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OBJECTIVE TESTING FOR THE AUDITORIUM SURVEY

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INTRODUCTION

The acoustic testing of new auditoria is still limited in most cases to measurement of the reverberation time and the background noise level. For the well known survey of the world's concert halls by Beranek /1/, completed in 1962, no objective acoustic measurements were, in fact, specifically taken! Comprehensive measurements suitable for survey purposes are therefore rare. The best documented examples are to be found in the two German objective/subjective surveys, conducted at Göttingen /2/ and Berlin /3/.

The physical requirements for valid measurement of the reverberation time are readily satisfied. The primary requirement is for a source capable of producing an adequate signal-to-noise ratio. The directionalities of the source and receiver are, within reason, not too critical and even modest overload of recorded responses is unlikely to influence the measured result. Such casual requirements do not hold for other objective measurements for auditoria.

The following discussion explores the selection of the individual measurements now being made for the auditorium survey and describes the specialist transducers used. A viable measurement programme must involve modest testing times. Measurements are made at between 10 and 12 audience positions in each auditorium.

THE PROBLEM OF COMPLETE DESCRIPTION

An auditorium is acoustically a linear system and as such the propagation between two points is fully described, ignoring directional information, by the impulse response. Many objective measurements are based on the impulse response (of an omnidirectional receiver) and much of the following discussion is concerned with ways of measuring it. The directional information is however also important but wholely successful recording of it remains to be achieved. The most promising technique to date involves an acoustic telescope /4/, which can be "steered" at will during analysis. However the current system is slow and limited to ca. 170ms of acoustic response at only one frequency.

With the exception of early lateral reflections /5/ little is known about the importance of the directional distribution of sound at the listener. For instance, some sound from behind is known to be desirable. In the absence of criteria by which to make judgements, our survey is limited, from a directional point of view, to measuring only the proportion of early lateral energy.

One apparent solution to the directional problem is to record the signals at the eardrums of a dummy head, since it is known that these two signals contain all the information available to the listener. This approach was used in both the German studies, but more exclusively by the Göttingen group. Though a dummy head technique reproduces automatically many of the physical directional effects which are both important and can be analysed (e.g. interaural time differences), it is only a truly valid approach, if the analysis is performed in the same way as our hearing system. However for many responses the mechanism of the hearing system is not fully understood and working models do not exist. For instance, to use the eardrum signals to isolate sound from behind is not possible at present. The outer ear also distorts in ways which in some cases are automatically compensated at the neural level. Dummy head recordings for objective measurements are thus not automatically the optimum solution; the use of a dummy head should be judged on its merits for the objective measure concerned.

As well as the problem of recording directional information at the listener, there is the problem of reproducing source characteristics. For speech this presents no insurmountable problems, the source is effectively a point source with reproducible directionality. However in the case of an orchestra, the source is not only distributed but each instrument exhibits complex directional characteristics. To attempt to reproduce this is a formidable challenge, which remains to be tackled. Any solution would involve much simplification and this should be undertaken on the basis of subjective experiments into listeners' sensitivity to source directionality. The present state of the art is more or less limited to observations concerning the difference between listening to recordings played through loudspeakers and a true orchestra, both in the same auditorium, as well as observations on placement of individual groups on the orchestra platform /6/.

To conclude this survey of the problems involved, it is clear that recording all the relevant objective information is currently not feasible, at least for a survey of many auditoria, and, where an orchestra is the sound source, that gross simplifications are necessary. The approach which has been adopted for this survey is to measure objective quantities based on simple transducer configurations (frequently omni-directional point sources or receivers) and that one aim of the survey is to assess whether these objective measures, in spite of their simplicity, are nevertheless useful. In addition, simple transducer systems are desirable for an assessment of an enclosure on purely acoustic grounds, such as an assessment of the degree of diffusion.

SOURCE TRANSDUCERS

Many impulse response measurements in auditoria have been made with spark sources, including the two German surveys already mentioned /2,3/. The advantages of the spark source are high intensity and an omni-directional characteristic, but there are also disadvantages of non-linear propagation in the vicinity of the source and imperfect reproducibility. The spectrum of a spark signal generally falls at 9 dB/octave with decreasing frequency (based on constant percentage band width). Though this characteristic can be compensated electronically during analysis, signal-to-noise problems have often been encountered at the lowest measurement frequencies with spark sources. Bearing also in mind problems of safety and of electromagnetic radiation interfering with measuring apparatus, it was decided to use loudspeaker sources exclusively.

Omni-directional loudspeaker sources are easy to produce which operate over limited frequency ranges. At lower frequencies dodecahedron arrays are popular and at higher frequencies tubes mounted on suitable drivers can be used. A wide band source is much more difficult and depends on a small transducer which can radiate down to low frequencies. For our measurements an omni-directional characteristic is required between 100 and 2500 Hz. A 50mm diameter cone loud-

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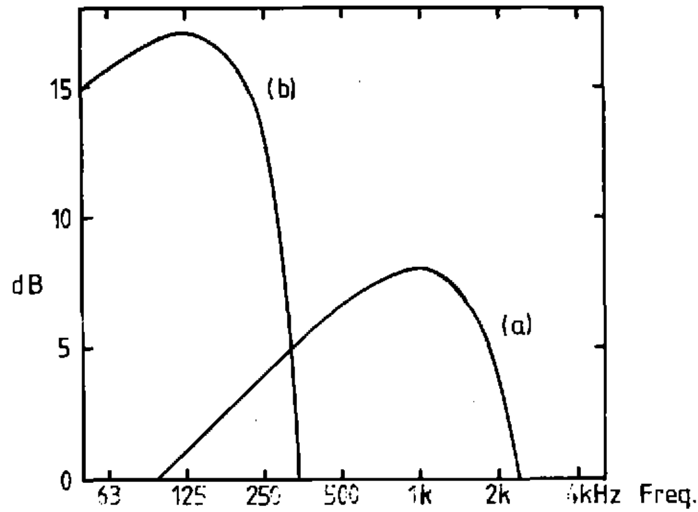
Figura 1



speaker does exist, which in a dodecahedron may be able to handle this requirement. We are however using two units to cover the frequency range: a dodecahedron operating up to the 1kHz octave and a cube array operating in the 2kHz octave.

A similar problem of the need for a small diameter transducer operating down to low frequencies occurs for a "speech source", with the correct directionality of a human speaker. Following success with a 1;8 scale speech source, extensive development of a loudspeaker driving into a tube was undertaken, until it was appreciated that the acoustic losses inherent in an inverted horn arrangement meant an inadequate signal-to-noise ratio. The current system uses a direct radiator, a 43 mm diameter dome tweeter mounted in a tapered box to provide acoustic shadowing equivalent to the human head. The directionality of this matches closely that measured for human speakers. Its lower limiting frequency is however around 350Hz, which is adequate for objective measurements for speech but not for actually playing speech through the transducer.

An advantage of loudspeakers is, of course, that any electrical signal can be fed to them. Adequate signal-to-noise ratio (i.e. better than 40 dB for an impulse signal measurement of reverberation time) is achieved with these systems by feeding from an amplifier with a large peak voltage capability. Most loudspeaker units will handle short duration pulses with a peak voltage well in excess of their continuous rating.

MEASUREMENTS FOR MUSIC AUDITORIA

The central measurement in the survey is the recording (onto tape) of the impulse response from a point source. Most objective measures for auditoria involve filtering in octave bands and for these the requirements of a true impulse response, can be relaxed to that of a reasonably flat frequency response over the relevant octave band(s). Half-cycle sine pulses are suitable for this purpose as a source signal. Figure 1, curve (a), shows the frequency response (on a constant percentage bandwidth basis) of a half-cycle 1kHz sine wave. It is usable in the 1kHz octave and below. However since background noise levels are generally much higher at low frequencies, the signal-to-noise situation is frequently inadequate at, say, 125Hz with this 1kHz signal. The spectrum of a 125Hz half-cycle wave with the same peak voltage is given in curve (b), which offers a 16dB improvement at 125Hz (the response above 350Hz is omitted from curve (b) for clarity).

In this way, the five octave frequency bands 125Hz-2kHz are covered with 3 or 4 impulse signals. The responses are recorded onto tape. To insure against overload, a peak reading meter is employed; the 'Peak' reading meter on a Nagra recorder with a stated integration time of 5ms does not respond fast enough for these pulse signals. For the assessment of music auditoria the following objective measures are derived from the omni-directional impulse response: Reverberation time, Early Decay Time (10dB), Ratio of early to late energy (80ms) and Centre Time. Other measures which have been proposed are known to be highly correlated with one or other of these /2,3/.

To measure the effect of early lateral reflections, the early lateral energy fraction /5/ is measured with a figure-of-eight directionality microphone. And finally the steady state level is measured with a sound level meter with known voltage noise signals fed to the loudspeakers. The sound power output of these loudspeakers has been measured in a reverberation chamber. In this way the relative loudness in different halls can be established.

THEATRE MEASUREMENTS

With speech, not only is the location but also the orientation of the source important. To restrict measurement time, we are limiting ourselves to a central source position facing into the auditorium and a position to one side facing across stage away from the recording positions. The latter configuration represents a potentially poor condition for speech intelligibility. From the impulse responses recorded at each position, the following objective measures will be derived: Reverberation time (R.T.), Early Decay Time (E.D.T.), 50 ms energy fraction and the Modulation Transfer Function (M.T.F.). For the R.T. and E.D.T. omnidirectional source responses are used. In addition to the 50ms energy fraction and the Modulation Transfer Function, a further measure of intelligibility based on a gated noise signal will be used. Loudness with the speech source, calibrated for sound power, is also measured. It is hoped to establish whether the M.T.F. measure works for theatre conditions and determine whether the simpler measures are adequate. Measurements in theatres take about 5 hours on site, whereas for music auditoria only 3 hours are needed.

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