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Misleading Measurements

Raymond Cooke
on speaker measurement

> **Errors like straws upon the surface flow;**
> **He who would search for pearls must dive below.**
>
> *John Dryden 1631–1701*

THAT quotation from 'All for Love' was first used in an acoustical context by G. A. Briggs nearly a quarter of a century ago to preface a chapter on vented enclosures. He went on to say 'there are always two methods of approach to the solution of a problem, particularly where the behaviour of sound is involved. One is by the scientist who is able to calculate to some extent what should happen; the other is by the investigator who simply tries to find out what actually happens. Whereas the scientist is often disposed to rely on theory, the practical man is always in danger of jumping to conclusions. The ideal state is probably one where the two methods can be co-ordinated.'

These wise words aptly describe the present state of affairs in loudspeaker technology where new theories and new methods combine with old fashioned experience to point the way ahead in the most exciting period of development since Rice & Kellogg's practical realisation of the moving coil speaker. A new found ability to make acoustical measurements in time as well as in the frequency domain and to relate one to the other makes it possible to see very clearly where we may have been misled by measurements in the past. This extension of our acoustic faculties naturally leads to a reassessment of traditional measuring techniques and how results may be interpreted.

It is astonishing how many people still believe that the performance of something as complicated as a loudspeaker can be depicted as a series of lines on a piece of paper, despite considerable contrary evidence over fifty years. The situation is no doubt due to general acceptance of scientific methods coupled with prodigous growth in technical reviewing during recent years. Graphs and oscillograms of one sort or other form the backbone of most published reviews of audio equipment and the enthusiast is informed about the general principles of audio measurements. What is not so widely appreciated is that acoustical measurements are prone to inaccuracies and that their interpretation calls for a degree of experience and insight which is probably unequalled outside of medical diagnosis. Pitfalls appear to be due to several causes, in particular, errors from environmental conditions, bad measuring technique and inexperienced interpretation.

THE MEASURING ENVIRONMENT

Much of the acoustical terminology in common use is in itself misleading because it expresses intentions rather than reality. When we speak of infinite baffles, omnidirectional radiators and free field response, these terms are subject to a great measure of qualification. Nowhere is this more true than in the case of the anechoic chamber, the operation of which is usually far from being truly anechoic. These chambers are generally intended to provide inverse square law conditions over a limited frequency range and within an operating area restricted to the middle portion of the chamber volume.

Anechoic chambers function by absorbing incident sound energy usually in walls of protruding wedge shaped structures made from soft materials such as fibreglass or polyurethane foam. Total energy absorption is impossible, ninety percent being the figure generally aimed for at middle frequencies. Below about 200 Hz absorption becomes progressively less due to inadequate physical length of the wedges while at high frequencies, say above 8 kHz, absorption is also reduced by the physical characteristics of the wedge material.

In amplitude-frequency response measurements, the loudspeaker under test is located near the centre of the anechoic room with the measuring microphone a short distance away along some desired measuring axis. Sounds from the loudspeaker reach the microphone both by direct transmission and after reflection from the nearby surfaces. Reflected sound coming from the chamber walls may be thought of as a sample of the direct sound which has been modified in frequency response and intensity due to the frequency dependent absorption of the wedges, plus a time delay due to the reflected path length. The reflected sound combines with the direct sound at the microphone and may augment or reduce it according to its phase, causing deviations in the amplitude-frequency response. The extent of these deviations can be predicted in terms of the strength of the reflected sound image. Obviously the more absorbent the wedges, and the greater the distance between walls and speaker, the weaker the image (or images) will be. In other words, large anechoic chambers fitted with long high grade absorbent wedges permit more accurate measurements at greater microphone-speaker distances.

TESTING OUT OF DOORS

There are in fact very few really large anechoic chambers of first class quality in existence and of these, still fewer are available for loudspeaker measurements. For this reason measurements out of doors are often resorted to in an attempt to obtain precise results.

Some investigators have proposed burying speaker systems flush with the ground, thereby confining acoustic radiation to a hemisphere. This technique has the merits of simplicity and repeatability, but the results are of limited value because the effects of diffraction around the loudspeaker enclosure at middle frequencies are ignored and vibration of the cabinet walls is inhibited by the sand or earth packed around the enclosure.

More meaningful measurements may be obtained with the speaker raised clear of all reflecting surfaces, such as for example by placing the loudspeaker on top of a tower in an outdoor location which is well clear of other large structures. A most important question then arises as to how high above the ground does the loudspeaker have to be in order for the reflections from the ground to

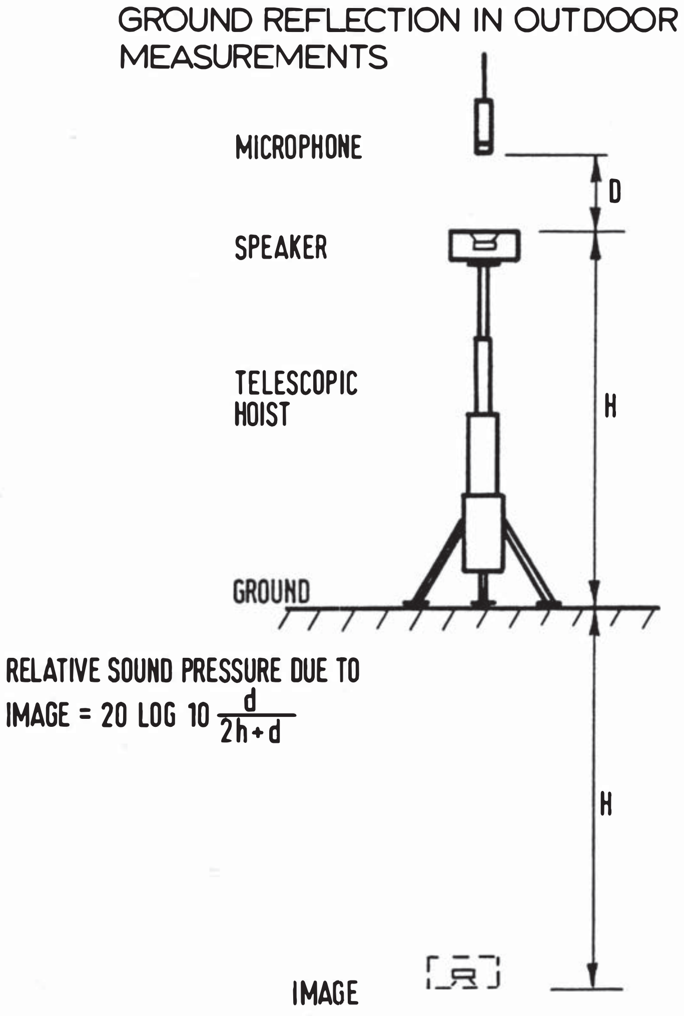


Fig 1 Ground reflection in outdoor measurements

be considered negligible? As in the case of the anechoic chamber there are three important aspects, namely the microphone to speaker distance, microphone to image distance and the orientation of the speaker with respect to the reflecting surface at the ground. The microphone to speaker distance must be large enough to sample realistically the sound field resulting from all the component radiators including secondary sources due to diffraction. In the case of small domestic loudspeakers a microphone distance of 1 metre is usually satisfactory, but larger systems may qualify for 2 metres or more.

The microphone to image distance (fig. 1) is related to the microphone–speaker distance in so far as the sound field at the microphone due to the image must be sufficiently attenuated relative to the direct output from the speaker so as to cause a negligible error in the direct sound pressure level over the band width of the test. For errors less than 1 dB the output from the image must be —19·3 dB, for 0·5 dB error the image must be —25 dB and for 0·25 dB error, the corresponding attenuation is 30·9 dB. If we assume that the image has a frequency response which is identical with that of the source and that it is of equal strength, then the relative distance of the image to the microphone based on inverse square law considerations would be 9·2, 17·8 and 35·1 times that of the speaker to microphone distance for errors of 1·0, 0·5 and 0·25 dB respectively. Assuming that the speaker faces upwards with the microphone located overhead at a distance of 1 metre the distance between the front surface of the speaker and the ground may be calculated at 4·1 m, 8·4 m and 17·0 m respectively.

Closed box loudspeakers display frequency-dependent polar characteristics, becoming progressively directional above a few hundred hertz. In these cases the error introduced by the ground reflection will diminish with rising frequency. The reflection coefficient of the ground surface is also usually frequency dependent. Therefore in practice the situation tends to be somewhat better than predicted by theory.

A succession of measurements taken with a fixed speaker–microphone distance of 1 metre, but with varying heights above the ground shows that the speaker to ground distance should be at least 8 metres in order to avoid noticeable discrepancies in the amplitude frequency response (fig. 2). Obviously, interference conditions become even more serious when the speaker microphone axis is horizontal.

It seems therefore that a loudspeaker system should be at least 8 metres above the ground to approximate free field conditions with a speaker–microphone distance of 1 metre. Mounting the speaker on its back and suspending the microphone above it minimises the influence of ground reflections for a given height. Any extension in speaker–microphone distance beyond 1 metre will necessitate an increase in the height of the loudspeaker if the same measuring accuracy is to be maintained.

TONE BURST TESTS

The use of interrupted tone signals for assessing transient performance of loudspeakers is frequently encountered. Here the characteristics of the acoustical environment require particularly close scrutiny to avoid misleading results. Anechoic chambers which perform adequately enough for steady state frequency response measurements are often totally inadequate for measurements in the time domain. Descrete reflections from floor grids, microphone cables and other solid objects provide traps for the unwary.

In fig 3 (a) a rectangular impulse has been employed to show the presence of a reflecting floor grid on which the speaker system is standing. The secondary impulse reflected by the grid can be seen 2 milliseconds after the initial impulse response. If interrupted tone is applied to the speaker at a frequency of 2·2 kHz a reflected sample of the direct sound fuses with the primary tone burst envelope and gives the appearance of 'ringing' (fig. 3 (b)). Removing the reflecting grid obviates the spurious effect in both tests. It is of course necessary to be very suspicious of any tone burst envelope having a rectangular outline to its tail instead of the exponential shape normally expected.

Even the microphone itself can cause significant reflections. In fig 4 the reflection of an impulse response can be clearly seen. This was caused by sound energy ricochetting between the flat front face of the half inch B & K microphone and the speaker baffle over a distance of 250 mm.

If we look at the cumulative decay spectra for a high quality loudspeaker, fig 5, it will be apparent that a tone burst taken at a fixed frequency is really a slice taken through the cumulative spectra, parallel with the time axis. Closer inspection shows that most of the persistent features do not decay at a fixed frequency but vary in frequency during the decay period. Moreover, the frequency 'gear change' is usually upwards. A simple tone burst slice is therefore incapable of accurately depicting the decay of low damped resonances since the line of least descent does not adhere to a single frequency. In general, tone burst envelopes tend to give an over-optimistic view of decay phenomena and can be very misleading. By contrast the human ear has no difficulty in tracking a low damped resonance as it decays, even though its pitch varies in the process.

It should also be remembered that most tone burst displays are viewed on a CRO with a linear amplitude scale. Resolution is therefore limited to 20 dB at the most, which is insufficient to reveal effects which are known to be significant at levels as low as 40 dB below the steady state response.

DIRECTIONAL EFFECTS

All loudspeakers exhibit frequency dependent directional behaviour. Indeed there is little that designers can do to control or mitigate increasing directivity with rising frequency as it is mainly a result of diaphragm size compared with the wavelength of sounds in air. If a loudspeaker system comprises several drive units mounted in a vertical array, then each unit will exhibit a characteristic directivity pattern in the frequency range over which it operates. The complete system will have directivity characteristics in the horizontal plane very similar to those of the individual drive units with slight variations caused by diffraction and other second order effects due to the enclosure.

Directivity patterns will be more complex in the vertical plane due to the spacing between the units and due to relative phase shift between various filter sections of the dividing network. It is therefore necessary to investigate directional effects to determine their influence on perceived sound quality.

A good balance of sound should be available over at least 60 degrees in the horizontal plane to serve a wide spread of listening locations and to ensure sharp stereo images. The vertical listening window can be more restricted, but it is important that sound quality radiated obliquely shall be free from serious irregularities.

This diffuse sound is integrated by the listening room and is subjectively assessed by the ear in conjunction with the directly perceived sound. Any serious irregularities in oblique radiation will be heard as coloration. Therefore in studying a speaker's directional characteristics, we are not so concerned with so called beaming effects due to steadily increasing directivity with rising frequency. This is to be expected as a natural consequence of the speakers' physical dimensions. The main area of investigation should be aimed over the mid-frequency range and include the vertical plane.

There are two methods of measurement

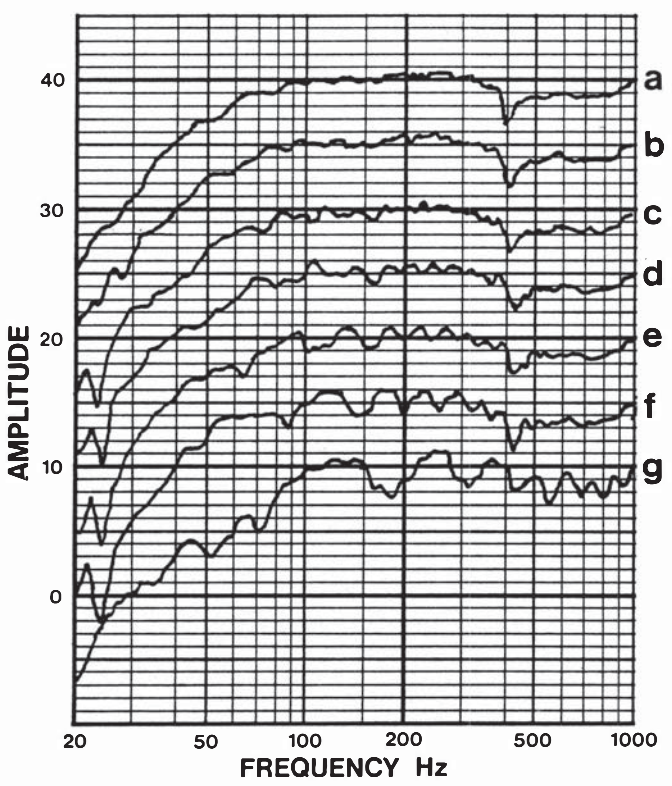


Fig 2 a) 8m, b) 7m, c) 6m, d) 5m, e) 4m, f) 3m; speaker facing upwards
g) speaker-mic. axis horizontal 2m above ground

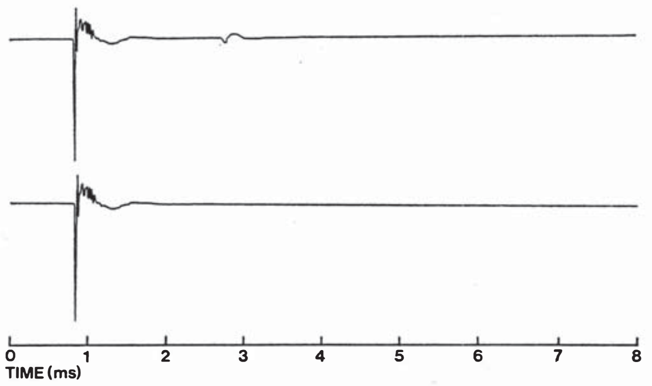


Fig 3 Reflection from floor grid
a) Impulse response with and without floor reflection

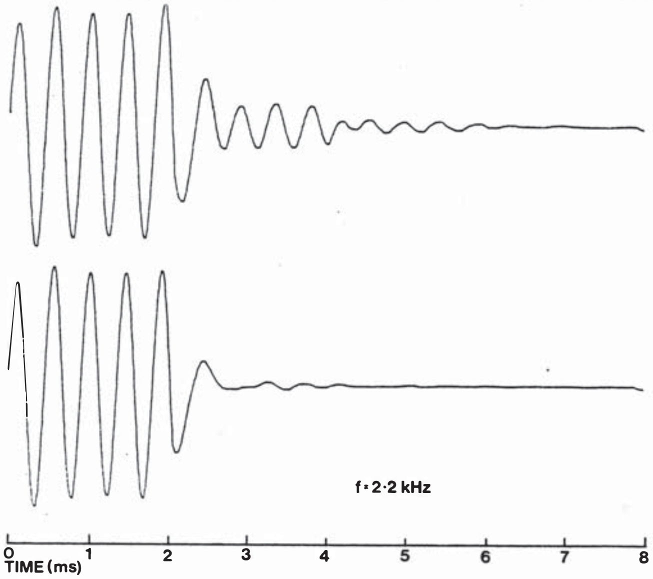


Fig 3 b) Tone burst response at 2·2kHz with and without floor reflection

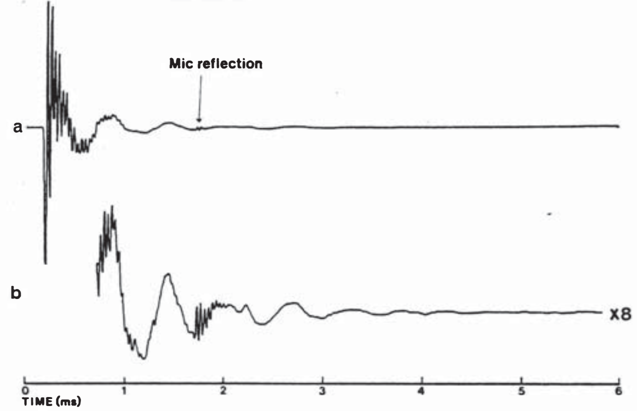


Fig 4 Reflection from microphone capsule
a) Impulse response of test speaker
b) As above with tail amplitude ×8

and display. In producing the so called polar diagram, measurements are made with steady tone at a fixed frequency, or with a narrow band of random noise, and the angular location of the microphone is varied continuously so as to produce a plot of sound pressure level against angle on polar coordinates. Measurements are taken at several frequencies. The weakness of this presentation is that one can never take measurements at enough different frequencies to be sure of revealing significant irregularities. In the course of the average technical review not more than eight different frequencies are plotted whereas at least twenty polar diagrams are needed for a thorough investigation.

In the alternative method, sound pressure level is plotted for continuously varying frequency at fixed angles. A family of curves taken at angular intervals of 15 degrees is usually adequate to reveal significant details. This form of presentation is more penetrating than the polar diagram since directional effects generally change more quickly with frequency than with angle.

Fig. 6 shows a family of characteristics for a two-way bookshelf speaker system of modern design and which enjoys a good reputation. Frequency response curves are plotted for the listening axis and 15°, 30° and 45° in the horizontal plane. The drive units are not vertically in line and interference effects produced by their physical location combined with electrical phase shift due to the filter network can be clearly seen in the 2–3 kHz region. The dips produced here are far more significant than the gradual off-axis attenuation of high frequencies. Moreover, polar diagrams taken at the usual fixed frequencies of 500, 1 k, 5 k, 10 k and 15 kHz would fail to reveal the trouble because they straddle the contentious frequency range.

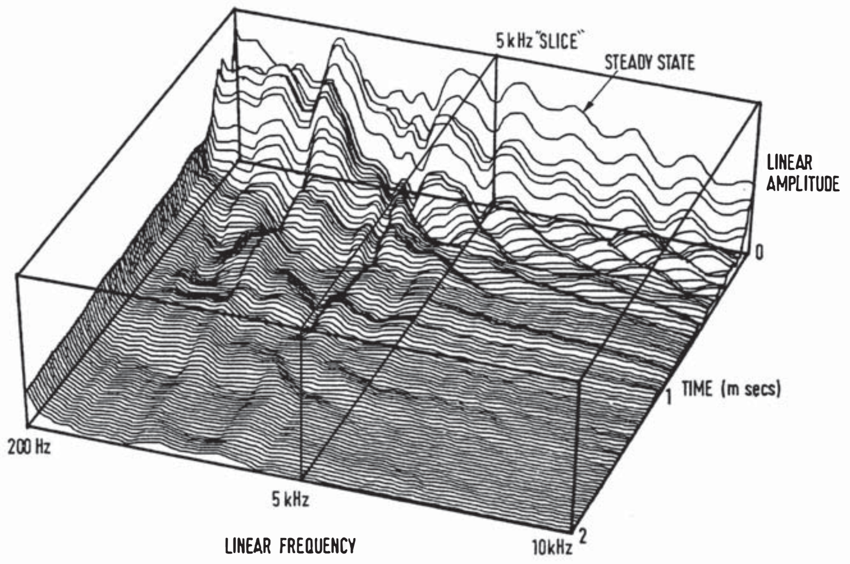
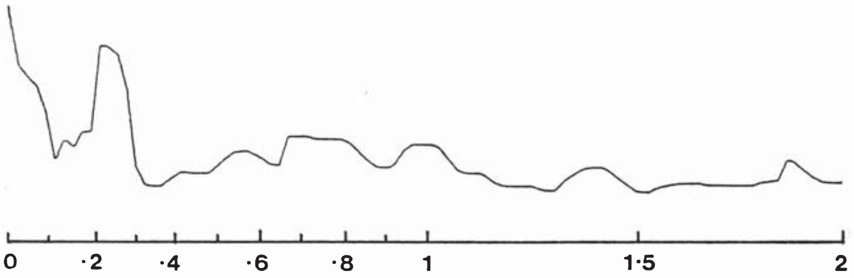


Fig 5 Tone burst envelope a) Cumulative decay spectra



b) Envelope of 'slice' through 5kHz

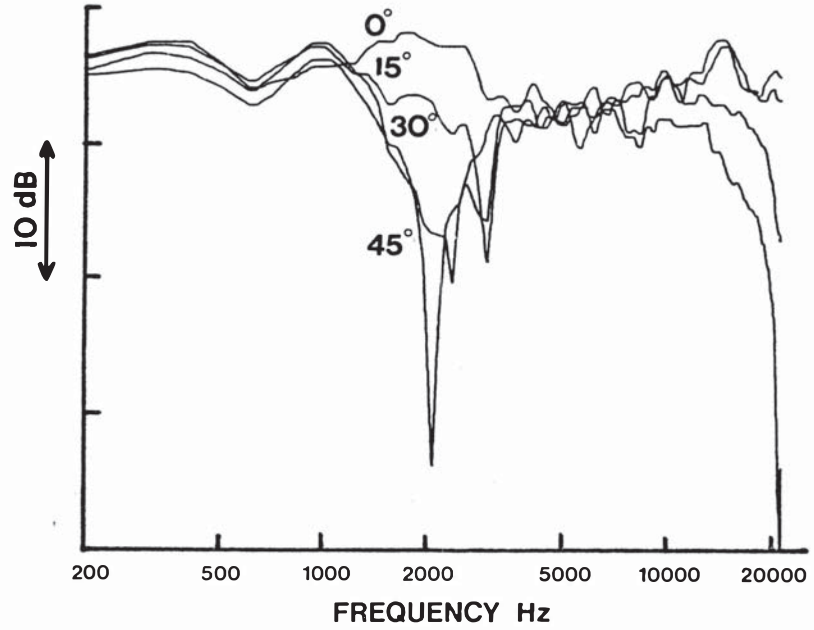


Fig 6 Family of oblique frequency response curves at 0°, 15°, 30° and 45°, 1m in horizontal plane
Freq. range 200Hz–20kHz (Log scale) measured at 1 metre at 0°, 15°, 30° and 45° in horizontal plane

SUMMARY

Anechoic chambers are intended for relatively simple steady state measurements. Reflections can produce spurious results in time domain investigations where low level influences become significant. Easement can be found in outdoor locations, but the speaker must then be raised at least 8 metres above the ground for negligible response deviations.

Tone burst tests are of little value because of poor visual resolution. Single frequency envelopes are unable to track low damped resonances which vary in frequency as they decay, and therefore tend to give over-optimistic assessments.

Polar diagrams taken at a few spot frequencies cannot expose directional features which influence overall sound quality. Amplitude-frequency response curves taken at a variety of angles offer a clearer and more penetrating presentation.

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