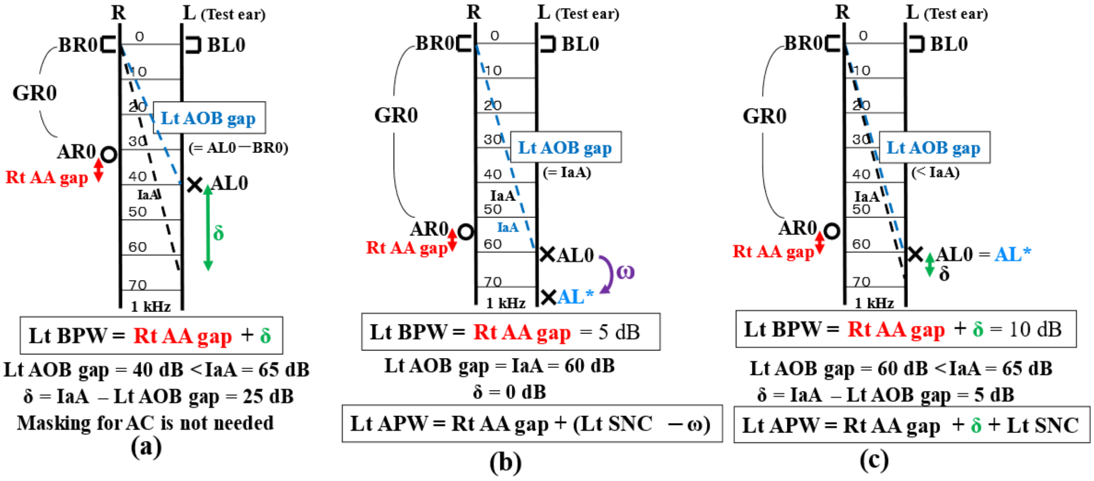


Figure 3-31 Rt AA gap and Lt AOB gap

If the true AC threshold in one ear is determined, the OM method is applicable and the true BC threshold in the same ear can be estimated. If both the true AC thresholds can not be determined, its configuration is a masking dilemma.

For practical purposes, AA gaps serve as a clear indicator to predict the difficulty level of masking.

As Rt AA gap is larger, masking for the left AC becomes easy. Therefore, it is recommended that masking for AC should be started at frequencies with wide AA gaps. The same holds for BC.

It should be noted that if the IaB value > 0 dB, Lt BPWs are larger by the IaA value.

If the examiner could previously predict the result of the test, pure tone audiometry will be performed more efficiently and becomes less of a burden on the participants being tested.

Lt APW = (Rt AA gap + δ) + (**Lt SNC** – ω).	Lt BPW = Rt AA gap + δ.
= (IaA – GR0) + (**Lt SNC** – ω).	= (IaA – GR0)
GR0: the non-test ear's apparent AB gap	

The two factors, Rt AA gap and δ, can be expressed as (IaA – GR0). If the apparent AB gap in the non-test ear (GR0) is small, masking for AC and BC in the test ear is easy.

3.7 The masking dilemma

(1) Three audiometric configurations of the theoretical masking dilemma

The masking dilemma preciously means that both the true AC and BC thresholds cannot be determined with masking noises of any level. Theoretically, the following three audiometric configurations are the cases (**Fig. 3-31**):

(a) Pattern [5]: bilateral true AB gaps are equal to IaA and BR* = BL*.

(b) Pattern [7-1]: bilateral true AB gaps are equal to IaA and BR* < BL* .

(c) Pattern [7-2]: the true AB gap in one ear is equal to IaA and the other is a complete hearing loss.

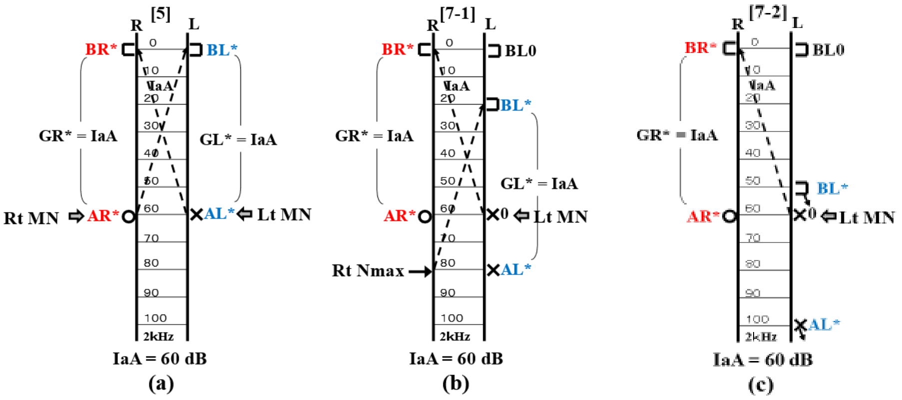


Figure 3-31 Theoretical masking dilemma: PWs = 0 dB or not present

(2) The plateau graph with no significant plateau: GR0 = GL0 = IaA.

When bilateral apparent AB gaps are equal to IaA (GR0 = GL0 = IaA), no plateaus are present or plateau widths of 0 dB cannot be identified. Therefore, the true AC and BC thresholds cannot be determined, which is an undecidable case for masking in theory.

The examiners cannot identify the actual configuration from the plateau graphs in **Fig. 3-32**.

We only know that the apparent AC and BC thresholds in at least one ear are true thresholds and the other ear is a complete hearing loss or its true AB gap is equal to IaA.

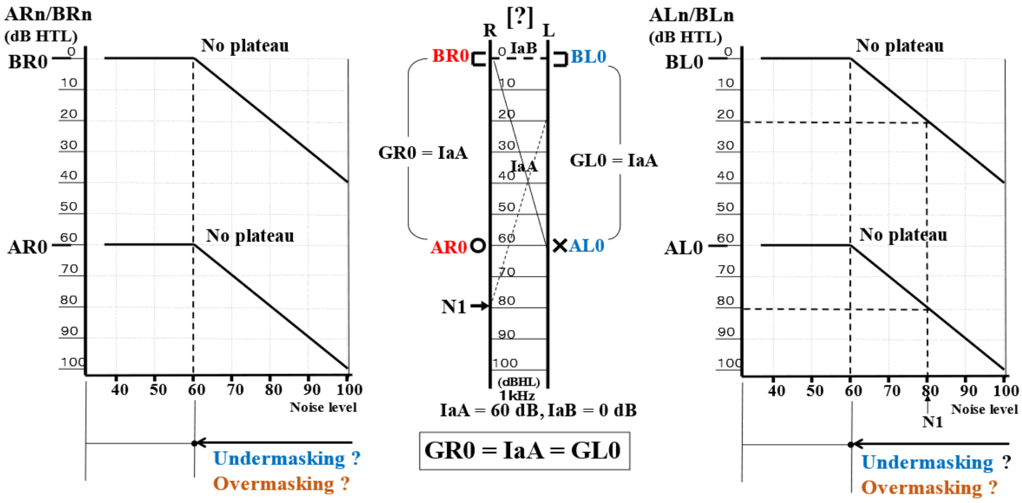


Figure 3-32 The plateau graphs with no plateaus

Clinically, even if the PW of 5dB is present, the true thresholds cannot be determined. Clinical masking dilemma is as follows: pattern [5] (Rt AA gap = 5dB) (**Fig. 3-11**), pattern [7-1] (Rt AA gap = 5dB) (**Fig. 3-22**) and pattern [7-2] (Rt AA gap = 5dB) (**Fig. 3-23**).