Reproduction of artificial head recordings through loudspeakers

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Again, one can easily pin-point the variations between results based on the same source, but measured according to different Standards.

4 How can we get around possible misunderstandings and make comparison even between professional acousticians easier ?

It goes without saying that we must expect acousticians to follow the Standards correctly, and expect them to be aware of the possible differencies in the measurement parameters when comparing results to those obtained by colleagues in other countries. Assuming this expectation to be valid possible problems discussed in this paper should not be overestimated. However, when laymen compare measurement results, these problems may often cause significant misunderstandings.

So, what can be done to avoid such misunderstandings ? As we see it, there are three ways:

1) The educational way.
   Train everybody who within their lifetime will need to compare measurements of sound or noise up to a level of a normal acoustician.

2) The international way.
   Remove all national Standards describing other measurement methods than those agreed upon in international commitees.

3) The instrumentational way.
   Measure all possible parameters of every source under investigation.

Method 1 will not be realizable. Method 2 would mean years of debates within the different commitees before any result (if at all) could be achieved. Method 3 would mean more measurements.

To help out, Norwegian Electronics has developed a new Sound Analyzer which simultaneously measures all the parameters mentioned in this paper. This enables the use of method 3 without having to perform more measurements. The Sound Analyzer Type 110 will do the following measurements simultaneously:

Detectors:	Max and Min "Fast"		
	Max and Min "Slow"		
	Max and Min "Impulse"		
	Peak(+) and Peak(-)		
Intergrators:	Leq	Leq,i	SEL
	Leq(4)	Leq(5)	Leq(6)
	T.max3	T.max5	
Statistical:	Ln (n= 1-99)		

It is our hope that this new instrument concept will make life easier for acousticians, and assist in avoiding misunderstandings when comparing results from sound measurements. As this battery operated instrument also contains digital filters, even the frequency content of the sound may be measured.

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REPRODUCTION OF ARTIFICIAL HEAD RECORDINGS THROUGH LOUDSPEAKERS

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1 INTRODUCTION

The basic concept of the artificial head recording technique is well-known. In any listening situation the input to the hearing mechanism consists of two one-dimensional signals, e.g. the sound pressure at the two eardrums. If a set of recording/playback equipment is able to create the same sound pressure at the eardrums of a listener as would have been in the concert hall, then the acoustic experience is reproduced correctly, including directional aspects, reflections, reverberation, etc.

In practice, recordings are made with microphones in the ear canals of a carefully designed model of a human head, including pinnae. Reproduction is carried out through headphones which ensures that each channel is only reproduced in one ear.

2 REPRODUCTION THROUGH LOUDSPEAKERS

The good directional characteristics of an artificial head recording are destroyed if it is reproduced through loudspeakers. This is due to the crosstalk which is introduced in any free-field listening. Crosstalk means that the right speaker is heard not only with the right ear but also with the left ear and vice versa.

However, it can be shown that it is possible to add an artificial crosstalk which cancels out the natural crosstalk. The principle is shown in the following.

X_{left} and X_{right} denote the two channels which are to be reproduced as sound pressure at the eardrums. Y_{left} and Y_{right} are the signals presented to the loudspeaker terminals. Z_{left} and Z_{right} denote the sound pressure at the two eardrums. X and Y have the unit V, while the unit of Z is Pa. The transfer functions from Y to Z are denoted with H as indicated in Figure 1. H has the unit Pa/V.

In matrix notation we have

$$(Z) = (H)(Y) \tag{1}$$

What we want is that

$$(Z) = k(X) \tag{2}$$

k being constant of unit Pa/V. If we combine (1) and (2) and solve with respect to (Y) we get

$$(Y) = k(H)^{-1}(X) \tag{3}$$

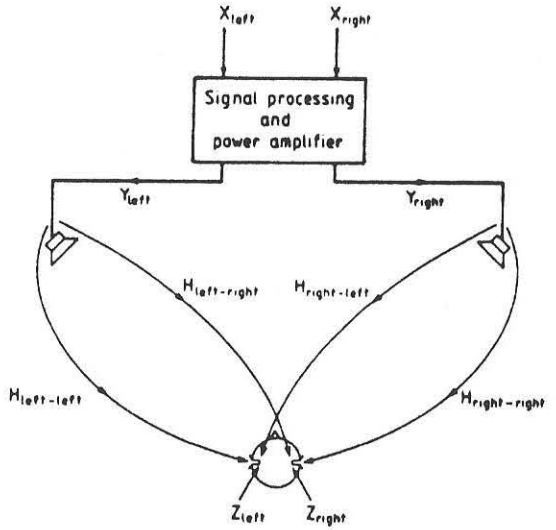

Figure 1. Principal diagram showing the transmission from recording (X_{left} and X_{right}) to sound pressure at the eardrums (Z_{left} and Z_{right})

Some further manipulation is appropriate. The solution used is given below in (4) and (5). Symmetri is assumed and the elements of (H) are divided into parts originating from the loudspeaker free-field response (C) and parts originating from the free-field correction of the head (A for sound coming from the same side as the ear, B for sound coming from the opposite side). For details, see ref. 1.

$$Y_{left} = \frac{1}{A} \cdot \frac{1}{1 - (B/A)^2} \cdot (X_{left} - X_{right} \frac{B}{A}) \frac{k}{C} \quad (4)$$

$$Y_{right} = \frac{1}{A} \cdot \frac{1}{1 - (B/A)^2} \cdot (X_{right} - X_{left} \frac{B}{A}) \frac{k}{C} \quad (5)$$

This signal processing is shown in block diagram form in Figure 2.

The blocks to the right perform a gain control and an equalization of the loudspeakers. The left blocks are similarly introduced in the direct signal path of both channels and thus also perform an equalization. Among other things this compensates for the fact that the ear canal appears two times in the transmission path: Once at the recording and once at playback.

The real suppression of the crosstalk is carried out by the cross-coupling of the two centre blocks.

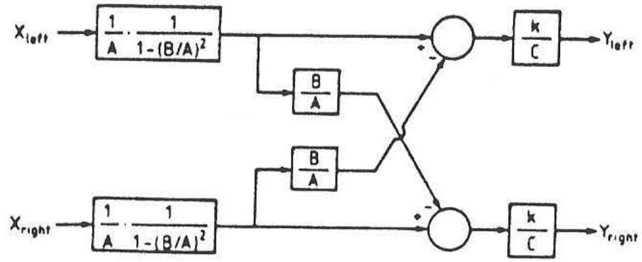

Figure 2. The signal processing of equations (4) and (5) shown in block diagram form

3 REALIZATION

Until now the effort has been concentrated on realization of the cross-coupling B/A. A possible way will be to approximate B/A with an analogue filter or a recursive digital filter. However, as accuracy is expected to be essential, it has been realized as a Finite Impulse Response filter using Motorola XSP 56200 processors. The transfer functions were measured on a Neumann Type KU 80i artificial head, and the impulse response of the filter, calculated as the inverse Fourier transform of B/S is shown in Figure 3. At the time of printing, the blocks k/C and $1/A(1-(B/A)^2)$ have not been realized.

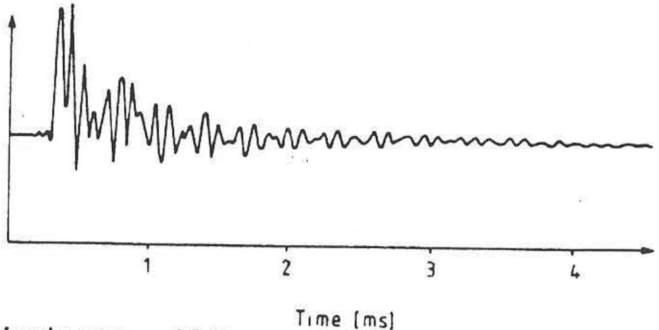

Figure 3. Impulse response of B/A

4 ASSESSMENT

The suppression of crosstalk is very effectively demonstrated in an anechoic room. With pink noise applied to both channels, the listener perceives the sound as being located in the head, like when listening with headphones. When the noise is applied to only one channel, the listener gets the impression of listening to a sound source located immediately outside the appropriate ear. If this ear is closed with a finger or an earplug, the listener is able to clearly indicate the correct position of the head by searching for minimum sound level at the opposite ear.

At present the reproduction of processed artificial head recordings have only been subjectively evaluated. In general, listeners agree that the directional reproduction is at least as good as with headphones. Many listeners even indicate a better spatial discrimination, especially in the front region. The effect of the system is unexpectedly independent of head position, when only the distances to the two speakers are kept equal.

5 FUTURE WORK

Further investigations have been planned on the following matters:

a) Quantitative and objective evaluation of the observations given above in Section 4.

b) Evaluation of the significance of the blocks $1/A(1-(B/A)^2)$ and k/C.

c) Significance of impulse duration in the realization of filters.

d) The possibility of realizing the blocks of Figure 2, using recursive Infinite Impulse Reponse filters.

e) The possibility of using a normal listening room. The system is not formally limited to anechoic rooms, but for normal living rooms much longer impulse responses occur, and more computing power is needed.

f) The construction of the artificial head. Figure 4 shows a principal diagram of the signal path from the sound field without a listener present to the sound pressure at the eardrum. It can be argued that full directional information is present in the open circuit Thevenin sound pressure at the entrance to the ear canal. If this pressure is recorded rather than the pressure at the eardrum, all transfer functions are more regular, and the blocks of Figure 2 become easier to realize. Furthermore, the final reproduction is less influenced by differences between the artificial ear and the ear of the listener, since a smaller part of the artificial ear is used. Recording with Neumann Type KU 81i artificial head is expected to approach this situation.

g) Problems at low frequencies where A and B are approximately equal.

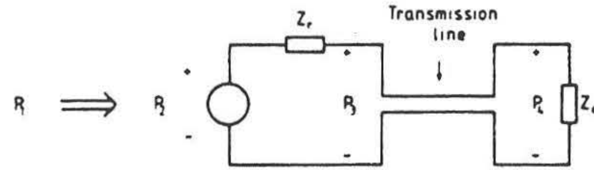

Figure 4. Principal diagram of the signal path from the sound field without a listener present to the sound pressure at one eardrum. P_1 denotes the pressure without a listener. P_2 the open circuit Thevenin pressure at the entrance to the ear canal. P_3 the actual pressure at the entrance to the ear canal. and P_4 the pressure at the eardrum. Z_r is the radiation impedance seen from the ear canal. and Z_e is the impedance of the eardrum. The ear canal is represented by a transmission line. Only the transmission from P_1 to P_2 is dependent on the angle of incidence and the distance to the sound source. Thus, it can be argued that P_2 contains full spatial information

6 ACKNOWLEDGEMENTS

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DESIGN OF A HEAD AND TORSO SIMULATOR

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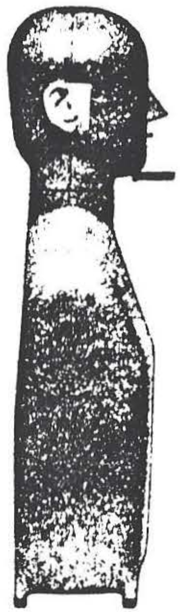

Fig. 1. The Head and Torso Simulator, Type 4128

1. INTRODUCTION

For many years acoustical equipment, such as telephones, headsets, close-talking microphones, hearing aids and so on, has been evaluated using couplers, artificial ears and artificial mouths, which are not very similar to the human being on whom the equipment is intended to be used. It is obvious that a solution to this problem is to use a human-like instrument with ear- and mouth-simulators, a so-called Head and Torso Simulator (HATS). It has been pointed out by CCITT: "HATS is the next logical step" .... But how should a HATS be designed? In the following it is briefly described how Brüel & Kjær's new Head and Torso Simulator, Type 4128, was designed.

2. DESIGN PHILOSOPHY

At the beginning of the project, the following requirements for the HATS were set up:

It should simulate a median human adult geometrically and acoustically.
The surface should be mathematically describable as far as possible.
A minimum parameter efficient simulator was wanted.

3. REFERENCE INFORMATION

The HATS is designed on the basis of the following reference information:
1. People in the house (photo study)
2. Experience with artificial mouth and ear design
3. ANSI S3.36 [1] and IEC 959 [2] documents
4. Humanscale™ geometric database [3]
5. CCITT document on artificial mouth [4]
6. Variety of scientific papers and reports
7. CCITT mouth field study [5]

4. CONSTRUCTIONAL REQUIREMENTS

The following base requirements should be met:
1. It should be stable, reproducible and well suited for production with present technology
2. It should have modular structure to make it easy to operate and easy to calibrate
3. There should be facilities to mount the device on a tripod etc. and to mount measurement objects on the device.

5. BODY

The body consists of a torso and a head. The head is removable from the torso by means of a bayonet clamp. The standard configuration of the head includes two removable pinna simulators, a turnable microphone holder and a removable mouth insert.