Consultancy report **Ref: 6824 R01**

Initial Circulation:

National Physical Laboratory:
Dr R Barham, Project Manager
Mr T Sherwood

Members of project steering group:
Mr G Frost, PC Werth
Ms P Smith, Institute of Hearing Research
Mr M Martin, OBE, Consultant
Prof M E Lutman, ISVR

Department of Trade and Industry:
Mr N Bolton

ISVR Consulting:
Mr B W Lawton
Mr S J C Dyne, Manager

Prepared By:

Dr M C Lower
Senior Consultant

In accordance with our quality assurance procedures, this report is countersigned by:

Mr S J C Dyne
Manager, ISVR Consulting

Interim report

Background information on Head and Torso Simulators and relevant standards

September 2003

ISVR Consulting
Institute of Sound and Vibration Research
University of Southampton
Highfield
Southampton SO17 1BJ

Tel: 023 8059 2162 Fax: 023 8059 2728 Email: consultancy@isvr.co.uk

Contents

1. Introduction 2

2. Head and Torso Simulators 3

2.1 HATS which have full ear simulators with ear canals and microphones placed at the eardrum position. 3

2.2 HATS with ear simulators as above, but which also incorporate an artificial voice. 3

2.3 HATS which do not contain a full ear canal but have microphones which block the ear canal entrance. 3

2.4 Scope of this study 4

3. Standards relating to HATS 5

3.1 Standards for occluded ear simulators: 5

3.2 Standards for manikins or HATS 5

3.3 Comparisons of standards for occluded ear simulators 5

3.4 Other standards relevant to ear simulators 7

3.5 Comparisons of standards for manikins and HATS 8

3.5.1 Dimensional properties and ear simulators 8

3.5.2 Summary of HATS standards showing where specifications for dimensional properties and ear simulators are the same or different .. 10

3.5.3 Acoustical properties – head related transfer functions 10

3.6 Conformance of commercially available Manikins and HATS to the various standards 12

3.6.1 Kemar 12

3.6.2 Brüel & Kjær HATS, type 4128 12

3.6.3 The Head Acoustics Types HMS II.3 and HMS II.4 13

3.6.4 Cortex Binaural Recording Head 14

4. Comments 15

5. References 16

Tables 1 to 4 19

Figures 1 to 13 23

1. Introduction

This interim report has been prepared for the project *Ear simulators and hearing aid testing*. The project is part of the Department of Trade and Industry's *National Measurement System Programme for Acoustical Metrology*, and is being undertaken jointly by the National Physical Laboratory (NPL) and ISVR Consulting, the consultancy group of the Institute of Sound and Vibration Research.

This report catalogues the available Head and Torso Simulators (HATS), compares the various national and international standards and other documents relevant to HATS, examines how the standards relate to each other, and how the HATS from various manufacturers conform to the standards.

2. Head and Torso Simulators

Head and Torso Simulators or Acoustic Manikins are anthropometric artificial heads incorporating ear simulators, designed for measuring or recording sound levels representative of those at the ears of real heads whether in a sound field or from headphones. There are various types, varying in complexity. These are:

2.1 HATS which have full ear simulators with ear canals and microphones placed at the eardrum position.

They can be used for the measurement of the sound output of earpieces, headphones, hearing aids and sound sources placed on, in or close to the ear. Examples include:

- Kemar, the Knowles Electronics Manikin for Acoustic Research [1, 2].
- Head Acoustics Type HMS II.4 [3].
- Cortex Instruments Binaural Recording Head (Mk1 and Mk2) [4].

These are all available for purchase.

2.2 HATS with ear simulators as above, but which also incorporate an artificial voice.

In addition to measuring sound output of earphones, etc, these can be used for measuring the responses of headset boom microphones, other microphones used close to the mouth, or telephone handsets. Examples include:

- Brüel & Kjær Type 4128C HATS [5].
- Head Acoustics, Type HMS II.3 [6].

2.3 HATS which do not contain a full ear canal but have microphones which block the ear canal entrance.

The use of these for measurements of headsets and earpieces is compromised or prevented by the lack of an ear canal, but these devices are most frequently used for making dummy head stereo recordings for replaying through headphones. Examples include:

- Brüel & Kjær Type 4100 HATS [7].
- Head Acoustics Type HMS III [8, 9].

2.4 Scope of this study

This study is mainly concerned with those HATS which contain a full ear canal and ear simulator, with or without an artificial mouth. The ear simulator generally comprises an 'occluded ear simulator', which contains the eardrum microphone and the inner 12 mm or 13 mm of ear canal. The 'occluded ear simulator' is so named because it represents the part of the ear canal remaining when the outer part of the canal is filled with an insert earpiece or hearing aid ear mould. In a HATS the 'occluded ear simulator' is often referred to as such even though not occluded. Instead the ear canal of the occluded ear simulator is extended using an ear canal extension to provide a full length ear canal representative of an adult ear canal.

3. Standards relating to HATS

There are various standards and recommendations covering the performance, construction or dimensions of (a) the occluded ear simulator as a separate component and (b) the HATS as a whole.

3.1 Standards for occluded ear simulators:

- ANSI S3.25-1979 (superseded but still cited). *American National Standard for an Occluded Ear Simulator* [10].
- IEC 60711:1981 *Occluded-ear simulator for the measurement of earphones coupled to the ear by ear inserts.* (This was originally numbered IEC 711-1981, and will eventually be renumbered as IEC 60318-4. BS 6310-1982 is technically identical.) [11].
- ANSI S3.25-1989 (Reaffirmed 1999). *American National Standard for an Occluded Ear Simulator.* (The current version of [10]) [12].

3.2 Standards for manikins or HATS

- ANSI S3.36-1985 (R 1996). *American National Standard Specification for a Manikin for Simulated in-situ Airborne Acoustic Measurements* [13].
- IEC TR 60959-1990. *Provisional head and torso simulator for acoustic measurements on air conduction hearing aids* [14].
- ITU-T Recommendation P.58. *Head and torso simulator for telephonometry* [15].

3.3 Comparisons of standards for occluded ear simulators

The ANSI S3.25 occluded ear simulator appears to have been written around the Zwislocki coupler or Zwislocki ear simulator, and was based on work by JJ Zwislocki of Syracuse University and practical implementations by Knowles Electronics Company. The standard cites reports by Zwislocki from 1970 and 1971.

The standard specifies physical details and the performance requirement for a device that provides an acoustic impedance and has sound pressure distributions approximating those in a median human adult ear between an earmould and the eardrum.

The current version of the standard describes, as an example, a four-branch coupler which would meet those requirements. The example appears to be identical to the Knowles Electronics Type DB-100 implementation of Zwislocki's design. The earlier version of the standard also gave construction details of a two-branch ear simulator, of a type also made by Knowles Electronics, but these details have been deleted from the current version.

More significantly the acoustic transfer impedance specification was changed between the 1979 and the 1989 (R1999) current version. Table 1 and Figures 1 and 2 give a comparison of the 1979 and 1989 transfer impedances.

The IEC 60711:1981 standard gives no clues as to the development or scientific basis of the device it describes. Although we cannot be sure, the IEC 60711 occluded ear simulator appears to be have been based on similar impedance and dimensional data to, possibly including, the same data as that on which the ANSI S3.25-1979 occluded ear simulator was based. However the IEC standard appears to have been written around, or at least developed in parallel with, the Brüel & Kjær B&K Type 4157 [16] occluded ear simulator, which appeared in the B&K 1980 catalogue a year before the standard was published. The ear canal length is not specified in millimetres but as a half-wavelength of 14 ± 1 kHz, so cannot be directly compared with the canal length in ANSI S3.25. The diameter specified in IEC 60711 is the same as in ANSI S3.25-1979, and the transfer impedance data is very similar to that in ANSI S3.25-1979.

Table 2 and Figures 3 and 4 show a comparison between the impedance data from IEC 60711 and ANSI 3.25-1979. The tolerances in the IEC standard are tighter. Because the standards differ, simulators conforming to IEC 60711 would not necessarily conform to ANSI S3.25-1979 and vice versa. It would however be possible to produce an occluded ear simulator with a transfer impedance falling within the overlapping tolerances of IEC 60711 and ANSI S3.25-1979, thereby conforming to both standards simultaneously. Whether this would be practicable is another matter, as the manufacturing tolerances of a device conforming to both standards would need to be much tighter than for a device conforming to only one of the standards.

Because the acoustic impedance specified in ANSI S3.25 changed between the 1979 and 1989 editions, it is no longer possible to produce an occluded ear simulator meeting both the ANSI S3.25 and IEC 60711 in their latest versions. Figure 5 shows the tolerance bands of impedances from the two standards no longer overlap at 1250 Hz and 1600 Hz. Figure 6 shows the difference between the impedances from the two standards in decibels. The difference is small and will not cause concern for many users in practice, but could be important to some more demanding users.

It is interesting to note that Brüel & Kjær's product data sheet for the Type 4157 claims conformance with IEC 60711-1981 and ANSI S 3.25-1979. It does not claim compliance with, nor refer to, ANSI S3.25-1989, although the data sheet has been updated since 1989 as the reference to the IEC standard number has been changed from IEC 711 to IEC 60711. Knowles Electronics in their product data [2] state that their Zwislocki coupler (part no. DB-100) conforms to ANSI S3.25-1989, with no mention of IEC 60711.

3.4 Other standards relevant to ear simulators

The IEC 60711 occluded ear simulator was adopted in ITU–T Recommendation P.57 *Artificial ears* [17] where it is referred to as the 'Type 2' artificial ear.

ITU-T P.57 also calls on the use of the IEC 60711 occluded ear simulator as part of its Type 3.1, 3.2, 3.3 and 3.4 artificial ears. Type 3.1 consists of the IEC 60711 simulator and an ear canal extension. It is used for testing earphones which seat at the bottom of the concha. Type 3.2 consists of the IEC 60711 simulator, an ear canal extension and a highly stylised 'pinna' adjustable to allow high or low sound leakage. Type 3.3 is of particular interest here as it consists of the IEC 60711 simulator, an ear canal extension, and the anatomically realistic pinna from the IEC TR 60959 HATS standard. The Type 3.3 artificial ear is, in effect, that part of a HATS required for supra-aural or circumaural earphone testing. The Type 3.4 artificial ear is similar to the Type 3.3 except that the pinna is much simplified and stylised and appears to have been adopted from a pre-existing design by Head Acoustics for their HMS II.3 system.

3.5 Comparisons of standards for manikins and HATS

3.5.1 Dimensional properties and ear simulators

ANSI S3.36-1985(R1996) gives dimensions of the head, torso, and pinnae of a manikin or HATS. The essential dimensions are those of the Kemar manikin and the standard appears to be based on the pre-existing Kemar. The ANSI S3.36 manikin incorporates ANSI S3.25 occluded ear simulators. No date is given for the ANSI S3.25 standard cited, implying that the most recent revision should be used. Thus without any change to ANSI S3.36 between 1985 and its reaffirmation in 1996, the specification for the manikin, specifically for its ear simulator, will have changed slightly, because of changes in ANSI S3.25 when it was reissued in 1989.

IEC TR 60959 gives dimensions of the head, torso and pinnae of a HATS and these are identical to those in ANSI S3.36. The IEC HATS however requires the IEC 60711 occluded ear simulator, and the standard notes that "Occluded ear simulators differing in detail from that specified in IEC Publication 711 are in current use in some countries. If such devices are used as part of the ear simulator, their characteristics should be stated when giving results of measurements of hearing aids made with the head and torso simulator".

The ITU-T Recommendation P-58 specifies a HATS for telephonometry. The major head and torso dimensions are very similar to, but not the same as those specified in IEC TR 60959 and ANSI S3.36. Figure 7 shows the inner and outer tolerance of the cross section of the ITU-T P.58 head in the median vertical plane. The crosses superimposed are the dimensions specified in IEC TR 60959 and ANSI S3.36. A few crosses fall outside the shaded area.

The ITU-T P.58 HATS appears to have been based on two pre-existing HATS, the B&K Type 4128 and the Head Acoustics HMS II.3. Head Acoustics' web site in fact claims they were involved with others in the development of ITU-T P.58 [18]. Without ready access to samples of the B&K and Head Acoustics HATS we cannot be certain, but we suspect from Figure 4 in the ITU document, reproduced here as Figure 7, that the inner tolerance of the ITU HATS head is the shape and size of the Head Acoustics HMS II.3 and the outer tolerance is the shape and size of the B&K HATS. If so, the ITU-T Recommendation P.58 is a standard which has been written to accommodate the existing hardware of two manufacturers, and with very minor changes to its already wide dimensional tolerances, could also have included existing manikins built to the dimensions of ANSI S3.36 and IEC TR 60959.

ITU-T Recommendation P.58 permits a choice of pinnae. The anatomically detailed pinnae have dimensions as specified in ITU-T P.57 for the Type 3.3 artificial ear. The P.57 document in turn states that pinnae for the Type 3.3 artificial ear has the dimensions as stated in IEC TR 60959. Thus the pinnae dimensions of the ITU P.58 HATS, the IEC TR 60959 HATS and the ANSI S3.36 HATS should be to the same specification. The P.58 HATS fitted with this pinna would be usable for hearing aid measurements as well as headphones and telephones.

The ITU-T P-58 recommendation also permits the HATS to be fitted with the simplified pinnae from the Type 3.4 artificial ear from ITU-T P.57. The P.57 Type 3.2 artificial ear can also be fitted into the HATS. These pinna would not be suitable for hearing aid tests.

3.5.2 *Summary of HATS standards showing where specifications for dimensional properties and ear simulators are the same or different.*

	ANSI S3.36	IEC TR 60959	ITU-T P.58
Head dimensions	H1	H1	H2
Torso dimensions	T1	T1	T2
Pinna dimensions	P1	P1	P1 or P2 or P3
Occluded ear simulator type	OES1	OES2	OES2

Notes

H1, T1, P1, etc are arbitrary labels for the data sets used for the purposes of this document only.

OES1 specified in ANSI S3.25-1989.

OES2 specified in IEC 60711, and adopted by ITU-T P.57 as Type 2 artificial ear.

P1 anatomically detailed pinnae (also used in ITU-T P.57 Type 3.3 artificial ear).

P2 simplified pinnae specified in ITU-T P.57 for the Type 3.4 artificial ear.

P3 stylised pinnae with high or low leak specified in ITU-T P.57 for Type 3.2 artificial ear.

3.5.3 *Acoustical properties – head related transfer functions*

In addition to specifying dimensions of the HATS, ANSI S3.36, IEC TR 60959 and ITU-T P.58 each give some basic acoustical responses in the form of head related transfer functions (HRTFs).

ANSI S3.36 and IEC TR 60959 give free-field HRTFs for 0° elevation and 0°, 90°, 180° and 270° azimuth*. The free-field HRTFs express the sound pressure level at the eardrum relative to the sound pressure level in the free field at the position corresponding to the centre of the head but with the HATS removed. These HRTFs are given in Table 3. ANSI S3.36 and IEC TR 60959 give the same target values, but differ only in the tolerances. ANSI give tolerances to tenths of a decibel, whereas the IEC document rounds the tolerances to the nearest half-decibel. Figure 8 shows the 'free-field frequency response' or HRTF for 0° azimuth. The target curve is the same

* By convention, 90° indicates the ear is facing the sound source, 270° indicates the ear is facing away from the sound source with the head in between.

for ANSI S3.36 and IEC TR 60959, but the tolerance values are plotted are from IEC TR 60959.

It is interesting to note that IEC TR 60959 gives exactly the same target values as ANSI S3.36 for the free-field response of the HATS, despite the fact that the two documents specify different occluded ear simulators as part of the HATS. The tolerances are however, probably wide enough to accommodate the differences between the two ear simulators.

ITU-T P.58 presents the free-field HRTFs in a different way. The free-field response for 0° azimuth is given directly (in P.58 Table 2) as the eardrum SPL minus the free-field SPL. The frequency responses for 90°, 180°, and 270° (in P.58 Table 4) however are given as eardrum SPLs relative to the eardrum SPL for 0° incidence, and not relative to the free-field SPL in the absence of the manikin. In Table 4 of this report we have combined the data from the two tables in the ITU document to show the free-field frequency responses for 0°, 90°, 180° and 270°. Figure 9 shows the free-field frequency response for 0° azimuth with tolerances as specified in ITU-T P.58.

Figure 10 shows a direct comparison between the IEC and ITU versions of the free-field frequency responses at 0° azimuth. The target values are exactly the same in the two documents, but the ITU standard accommodates HATS with different dimensions from different manufacturers by allowing asymmetric tolerances.

Figures 11, 12 and 13 show comparisons between the IEC and ITU free-field frequency responses for sound incident from 90º, 180º and 270º respectively. Although in each of these figures the two curves are similar, there are detailed differences, but the tolerance bands are wide and overlap.

3.6 Conformance of commercially available Manikins and HATS to the various standards.

3.6.1 Kemar

The design of Kemar was described by Burkhard and Sachs in the Journal of the Acoustical Society of America in 1975 [1], and in the conference proceedings published as "Manikin Measurements" [19]. Kemar conforms to ANSI Standard S3.36 when fitted with Knowles DB-066 and DB-065 left and right ear pinnae. These pinnae are larger than those supplied with the original Kemars. The details of the larger pinnae are described by Maxwell & Burkhard [20].

The ear simulators are Knowles Type DB-100 types built to Zwislocki's design and conforming to ANSI S3.25-1989.

(Presumably it would be possible to install an IEC 60711 ear simulator in Kemar in place of the ANSI S3.25 ear simulators, by redesigning the ear canal extensions and mounting plates, and Kemar would then conform to IEC TR 60959).

3.6.2 Brüel & Kjær HATS, type 4128

Brüel & Kjær state that the Type 4128 Head and Torso Simulator conforms to ANSI S3.36-1985 and IEC TR 60959 for measurements on air-conduction hearing aids, and ITU-T Recommendation P.58 for measurements on telecommunications devices. Technically this cannot be so, as a head built to the ANSI and IEC dimensions does not fall within the tolerances of the ITU specification. Inspection of the typical listener free-field frequency response in the B&K product data sheet [5] suggests that the response is within tolerance band of the IEC TR 60959. There is a sharp dip to –6 dB in the response at 8 kHz which puts the response outside the ITU-T P.58 tolerance band, though for most purposes this will not cause concern in practice. The Type 4128 HATS first appeared in the B&K catalogue in 1989, and apparently predates the ITU Recommendation P.58 which was not cited.

B&K claim the ear simulator of the type 4128 HATS conforms to IEC 60711, ITU-T P.57 and ANSI S3.25 but do not specify which version of S3.25. Presumably this HATS conforms to the earlier 1979 version and not the current ANSI S3.25-1989 (R1999).

B&K state in their current data sheet that the pinna simulators have “dimensions similar to those specified in ITU-T Rec. P.58, IEC TR 60959 and ANSI S3.36”, and that “minor adjustments in the dimensional details have been made which enable the 4182C to conform with the acoustic specifications of these documents in the frequency range 100 Hz to 8 kHz”. In other words, the pinnae dimensions do not conform to the standards. The reference to the “minor adjustments” also appears, word for word, in the 1989 B&K catalogue and the adjustments were therefore made so as to conform to IEC TR 60959 and ANSI S 3.36 as no claims were made about conformance with ITU-T Recommendation P.58, which had not then been published.

There is an implication from the B&K reference to “minor adjustments”, that, if pinna dimensions conform to the standard, then the overall acoustic performance of the HATS cannot meet the acoustical performance specification of one or more of the standards. A question arises of (a) whether one or more of the standards has internal inconsistencies, or (b) whether all of the standards individually are internally consistent but by modifying the dimensions, B&K have been able to meet slightly different performance requirements within the required tolerances.

3.6.3 The Head Acoustics Types HMS II.3 and HMS II.4

The HMS II.3 and HMS II.4 systems from Head Acoustics differ only in that the HMS II.3 has an artificial mouth and the HMS II.4 does not.

Head Acoustics GmbH claim that the head and torso dimensions of their HMS II.3 and II.4 Head and Torso Simulators conform to the dimensions and cross-sectional planes of ITU-T Recommendation P.58. However, the HMS II.3 and II.4 only model the head and shoulders not the head and torso, and from the photos available on the data sheets, it looks likely that the torso has insufficient height, so that the ‘HATS height’ dimension in the HMS II.3 and II.4 is less than 600 mm specified as the minimum in ITU-T P.58. As Head Acoustics apparently helped draft ITU-T P.58 this seems a surprising oversight.

The occluded ear simulator conforms to IEC 60711, and hence ITU-T P.58. Two types of pinnae, both types conforming to ITU-T P.58, are available as options: These are the simplified pinnae as specified for the ITU-T P.57 Type 3.4 artificial ear (which Head Acoustics designed and ITU adopted), and the anatomically shaped pinnae conforming to the ITU-T P.57 Type 3.3 artificial ear.

3.6.4 Cortex Binaural Recording Head

We have not seen the Cortex head and the only information we have available is from the Cortex web site [4]. Cortex reports that the dimensions of its head and torso conform to IEC TR 60959, and the ear simulator fulfils the requirements of IEC 60711 and ANSI S3.25-1979 (ie the original version). It is available in two versions, the Mk 1 which has a mechanism in the neck allowing the head to be tilted, and the Mk 2 which does not have a tilting mechanism.

The frequency response presented on the manufacturer’s web site [4] suggests that the response may fall outside the ITU-T P.58 tolerance band at 8 kHz, but as the manufacturer does not claim to comply with P.58, they cannot be criticised for this.

4. Comments

We have not been party to the development of the standards and the deliberations of the various committees. However it seems that, in this specialised field, the standards appear to have been led by the hardware, not vice versa. It would possibly be more accurate to say that a particular standard conforms to a particular HATS, not that the HATS conforms to the standard. Slight deviations from and “minor adjustments” to the standards, and revisions between different versions of the same standard, suggest that manufacturers continue to lead with the standards left to follow. This is not surprising and is possibly inevitable given the considerable amount of research and development involved and the need for access to facilities for manufacturing precision prototypes.

The ANSI S3.25 occluded ear simulator and the IEC 60711 model were never identical but were originally very similar with overlapping tolerance bands. Regrettably the specification and performance of the ANSI occluded ear simulator has diverged from the IEC 60711. Presumably the change in the ANSI standard was to reflect the experience of manufacturers in meeting the standard, as there seems no scientific need for the change.

There are differences in head and torso dimensions among the Knowles, B&K and Head Acoustics HATS. How important are these differences? Given the wide variation in head and torso dimensions of real humans, each of these different HATS will be representative of an approximately median person and all would be acceptable for many purposes. However there are questions which need to be asked. Should standards have tolerances wide enough to encompass all the different HATS? Will wide tolerances lead to difficulties if different laboratories use different HATS? What precision and repeatability is necessary in measurements made using a HATS?

It is intended that the present project should include comparative measurements of the acoustical responses of as many of the commercially available HATS as can be brought together for testing.

5. References

1 Burkhard MD and Sachs RM, 1975; Anthropometric manikin for acoustic research. *Journal of the Acoustical Society of America*, **58**(1), 214 – 222.

2 Knowles Electronics Inc, Knowles Electronics Company; *Knowles DB Series product description*. Reference number S-554-1000.

3 Head Acoustics GmbH; *Data Sheet HMS II.4 (Code 1240).* Data sheet reference number 12.02 D1240e6.

4 Cortex Instruments; *Binaural Recording Head Mk 1.* Web page at http://www.cortex-instruments.de/mk1_e.htm

5 Brüel & Kjær; *Product data. Head and torso simulator - Type 4128C. Handset positioner for HATS – Type 4606.* Reference number BP 0521 - 19 01/09. Available online at http://www.bksv.com/pdf/Bp0521.pdf

6 Head Acoustics GmbH; *Data Sheet HMS II.3 (Code 1230).* Data sheet reference number 09.02 D1230e10. A similar data sheet reference number 08.00 D1230e8 is available online from Head Acoustics Inc.(USA) at http://www.headacoustics.com/datasheets/hms2-3.pdf

7 Brüel & Kjær; *Product data. Sound quality head and torso simulator - Types 4100 and 4100D*. Reference number BP 1436 - 13 01/08. Available online at http://www.bksv.com/pdf/Bp1436.pdf

8 Head Acoustics GmbH; *HMS III Artificial Head.* Web page at http://www.head-acoustics.de/2s-und-v/hms/P-h30-e.htm

9 Head Acoustics Inc.(USA) *Data Sheet HMS III.0 (Code 1307).* Data sheet reference number 05.2001 D1307e6 available online at http://www.headacoustics.com/datasheets/1307HMSIII.0.pdf

10 ANSI S3.25-1979; *American National Standard for an Occluded Ear Simulator*. American National Standards Institute, Washington DC. (This standard has been superseded but it is still cited in manufacturers' literature).

11 IEC 60711:1981; *Occluded-ear simulator for the measurement of earphones coupled to the ear by ear inserts.* International Electrotechnical Commission, Geneva. (This was originally numbered IEC 711-1981, and will eventually be renumbered as IEC 60318-4. BS 6310-1982 is technically identical).

12 ANSI S3.25-1989 (Reaffirmed 1999); *American National Standard for an Occluded Ear Simulator* (Current version). American National Standards Institute, Washington DC.

13 ANSI S3.36-1985 (R 1996); *American National Standard Specification for a Manikin for Simulated in situ Airborne Acoustic Measurements.* American National Standards Institute, Washington DC.

14 IEC TR 60959-1990; *Provisional head and torso simulator for acoustic measurements on air conduction hearing aids.* International Electrotechnical Commission, Geneva.

15 ITU-T Recommendation. P.58; *Head and torso simulator for telephonometry.* International Telecommunication Union, Geneva.

16 Brüel & Kjær; *Product data. Ear simulator – Type 4157*. Reference number BP0262-17 01/08. Available online at http://www.bksv.com/pdf/Bp0262.pdf

17 ITU-T Recommendation. P.57; *Artificial ears.* International Telecommunication Union, Geneva.

18 Head Acoustics GmbH; *Head Acoustics – History of artificial head technology*. http://www.head-acoustics.de/1head/W-hist-e.htm

19 Burkhard, MD, 1978; *Manikin Measurements*. Conference proceedings published by Industrial Research Products Inc, Elk Grove Village, Illinois. (A Knowles Company).

20 Maxwell RJ and Burkhard MD, 1979; Larger ear replica for KEMAR manikin. *Journal of the Acoustical Society of America*, **65**(4), 1055 – 1088.

Table 1 Acoustic transfer impedances for the occluded ear simulators specified by different versions of ANSI S3.25

Frequency, Hz	Acoustic transfer impedance MPa.s/m^3					
	ANSI S3.25-1989 (R1999)			ANSI S3.25-1979		
	Modulus	Tolerance		Modulus	Tolerance	
100	168.5	+10.0	-9.4	175.0	+8.0	-8.0
125	134.8	+8.0	-7.5	140.0	+6.0	-6.0
160	105.3	+6.2	-5.9	110.0	+6.0	-6.0
200	84.2	+5.0	-4.7	87.7	+4.5	-4.5
250	67.4	+4.0	-3.8	69.8	+4.0	-4.0
315	53.5	+3.2	-3.0	56.0	+3.0	-3.0
400	42.2	+2.5	-2.4	44.5	+2.5	-2.5
500	33.3	+2.0	-1.9	35.4	+3.0	-3.0
630	25.8	+1.5	-1.5	27.8	+2.5	-2.5
800	20.9	+1.5	-1.4	21.9	+3.0	-3.0
1000	20.3	+1.5	-1.4	20.3	+2.0	-2.0
1250	18.2	+1.3	-1.2	20.8	+3.5	-3.5
1600	16.7	+1.2	-1.1	18.7	+2.5	-2.5
2000	15.0	+1.3	-1.2	16.6	+2.0	-2.0
2500	13.4	+1.1	-1.0	14.0	+2.0	-2.0
3150	11.6	+1.0	-0.9	11.9	+2.0	-2.0
4000	10.5	+1.0	-0.9	10.5	+1.5	-1.5
5000	10.3	+1.3	-1.2	9.8	+1.5	-1.5
6300	10.9	+1.3	-1.2	10.4	+1.0	-1.0
8000	12.4	+2.4	-2.0	11.0	+1.5	-1.5
10000	19.6	+5.1	-4.1	15.5	+5.0	-5.0

Table 2 Acoustic transfer impedances specified by current standards, ANSI S3.25:1989 and IEC 60711

Frequency, Hz	Acoustic transfer impedance MPa.s/m³					
	ANSI S3.25:1989 (R1999)			IEC 60711		
	Modulus	Tolerance		Modulus	Tolerance	
100	168.5	+10.0	-9.4	173.5	+10.5	-9.7
125	134.8	+8.0	-7.5	140.3	+8.3	-7.9
160	105.3	+6.2	-5.9	109.6	+6.5	-6.1
200	84.2	+5.0	-4.7	88.7	+4.2	-4.0
250	67.4	+4.0	-3.8	71.0	+3.3	-3.2
315	53.5	+3.2	-3.0	56.3	+2.7	-2.5
400	42.2	+2.5	-2.4	44.9	+2.1	-2.0
500	33.3	+2.0	-1.9	35.9	+0.9	-0.9
630	25.8	+1.5	-1.5	28.8	+1.4	-1.3
800	20.9	+1.5	-1.4	23.0	+1.1	-1.0
1000	20.3	+1.5	-1.4	21.6	+1.3	-1.2
1250	18.2	+1.3	-1.2	21.0	+1.2	-1.2
1600	16.7	+1.2	-1.1	18.8	+1.1	-1.1
2000	15.0	+1.3	-1.2	16.3	+1.2	-1.1
2500	13.4	+1.1	-1.0	14.3	+1.0	-1.0
3150	11.6	+1.0	-0.9	12.6	+1.1	-1.0
4000	10.5	+1.0	-0.9	11.3	+1.1	-1.0
5000	10.3	+1.3	-1.2	10.5	+1.3	-1.1
6300	10.9	+1.3	-1.2	10.6	+1.3	-1.2
8000	12.4	+2.4	-2.0	10.9	+2.0	-1.7
10000	19.6	+5.1	-4.1	14.3	+3.7	-2.9

Table 3 Free-field frequency response (HRTF) of the HATS as specified in ANSI S3.36-1985 and IEC TR 60959:1990

Frequency, Hz	SPL at eardrum minus SPL in free field, dB (common to ANSI S3.36 and IEC TR 60959)				Tolerance, dB	
	Azimuth angle				ANSI S3.36	IEC TR 60959
	0°	90°	180°	270°		
100	0.0	0.0	0.0	0.0	±1.3	±1.5
125	0.0	0.5	0.0	0.0	±1.3	±1.5
160	0.0	1.0	-0.5	0.0	±1.3	±1.5
200	0.0	1.5	-0.5	0.0	±1.3	±1.5
250	0.5	2.0	0.0	0.0	±1.3	±1.5
315	1.0	3.0	0.0	0.0	±1.3	±1.5
400	1.5	4.0	1.0	0.5	±1.8	±2.0
500	2.0	5.5	1.5	1.0	±1.8	±2.0
630	2.5	7.0	2.5	2.0	±1.8	±2.0
800	3.5	7.5	4.0	2.5	±1.8	±2.0
1000	3.5	7.5	5.0	2.5	±1.8	±2.0
1250	3.5	8.5	6.5	3.0	±1.8	±2.0
1600	5.0	9.5	7.0	4.5	±2.8	±3.0
2000	12.5	12.0	10.0	6.5	±2.8	±3.0
2500	18.5	17.0	14.0	9.0	±2.8	±3.0
3150	15.5	17.0	13.0	7.5	±2.8	±3.0
4000	13.0	12.5	10.5	-	±2.8	±3.0
5000	11.0	15.5	7.0	-	±2.8	±3.0
6300	5.0	17.0	0.5	-	±5.8	±6.0
8000	2.0	15.0	-1.5	-	±8.0	±8.0
10000	7.0	3.0	-6.0	-	±8.0	±8.0

Table 4 Free-field frequency response (HRTF) of the HATS as specified in ITU-T P.58

Frequency, Hz	SPL at eardrum minus SPL in free field, dB							
	0° azimuth			90°	180°	270°		
	Target value	Tolerance		Target value	Target value	Target value	Tolerance (90°, 180°, 270°)	
100	0.0	+1.0	-1.0	0.0	0.0	0.0	+2.0	-2.0
125	0.0	+1.0	-1.0	0.5	0.0	0.0	+2.0	-2.0
160	0.0	+1.0	-1.0	1.0	-0.5	0.0	+2.0	-2.0
200	0.0	+1.0	-1.0	1.5	-0.5	-1.0	+2.0	-2.0
250	0.5	+1.0	-1.5	2.0	0.0	-0.5	+2.0	-2.5
315	1.0	+1.0	-1.5	3.0	0.3	0.0	+2.5	-3.0
400	1.5	+1.0	-1.5	4.0	0.5	0.5	+3.0	-3.5
500	2.0	+1.5	-1.0	5.5	1.0	1.0	+3.5	-3.0
630	2.5	+1.5	-1.0	7.0	2.5	2.0	+3.5	-3.0
800	3.5	+2.5	-1.0	7.5	4.0	2.5	+4.5	-3.0
1000	3.5	+2.0	-1.5	8.0	5.0	2.5	+4.0	-3.5
1250	3.5	+2.5	-1.5	9.3	6.0	3.0	+5.0	-4.0
1600	5.0	+2.0	-3.0	10.0	6.0	4.5	+4.0	-5.0
2000	12.5	+1.0	-3.5	12.0	10.5	8.5	+3.0	-5.5
2500	18.5	+1.0	-4.0	18.5	16.0	12.5	+3.0	-6.0
3150	15.5	+5.0	-2.0	17.0	12.5	7.5	+7.0	-4.0
4000	13.0	+3.0	-1.0	14.5	10.0	-	+5.0	-3.0
5000	11.0	+4.5	-2.5	14.5	7.0	-	+9.0	-7.0
6300	5.0	+4.0	-2.5	17.0	4.0	-	+8.5	-7.0
8000	2.0	+9.0	-3.0	14.0	5.5	-	+15.0	-9.0
10000	7.0	+3.0	-6.5	13.0	4.0	-	+3.0	-6.5

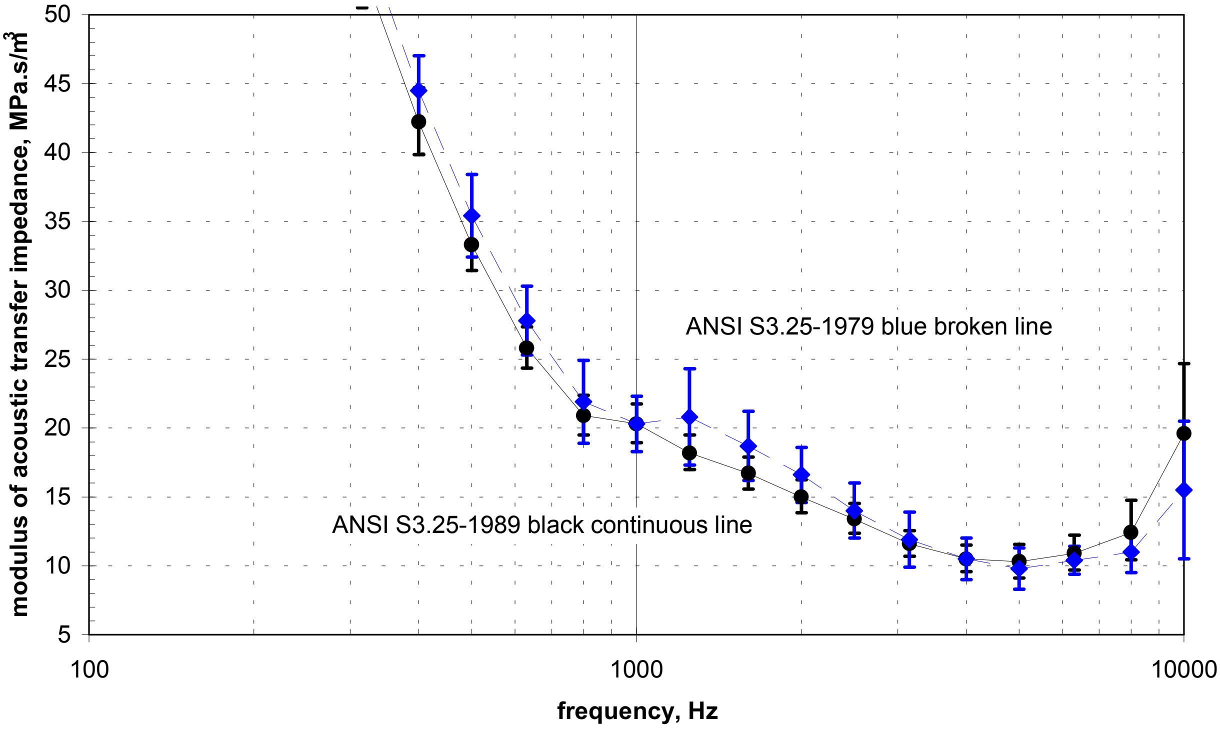

Figure 1 **Comparison of the acoustic transfer impedances and tolerances of the current ANSI S3.25-1989 and original ANSI S3.25-1979 occluded ear simulators**

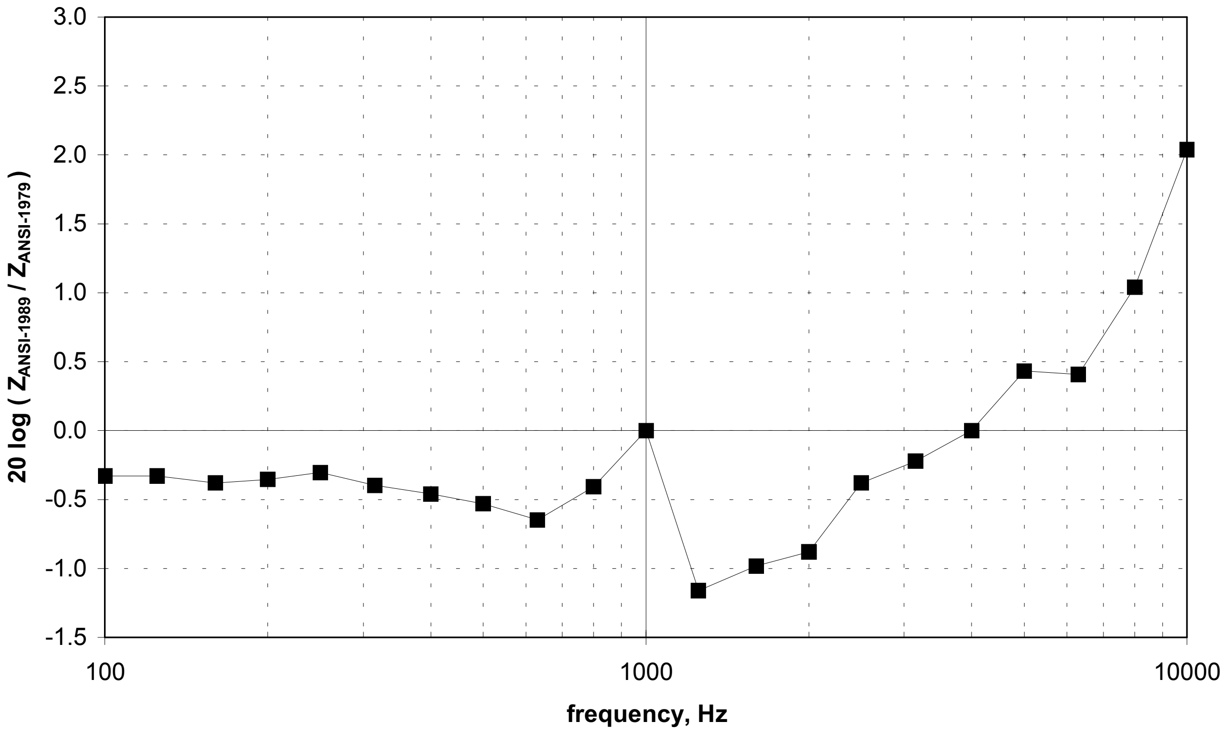

Figure 2 **Modulus of the acoustic transfer impedance of the ANSI S3.25-1989 occluded ear simulator relative to the ANSI S3.25-1979 occluded ear simulator**

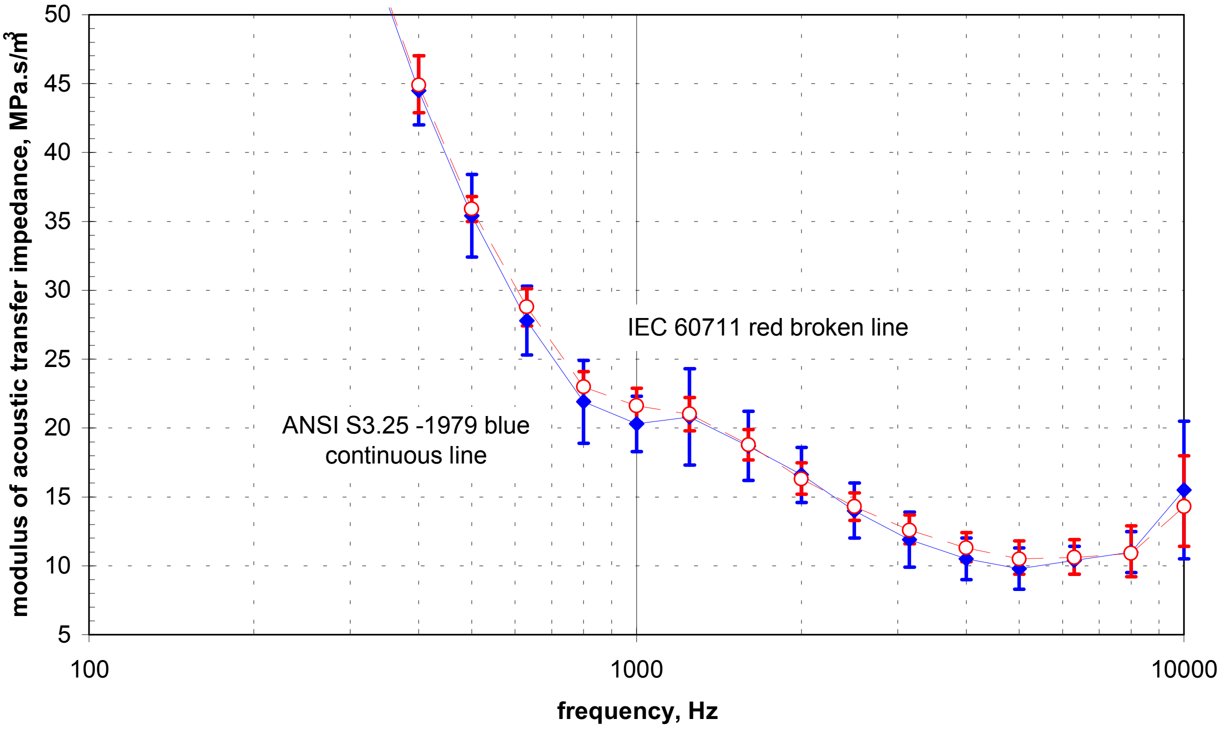

Figure 3 Comparison of the acoustic transfer impedances and tolerances of the original ANSI S3.25-1979 and IEC 60711 occluded ear simulators

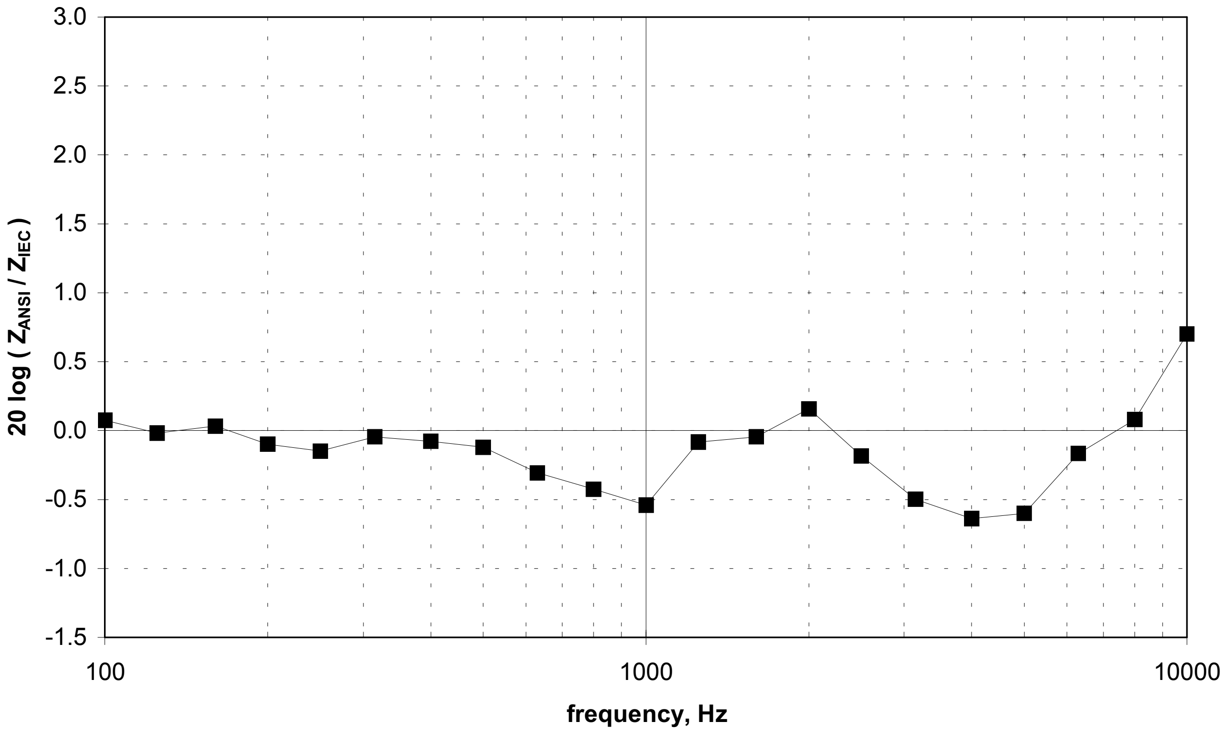

Figure 4 Modulus of the acoustic transfer impedance of the original ANSI S3.25-1979 occluded ear simulator relative to the IEC 60711 ear simulator

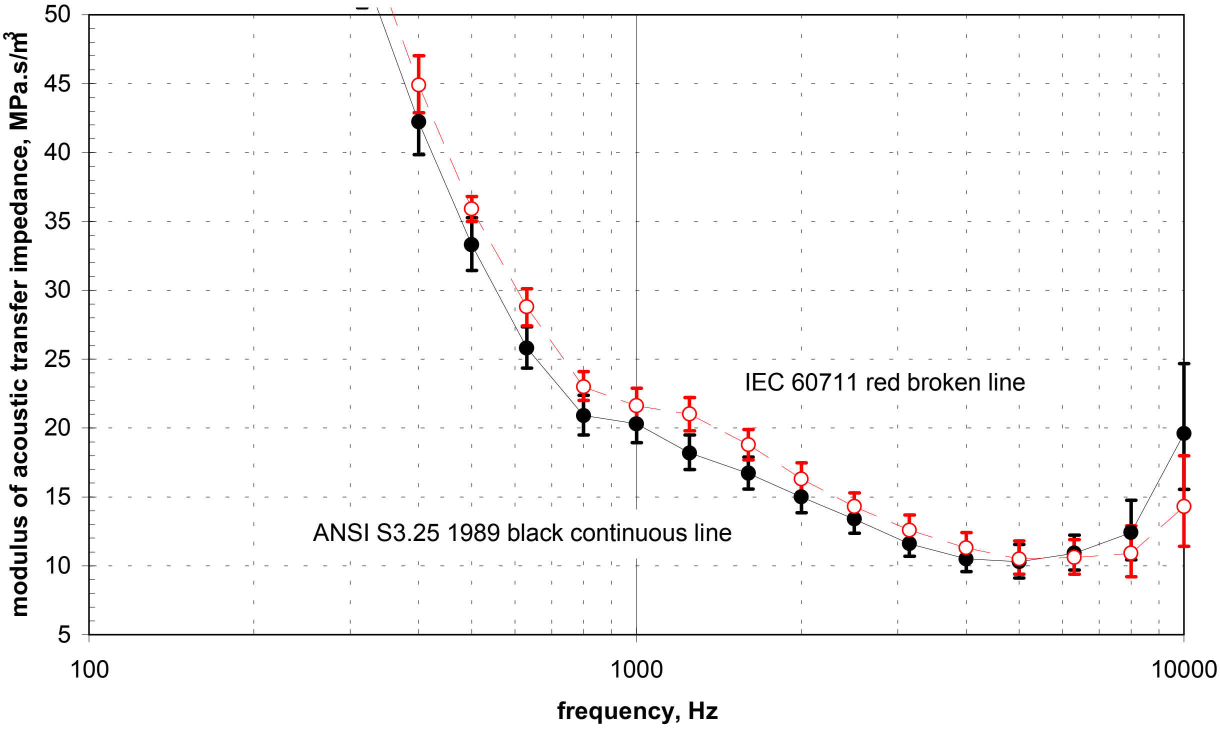

Figure 5 Comparison of the acoustic transfer impedances and tolerances of the current ANSI S3.25-1989 and IEC 60711 occluded ear simulators

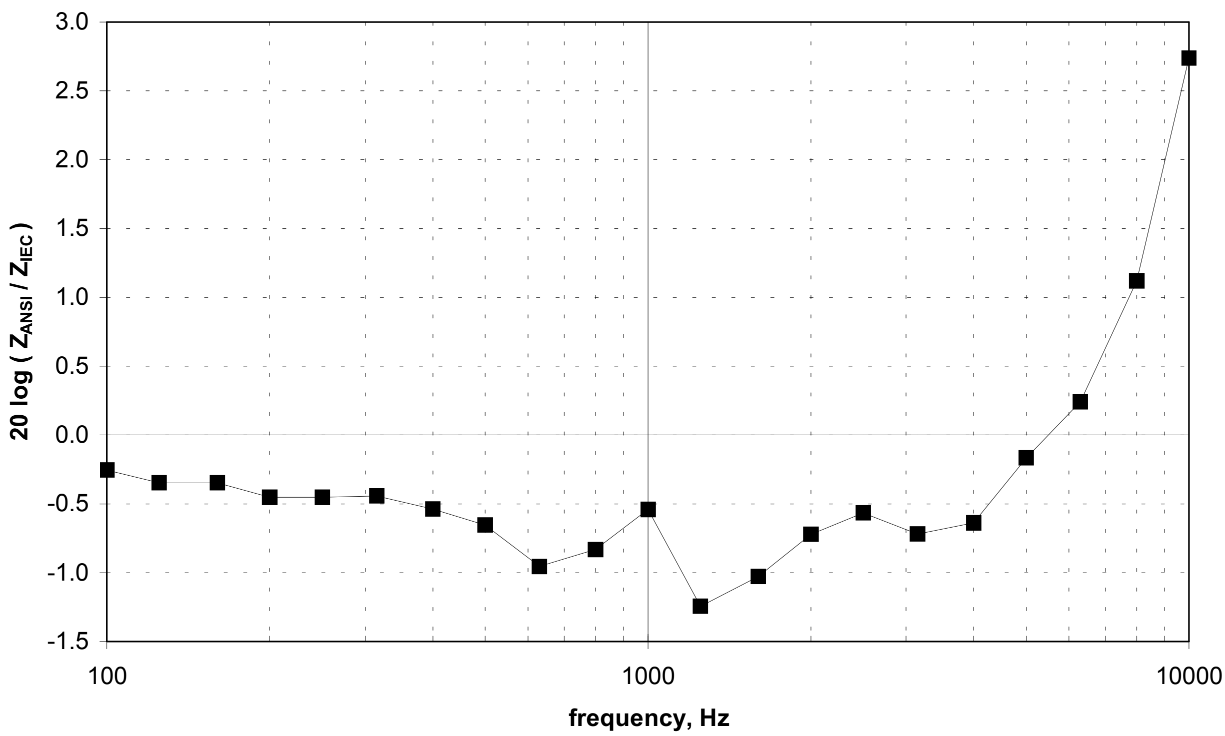

Figure 6 Modulus of the acoustic transfer impedance of the current ANSI S3.25-1989 occluded ear simulator relative to the IEC 60711 ear simulator

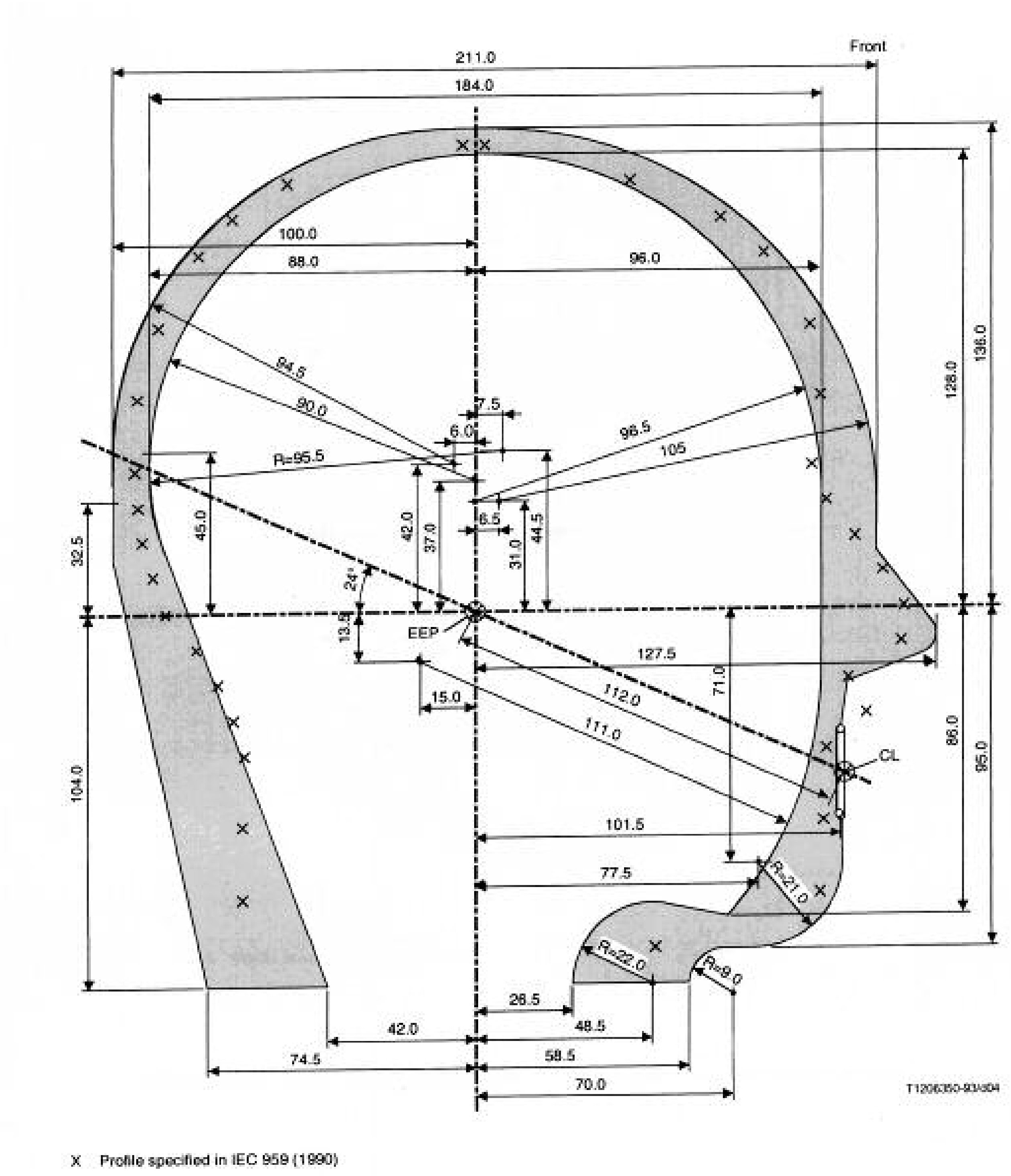

Figure 7 **Inner and outer limits of the cross section in the median vertical plane of the HATS specified by ITU-T Recommendation P.58, with the profile of the IEC TR 60959/ANSI S3.36 head superimposed as crosses**

Acknowledgement: This figure was scanned from Figure 4 of ITU-T P.58

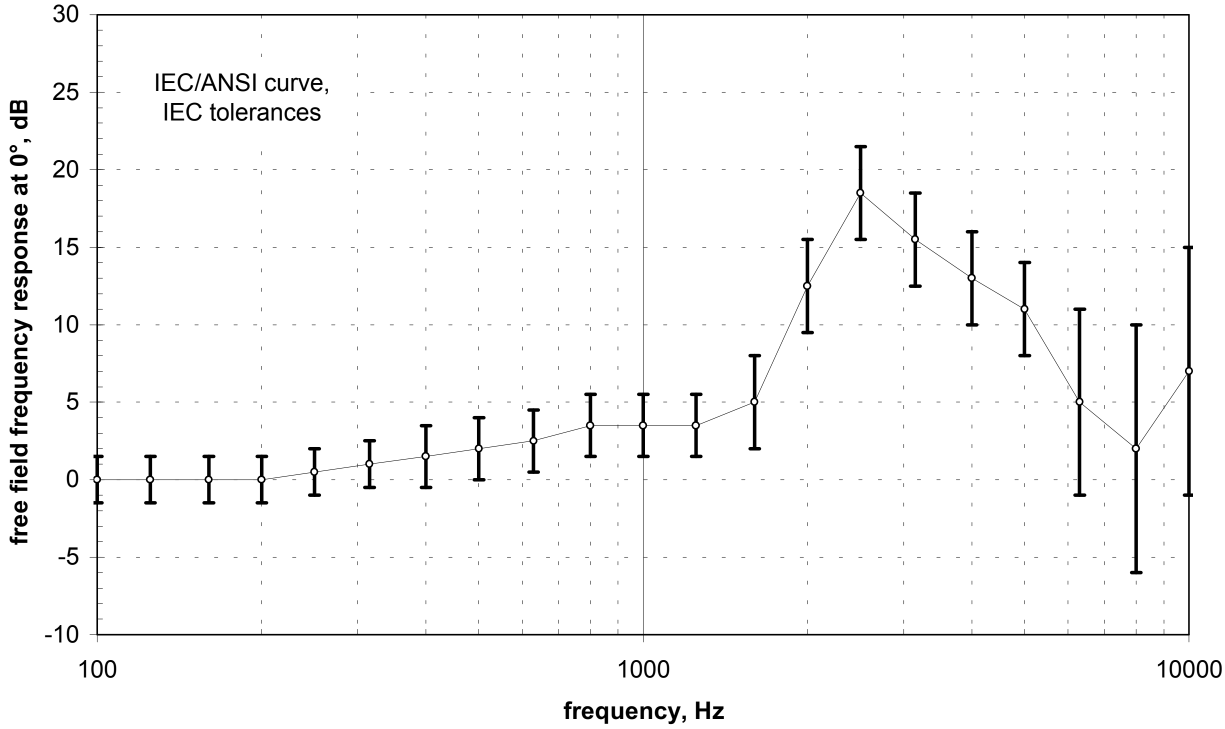

Figure 8 HATS free-field frequency response curve as defined by ANSI S3.36 and IEC TR 60959, with tolerances from IEC TR 60959

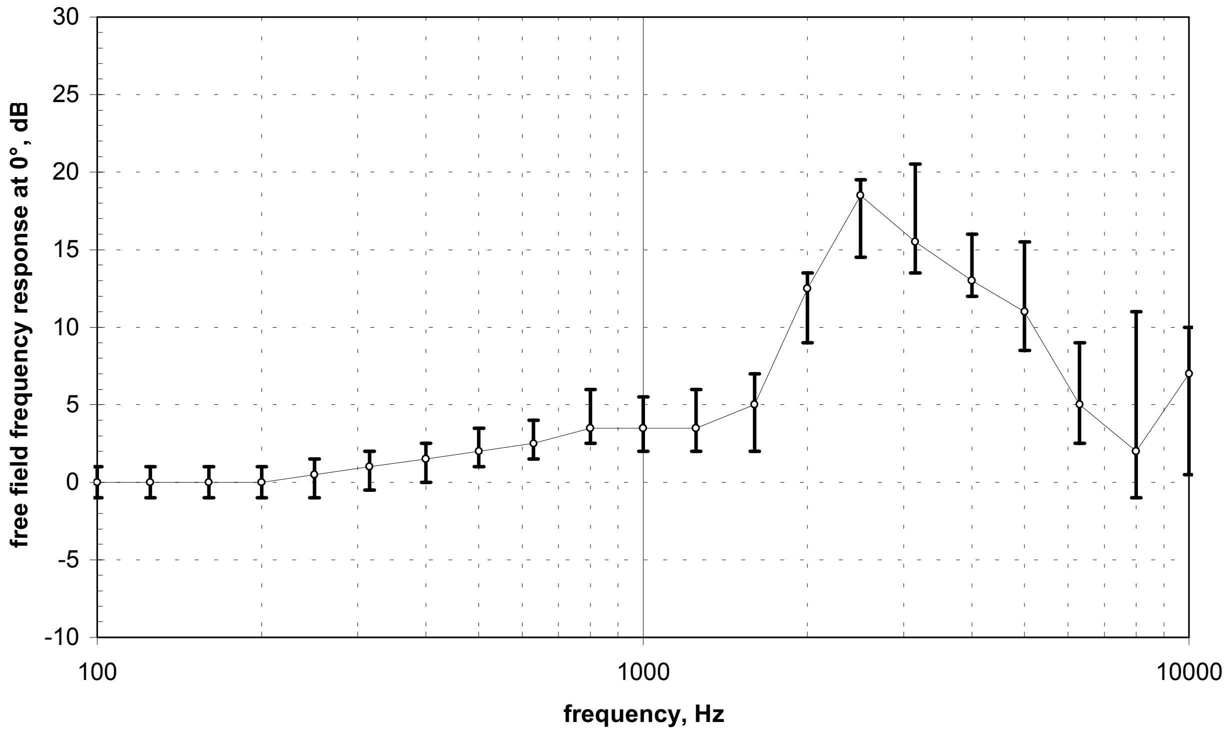

Figure 9 HATS free-field frequency response curve as defined by ITU-T P.58

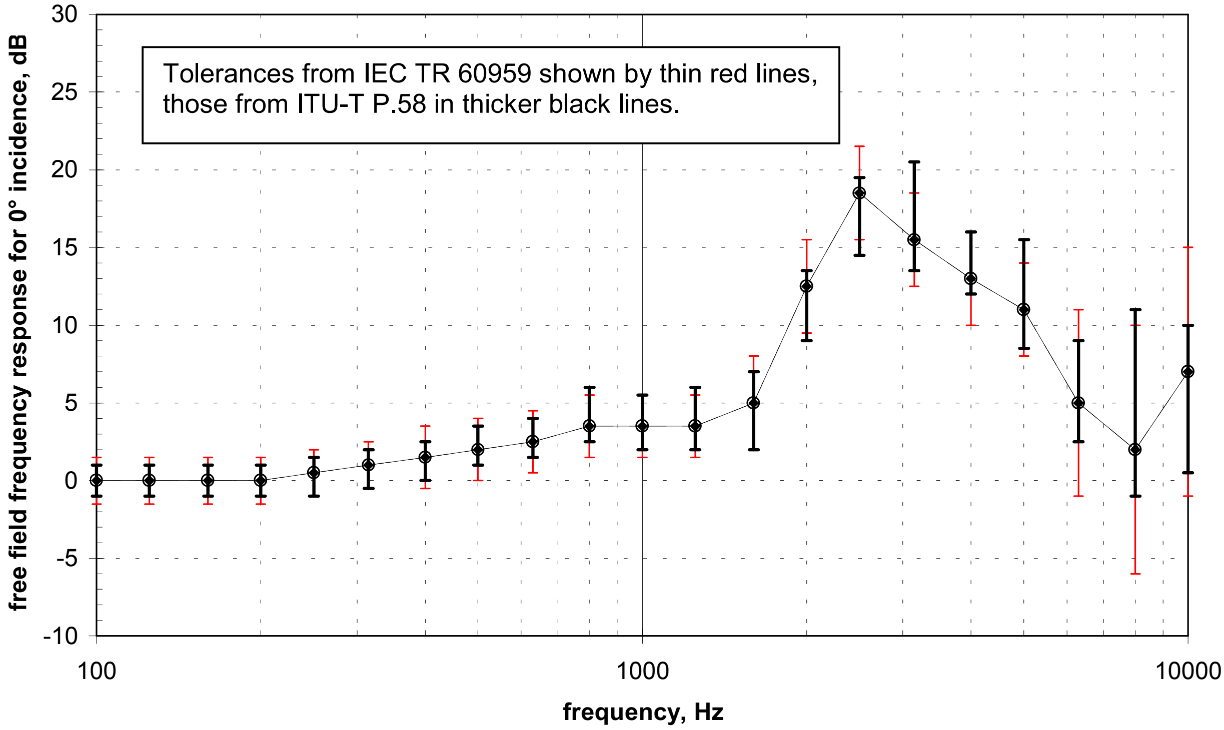

Figure 10 HATS free-field frequency response curves for 0º (frontal) sound incidence as defined by IEC TR 60959 and ITU-T P.58

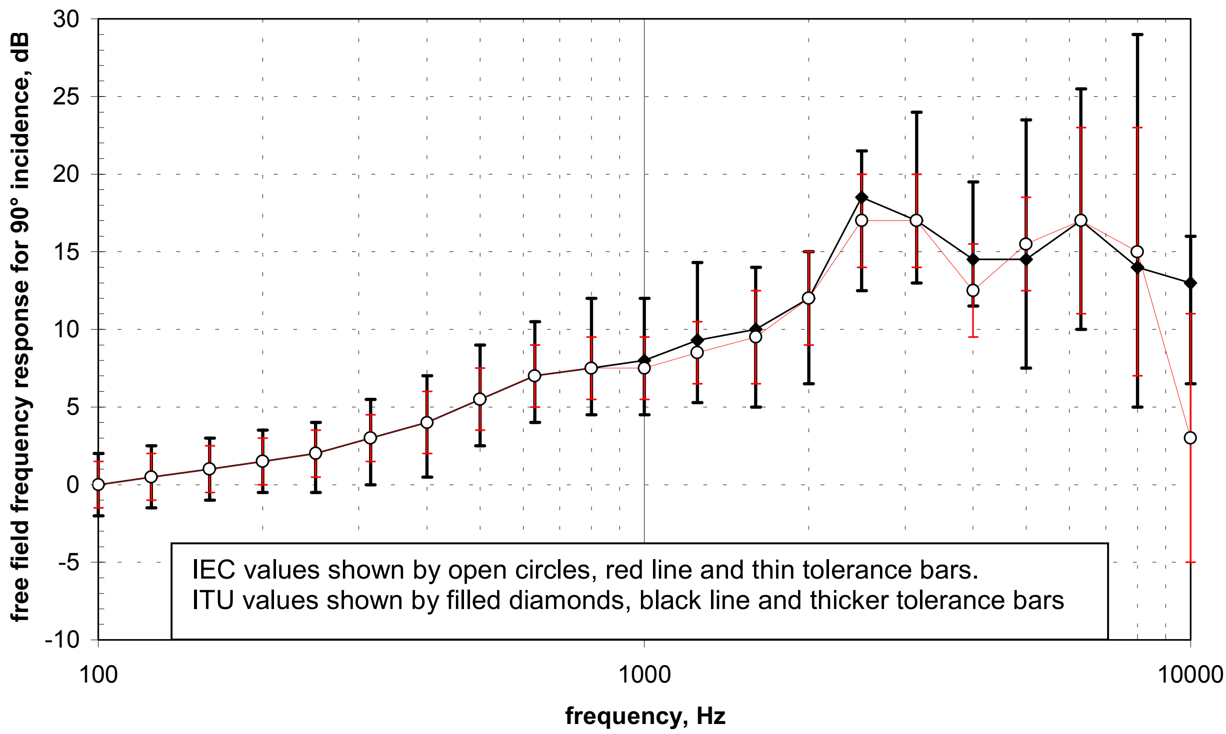

Figure 11 HATS free-field frequency response curves for 90º sound incidence as defined by IEC TR 60959 and ITU-T P.58

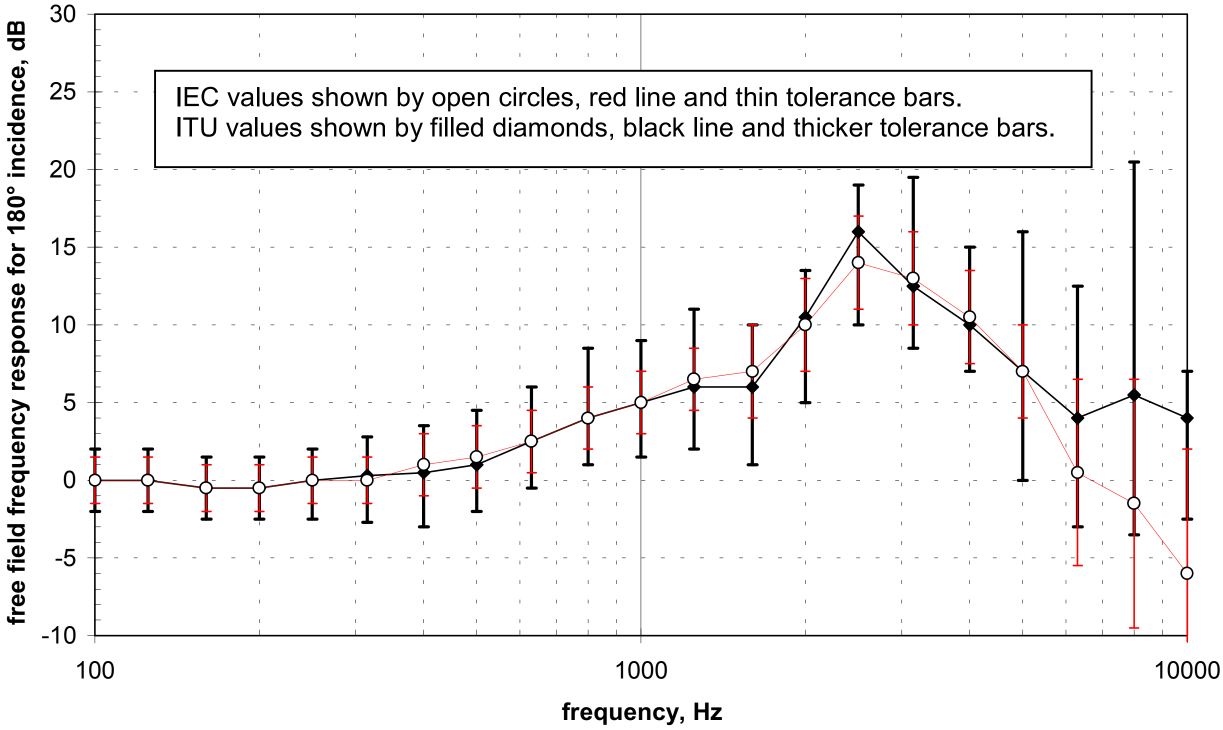

Figure 12 HATS free-field frequency response curves for 180º sound incidence as defined by IEC TR 60959 and ITU-T P.58

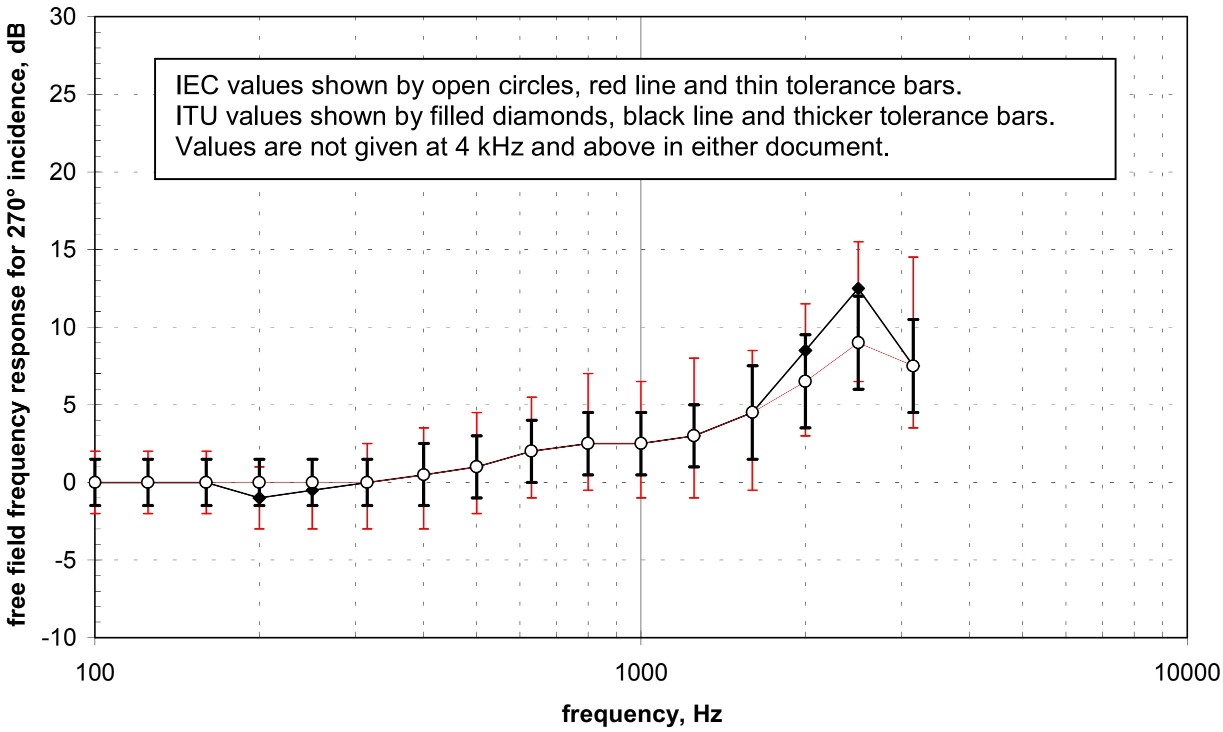

Figure 13 HATS free-field frequency response curves for 90º sound incidence as defined by IEC TR 60959 and ITU-T P.58