

Acoustics

BULLETIN

VOL 29 No5 Sept/Oct 2004



Acoustic limiting in telephony headsets

Low-frequency acoustic modelling
of biological tissue

Small-scale acoustic modelling
of vehicle compartments

The making of a sound level meter

Pioneers: Harvey Fletcher



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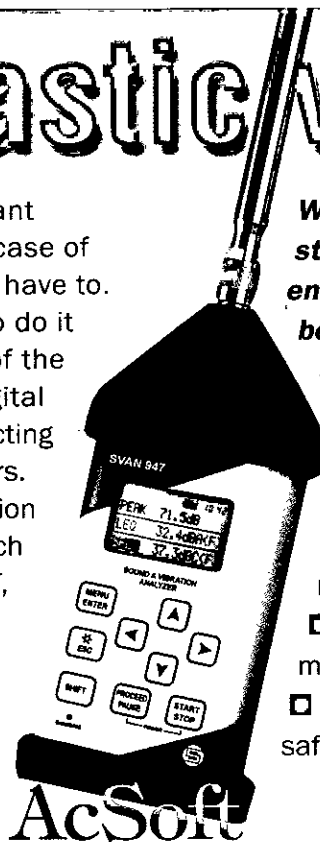
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Acoustics

BULLETIN

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Institute of
Acoustics

The Institute of Acoustics was formed in 1974 through the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society and is the premier organisation in the United Kingdom concerned with acoustics. The present membership is in excess of two thousand and since 1977 it has been a fully professional Institute. The Institute has representation in many major research, educational, planning and industrial establishments covering all aspects of acoustics including aerodynamic noise, environmental, industrial and architectural acoustics, audiology, building acoustics, hearing, electroacoustics, infrasonics, ultrasonics, noise, physical acoustics, speech, transportation noise, underwater acoustics and vibration. The Institute is a Registered Charity no 267026.

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Dear Members

2004 is the thirtieth anniversary of the birth of the Institute of Acoustics, though we can claim a generation or so of antenatal experience in the guise of the British Acoustical Society and the Acoustics Group of the Institute of Physics from whose amalgamation we were formed in 1974. Thirty years on we can be reasonably satisfied that the single, independent Institute foreseen by our founders has achieved much of their vision. However, as I've mentioned in an earlier letter, we cannot rest on our laurels and there remains plenty to be done in a continuously evolving environment.

By the time you read this, I hope that you will be aware that we intend to mark our thirtieth anniversary year at the Autumn Conference dinner on 6 October at the Oxford Hotel, Oxford. The Institute is especially pleased to have been able to arrange for Dr Leo Beranek to speak at the dinner. In 1948 Leo Beranek co-founded the American consulting firm Bolt Beranek & Newman, later BBN Technologies, famous for its wide-ranging work in acoustical engineering and computing. Many of us will have Dr Beranek's books on our shelves and will be aware of his enormous influence. Now in his ninetieth year, Leo Beranek continues to pursue his consulting interests in concert hall and opera house design. His breadth of knowledge and experience will surely result in a fascinating address.

We will also be publicly announcing our new award for acoustical engineering excellence. The Institute of Acoustics Engineering Medal is to be awarded on a bi-annual basis to registered engineers at Chartered, Incorporated or Engineering Technician grade in recognition of their outstanding contribution in the field of acoustical engineering. I am delighted to announce that the first such medal will be presented to Rob Harris of Arup Acoustics during 2005, in recognition of his thorough theoretical and practical engineering approach to innovative acoustical design.

Having mentioned our new medal, it is perhaps timely to remind everyone that nominations for our various medals and awards may be made at any time either by using the standard forms available from the Institute or by writing in confidence to me.

I look forward to seeing you all at Oxford on 6 October.

Tony Jones
President

Editor's Notes



Ian F Bennett BSc CEng MIOA
Editor

I have the impression that acousticians tend to have a relatively advanced appreciation of 'green' issues such as recycling. In my role as Editor I get all sorts of interesting things through my real and virtual letterboxes, but one of the more useful that arrived recently was a communication from the Roy Castle Recycling Scheme. Many of us have unwanted mobile phones still kicking about, and these are actually worth cash to those charities able to handle sufficient volumes of them. Apparently my Nokia 402 is worth a couple of quid, so since I never paid Orange a penny for it in the first place, off it goes! Empty printer cartridges too can usually end up in landfill sites, where they take hundreds of years to degrade, when they

can be recycled or remanufactured. Although the major printer manufacturers do have schemes of their own, I am sure I am not the only office-based worker who cannot be bothered sending off empty cartridges, and I usually lose the pre-addressed envelope anyway.

Help is at hand to overcome this inertia, and I am grateful to Janine Drew of the Roy Castle Lung Cancer Foundation for telling me about it. Your (and my) empty printer cartridges and brick-style mobile phones can be posted to: Roy Castle Recycling Appeal, 31-37 Etna Road, Falkirk, FK2 9EG. Other charities also participate in the scheme, including Marie Curie Cancer Care, Cancer Research UK, and the RNIB. You can visit www.recyclingappeal.com/uk/ to find out more, and they will even send you a Freepost envelope on request. End of homily. Space is at a premium this issue, so we are not bringing you the customary preview of the Autumn Conference and Reproduced Sound



The Oxford Hotel, our Autumn Conference and Reproduced Sound venue

20. However, members will have had a 'flyer' from Head Office by now. The Conference theme is 'environmental acoustic modelling' and the event is on 6 and 7 October 2004. There is an interesting and varied programme of papers in prospect, ranging from the European Harmonoise project, through noise studies in London and Merseyside, to a detailed discussion of the revision of PPG24. The R W B Stephens medal lecture and the Rayleigh medal lecture will also be given at the conference, by Greg Watts and Alan Cummings respectively. Reproduced Sound 20 as usual follows straight on, and is subtitled 'improving the listening experience': it takes place from Friday 8 to Sunday 10 October. Both conferences are, as last year, at the Oxford Hotel, and I can recommend the Old Speckled Hen. Who knows, there might be other guest ales available next month... The Institute web site has full details of both conferences. The last time I looked the Institute site at www.ioa.org.uk still had a 'temporary' feel to it, but all the information is there all right! The sound reproducers also have their own site at www.reproducedsound.co.uk which gives a potted history of the Reproduced Sound series of conferences and useful information about how to get there.

Ian Bennett

Ian Bennett
Editor

Noise control for HVAC systems

The effective control of noise from HVAC systems to meet regulations and end-user specifications

This one-day conference, taking place on 20 October 2004 at Earls Court Exhibition Centre, London, will include presentations from several leading industry specialists. Organised by H&V News, the event is endorsed by the Association of Noise Consultants (ANC) and the Federation of Environmental Trade Associations (FETA)

The provisional programme includes:

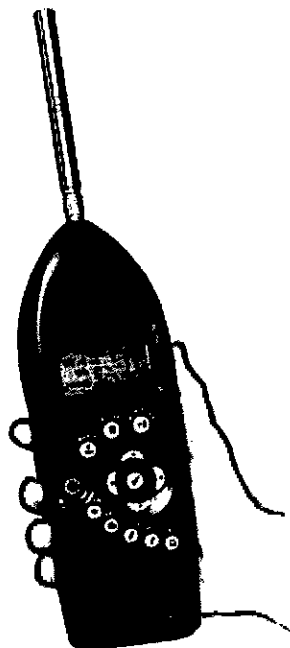
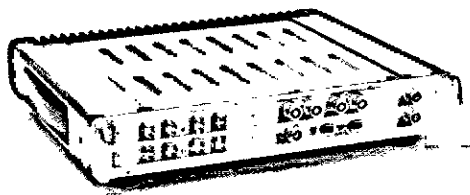
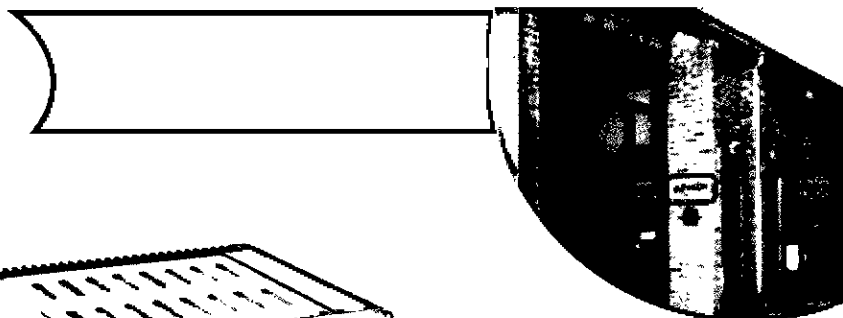
- ☐ Examining guidelines and current legislation for noise control for the HVAC industry
Peter Henson, Bickerdike Allen Partners
- ☐ Applying Building Bulletin 93 - the control of acoustics in schools - and its impact on the HVAC industry
Richard Daniels, Building Service Engineer, Schools Building & Design Unit, Department for Education and Skills, and **Andrew Parkin**, Principal Acoustic Consultant, R W Gregory LLP
- ☐ Sound testing and measurement - evaluating methods and criteria for compliance
Jack Dalziel, Senior Consultant, Sound Research Laboratories
- ☐ Creating quieter HVAC systems: design of air-cooled chiller systems
Ian Lilley, Director of Marketing, York International
- ☐ Creating quieter HVAC systems: Fan Coil Unit (FCU) acoustic design
Michael Price, Engineering Manager, Biddle Air Systems
- ☐ Dealing with external noise from HVAC systems
Jeremy Butt, Executive Acoustic Engineer, Hoare Lea
- ☐ Reviewing the use of natural ventilation and controlling noise levels
Bob Peters, Principal Consultant, Applied Acoustic Design
- ☐ Working with specifiers for quieter buildings and understanding customer expectations of noise in HVAC systems
Nigel Chandler, Consultant, Sound Research Laboratories

On-line registration is available at www.hvacnoisecontrol.co.uk
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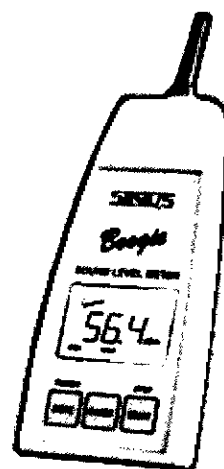
EXAMINATION RESULTS

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Investigating the acoustic properties of vehicle compartments

Using reduced-scale simplified models

R Gorman and V V Krylov

Vehicle interior noise has been an important problem for the car industry for at least the past four decades (1). With many noise generation mechanisms, including structural and airborne sources, it is a very complex subject that employs a variety of modelling techniques. These include experimental techniques using excitation of sound inside cavities by means of a loudspeaker (2) or an electromagnetic shaker (3, 4). Finite Element Analysis and Trefftz-based methods are being used widely to predict acoustic responses of both regular and irregular cavities (5, 6). In spite of noticeable progress, there is still insufficient understanding of the acoustic resonant properties of a vehicle interior which are paramount in defining levels and frequency contents of vehicle interior noise.

This article investigates the acoustic resonant frequencies and the corresponding modal shapes in a quarter scale model of a generic five-door saloon. As a first step, a simple rectangular cavity is investigated using experimental techniques similar to the ones employed in **References 2,3,7**. A Spectrum Analyser is used to measure the frequency response and spatial patterns of the cavity via a microphone. A small speaker is placed in one corner of the cavity at an angle of 45° to the floor, outputting white noise at the frequency range of 100Hz - 2100Hz. The speaker is then used to output these frequencies as a single sinusoidal mode to measure the spatial distribution of the acoustic pressure. The results are compared with analytical calculations to determine errors within experimentation.

As a second step, the rectangular cavity is modified with added sides to create an octagonal cavity. Similar measurements are taken and analysed to help determine the induced irregularity on both frequency response and mode shapes of the cavity. The final modification to the cavity involves added wooden seats, giving a more realistic representation of a vehicle interior. Again this is measured and analysed using the same techniques. The results of these measurements are compared with the earlier experimental work (8) in which the authors measured the effects of added seats and noticed that the sound pressure level of the frequency response has been lowered and resonant frequencies shifted depending on the orientation of the seats.

To model the effects of trim, felt is added to the wooden interiors of all of the three above mentioned quarter scale cavities. This is to help understand the effects of different absorption materials in the cavity, of a real car interior. Measurements of the frequency response are then compared with the BIW (Body In White) cavities.

To perform theoretical analysis of the above models, Finite Element Analysis (FEA) is used, with the boundary properties of the walls set as rigid. Different mesh sizes are used to better understand the capabilities and accuracy of the FEA programs, such as *Patran* and *Nastran* software packages. The results of both frequency

response and mode shapes are compared with the obtained experimental data.

Finally measurements are taken of the frequency response and mode shapes of a compartment of a real car, the Ford Fiesta. The results are compared with measurements for the model of the irregular cavity lined with felt, as this is the closest representation to a real car interior.

Experimental techniques

A rectangular box has been made to represent the simplest quarter scale model of a car interior, with the dimensions 0.55 x 0.35 x 0.25m³ (see *Figure 1*). The model was made out of 12mm thick wood, thus simulating

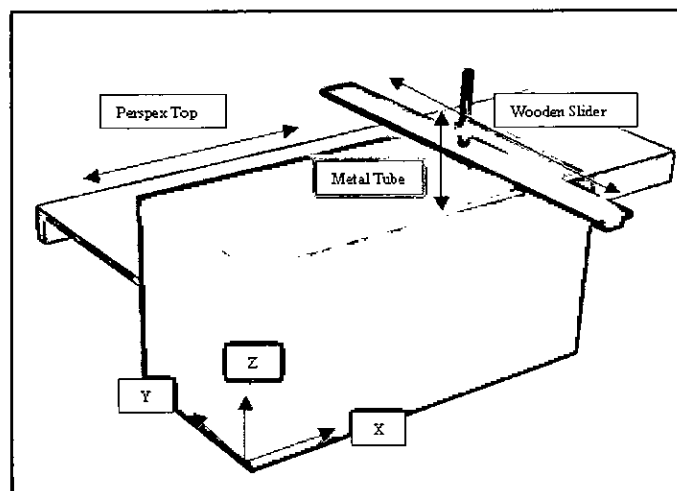


Figure 1: Diagram of the rectangular cavity

rigid wall conditions. The top section of the model has been made with a sliding Perspex plate of 10mm thickness, which was able to move across the X plane. The rectangular box is the basic element of construction, so that other sections could be added at a later stage. A gap in the Perspex held a wooden slider, which held the microphone in a section of metal piping. The wood was able to move across Z plane, and the piping could move up and down the Y plane allowing the microphone to reach all parts of the box. A grid of 30mm squares was marked on the bottom of the box, so that the microphone could be positioned accurately. An 8Ω, 2 inch *Visaton* medium range speaker was used to generate the sound inside the cavity. The speaker was attached to a small section of wood at a 45° angle so that it could be positioned in the corner of the cavity, guaranteeing that the acoustic modes are excited fully.

An *HP 3566A PC Spectrum Analyser* was used to measure the frequency response of the cavity. To undertake this, the speaker was excited in the frequency range of 100 - 2100Hz, in 400Hz bands, so that greater accuracy could be taken. This range is within the modal region, and gives an ample supply of modes to compare with the analytical and numerical solutions. The speaker was moved in three

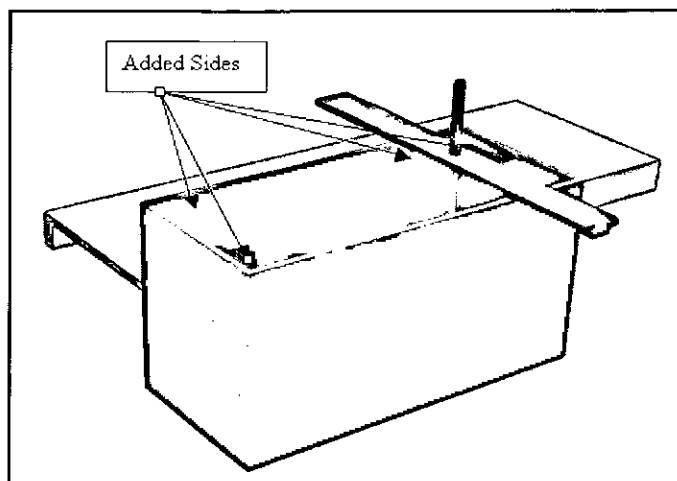


Figure 2: Diagram of octagonal cavity

positions, and the measurements were repeated to give an average.

The second stage of the experiment was to find the spatial distributions of acoustic pressure in the modes to compare with the analytical results. A plane across $Y = 0.18\text{m}$ represents an approximation of the head position of the passengers in the car, so this plane was used for measurements of modal distributions of 3 modes: (1,0,0), (0,1,0) and (3,1,0). Because a single plane was being used, axial and tangential modes could be measured in the X and Y directions only. If a mode in the Z direction or if an oblique mode was required, a plane in either the X or Z direction would need to be used. The speaker was excited at the chosen resonant frequencies of the modes, according to the measurements of the initial experiment: 306Hz, 579Hz and 1093Hz respectively. The microphone was positioned on the chosen plane, and the Sound Pressure Level (SPL) was measured for every point on the grid (every 30mm^2). The results were then plotted in *Matlab* to give the spatial distribution of the modes.

To give a better representation of a car interior, extra sides made of 12mm wood were added to the corners of the model giving an octagonal shaped cavity (see Figure 2). As before, the frequency response of the cavity was investigated. The first 11 modes of the cavity were measured this time (their values taken from the first 11 peaks on the graph of its frequency response).

The final quarter scale model represented the above-mentioned octagonal cavity with added seats made out of 50mm wooden blocks. One of the sides making the octagonal cavity was taken out to give extra room in the model (see Figure 3). As with the rectangular and octagonal cavities, the resonance frequencies and modal shapes were measured. As a section of the seats obscured

continued on page 10

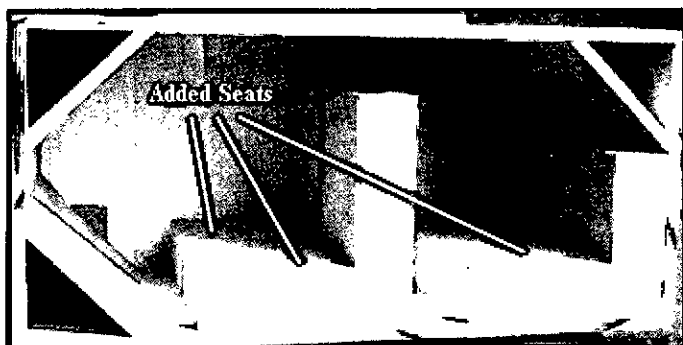
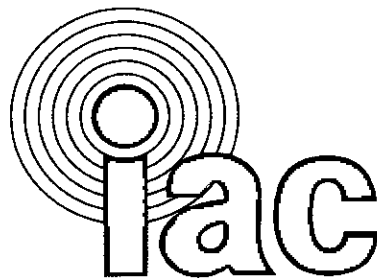


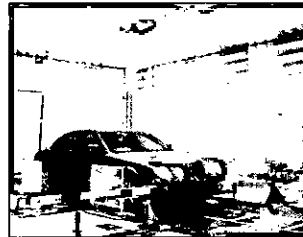
Figure 3: Irregular cavity with added seats



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Investigating the acoustic properties of vehicle compartments

Using reduced-scale simplified models

continued from page 9

part of the plane being measured, so on the spatial distribution graphs a corresponding gap was left.

Experimental results

Rectangular cavity

The measured resonance frequencies of the rectangular cavity before alterations are reproduced in *Figure 4*. The comparison of the experimental results with the analytical ones, calculated according to the well known formula, shows that the resonant frequencies found in the experiment agree well with the analytical solutions for lower order modes, with an error of less than 3% for the first eight modes. It is harder to predict which of the

compared with the analytical form.

The error in the measured resonant frequencies for the rectangular cavity is small for low frequencies, with the maximum of 2.66% (2dp). These errors are within usual limits known from earlier papers on similar topics (2, 8). The errors are due to a number of factors, eg. frequency-dependant absorption of the cavity walls, added reflections from the speaker and the microphone, temperature variations in the room, etc.

Finally the cavity would have been subjected to outside noise from the various electrical appliances used, including the Spectrum Analyser, computer and amplifiers. This sound could have shifted the resonance frequencies slightly.

Octagonal cavity

The frequency response of the octagonal cavity was measured using the same techniques as in the previous section. The results show that in this case the peaks are less frequent and generally lower in amplitude (see *Figure 6*). The sound pressure distribution was measured for the first nine peaks of the frequency response and also for two frequencies, 702Hz and 967Hz, which were significant troughs on the graphs of the single speaker position. Thus, the frequencies of the chosen 11 modes were 360Hz, 578Hz, 685Hz, 702Hz, 729Hz, 881Hz, 967Hz, 1056Hz, 1128Hz, 1221Hz and 1280Hz. Two different planes of the box, the Y plane and the X plane were measured for some of the modes to determine all X, Y and Z values, because the cavity is no longer rectangular.

As one can see, the modes of the octagonal cavity are less frequent, but have a similar average Sound Pressure Level to the original cavity. Because the box is no longer rectangular, the standard analytical equations are no longer applied, although they can still give some idea of the resonant frequencies and the shapes of the modes.

Irregular cavity with added seats

The third and the last type of cavity measured had added blocks of wood representing seats in the cavity (see *Figure 3*) to make it more realistic to a vehicle interior. The frequency response was measured again and

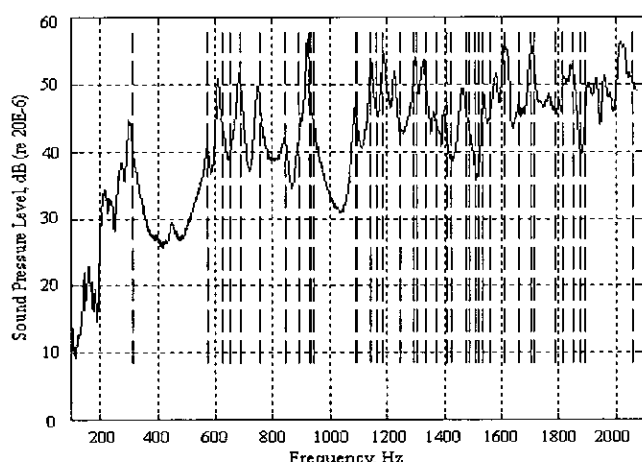
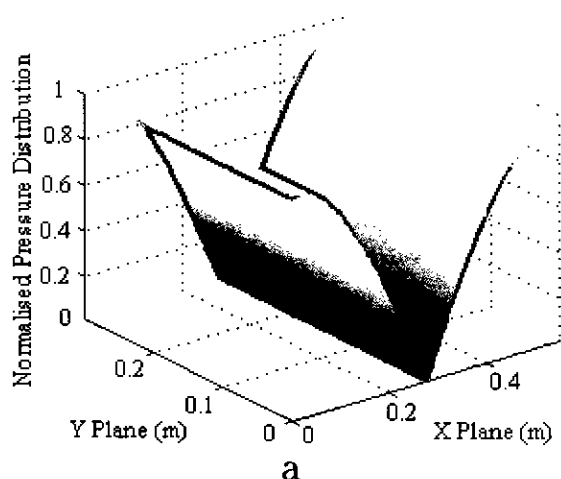


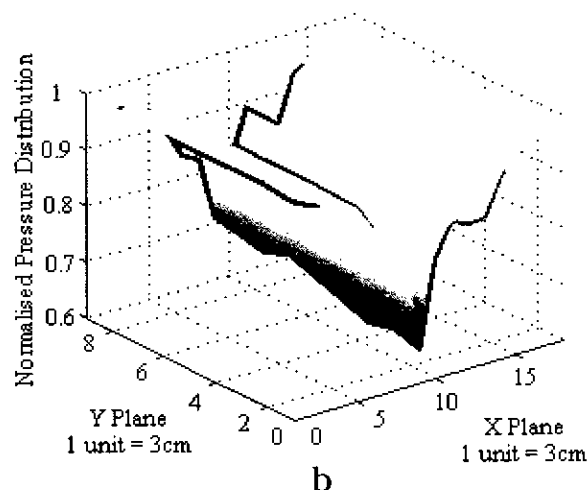
Figure 4: The measured frequency response of the rectangular cavity- vertical lines show theoretical resonant frequencies

higher measured frequencies corresponds to a specific mode calculated analytically as the modes become denser the higher they are. In this case, the modal shapes need to be measured to confirm which particular modes are excited at measured frequencies.

The sound pressure distribution was measured for 3 modes: (1,0,0), (0,1,0) and (3,1,0), to compare it with the well-known analytical solutions and to confirm their association with the measured resonant frequencies. *Figure 5* shows the measured shape of the mode (1,0,0)



a



b

Figure 5: Sound pressure distribution in the rectangular cavity for the mode (1,0,0) at $Z = 0.18\text{m}$, and $f = 306\text{Hz}$; a - calculation according to equation (2), b - experimental

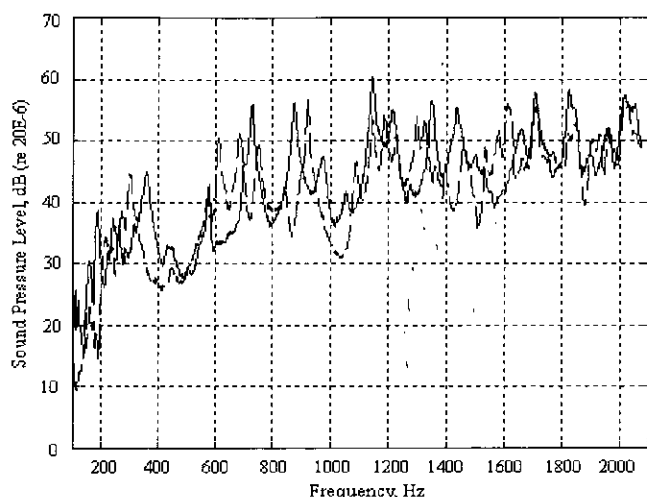


Figure 6: Comparison of the frequency responses of the rectangular and octagonal cavities, dashed and solid curves respectively compared to the previous two experiments. The results are shown on *Figure 7*. It can be seen that the peaks are similar in Sound Pressure Level at lower frequencies to the rectangular cavity, but are less frequent. At higher frequencies the peaks have reduced amplitudes and increased bandwidths, and again they are less frequent. Unfortunately for the irregular cavity it is impossible to obtain any simple classification of the modes corresponding to the measured resonant frequencies: 267Hz, 576Hz, 642Hz, 700Hz, 770Hz, 870Hz, 932Hz, 942Hz, 1042Hz and 1115Hz (first ten modes have been investigated).

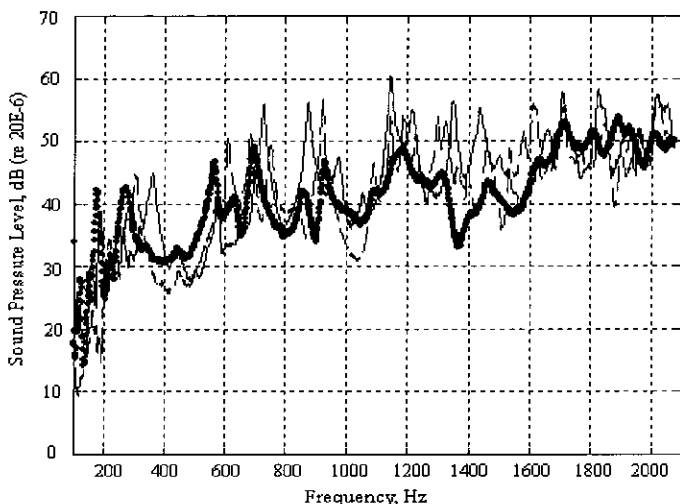


Figure 7: Comparison of the frequency response of the rectangular cavity (dashed curve), the octagonal cavity (solid curve) and the irregular cavity with added seats (dotted curve)

It can be seen from *Figure 7* that the sound pressure has been reduced significantly, with results up to approximately 25dB lower than for the rectangular cavity. This is in agreement with **Reference 9** that has also shown that by adding chairs to a model the sound pressure is reduced, with results of up to 15-20dB lower for a frequency range of 300-800Hz. Authors of **Reference 10** concluded that the seats in a vehicle account for nearly half of its absorption. This is probably because there is a greater area of absorption and reflection from the added blocks of wood and the previously added sides of the cavity. It can also be seen that the resonant frequencies have generally been shifted lower than the results measured for the empty cavity. The results presented here are again in close agreement with

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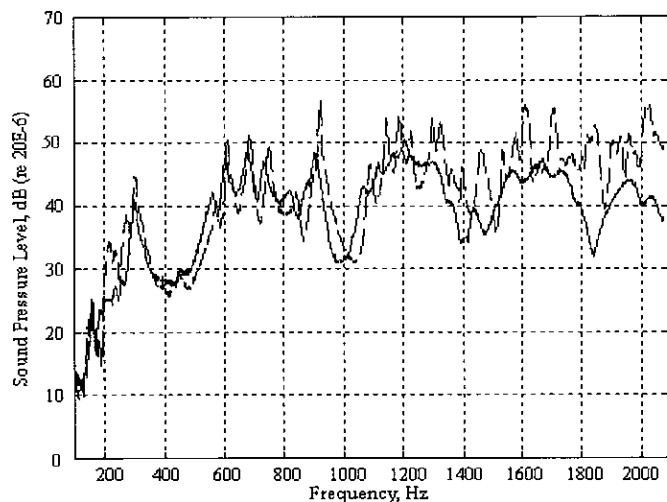


Figure 8: Frequency response of the rectangular cavity with and without felt, solid and dashed curves respectively

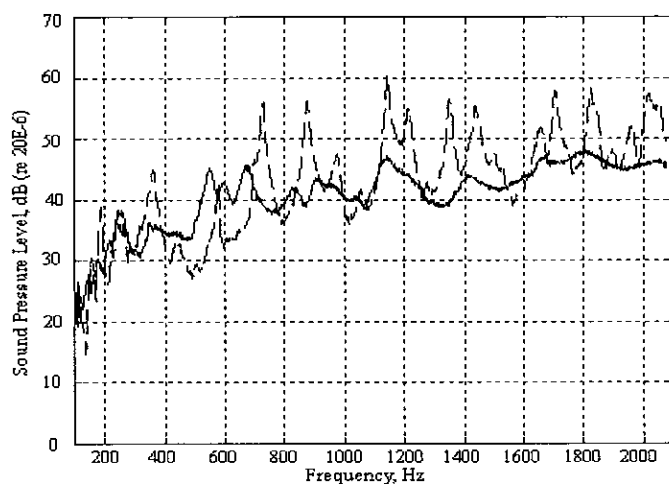


Figure 9: Frequency response of the octagonal cavity with and without felt, solid and dashed curves respectively

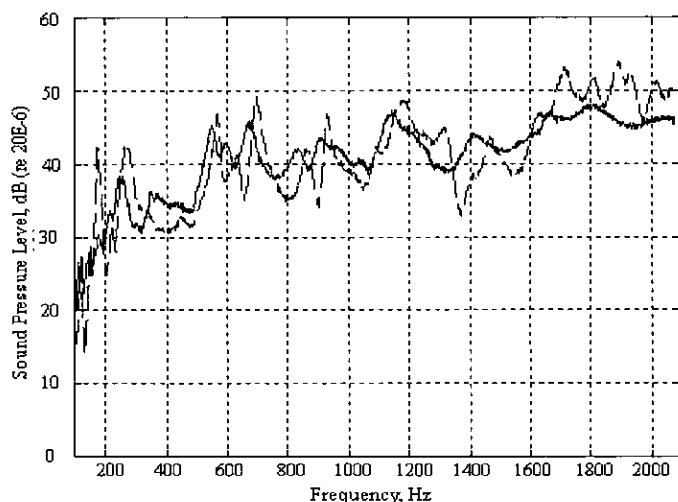


Figure 10: Frequency response of the irregular cavity with and without felt, solid and dashed curves respectively

previous works (9, 11). As was suggested in **Reference 11**, this phenomenon might be due to an increase in the effective length of the cavity due to the presence of seats. It was also noticed (9) that seat positions had an effect on these resonant frequencies, but this area was not investigated here.

Adding absorption material

Felt material was added to all three cavities under investigation to study the absorption effect of trim in a real vehicle interior. The felt was attached to the wooden interior walls of the cavities, leaving the Perspex top uncovered to give the effects of windows. The frequency response of the cavities with the added felt was measured in the same way as before, taking an average of the three speaker positions.

Figures 8, 9 and 10 show the comparisons of the three cavities with added felt, the rectangular, octagonal, and irregular cavities, respectively. When comparing the rectangular cavities, it can be seen that the felt has reduced the overall Sound Pressure Level (SPL). The higher frequencies have been affected the most with a drop in SPL of 36dB toward the 2kHz range, and only 6dB difference in the 300Hz range. As with the added chairs, the frequency responses have tended to lower and the peaks less frequent, with a flatter response towards the high frequency end.

For the octagonal cavity, the SPL had reduced considerably overall, to about 35dB. The peaks have a flatter response, especially at higher frequencies. For the irregular cavity the SPL is only slightly reduced in comparison to the un-felted cavity, up to 19dB drop. There are fewer peaks, which have a very flat response in the high frequency region. For both the octagonal and irregular cavities the resonant frequencies are once again shifted to the left of the spectrum.

Thus, the SPL for all three cavities has been reduced with the added felt. The best absorption is in the high frequency range. This is due to the fabric used having a higher absorption coefficient at the high frequency end. The thickness of the material would have to be large to reduce the SPL at lower frequencies, as investigated in **Reference 10**. It can be seen that there is relatively little difference to the SPL for the irregular cavity. As was suggested in **Reference 10**, the seats account for about a half of the absorption in the cavity already, so the felt probably has little effect when added to this.

It was found that the number of peaks have been reduced at the higher frequency end. This agrees with the results of **Reference 9**. The peaks also have a flatter response, which agrees with the results of **Reference 8**. Finally the peaks have been shifted to the left of the spectrum as with the irregular cavity with added seats. This was also shown in **Reference 12** where it was concluded that the presence of non-rigid boundaries could shift the values of acoustic resonance frequencies.

Finite Element Analysis

Finite Element Analysis (FEA) for determining the frequency response and mode shapes of acoustic cavities was first introduced in the 60's. In this study hexahedral and tetrahedral elements were used to analyse the three above mentioned quarter scale models

of the vehicle interior. *Patran* and *Nastran* software packages were used to create and analyse the FEA of the cavities, investigating frequency response and mode shapes. Hexahedral elements were used for the rectangular cavity, using *IsoMesh*. For the octagonal cavity, the surface of the octagonal face was split into three sections, creating four sized surfaces to enable analysis. *Isomesh* and *Paver* were used to mesh the surfaces of the octagon, and then these elements were

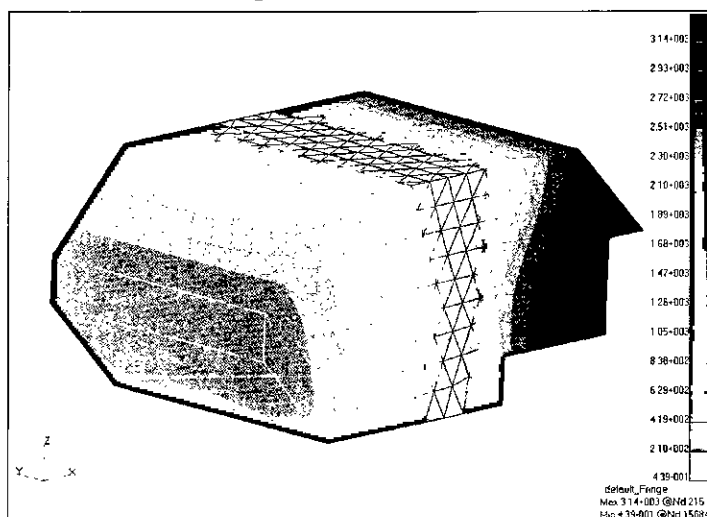


Figure 11: FEA picture of mode (1,0,0) of the irregular cavity

extruded into the three-dimensional cavity. *TetMesh* was used to mesh the irregular cavity, using tetrahedral elements.

Different mesh sizes were investigated to test the ability of the FEA programs. At high frequencies the error is increased due to the short wavelength in relation to the element size. In practice, the ideal size of elements used is about six per wavelength of the highest frequency of interest. In the measurements described above the highest frequency is 2100Hz, (a wavelength of 0.16m). Therefore, the maximum element size is approximately 27mm. The models were scaled up in the analysis to a full size vehicle interior and the same measurements were taken, to see whether the FEA would work better with lower frequencies. Unfortunately, the increase in size to the models added errors because of the larger processing power needed, so had little effect on the results.

The analysis of the rectangular cavity was very successful when compared to the analytical solutions, with only a 2% error for the first 25 resonant frequencies. There was only one discrepancy with the mode shapes, mode numbers 22 and 23, where the mode shapes have been swapped. This is probably because the difference in frequency is a fraction of a Hertz.

For the octagonal cavity, the FEA results for the first six resonant frequencies are very accurate compared to the experimental data, within 1% error. Also the mode shapes are the same. The next five modes though have large errors up to approximately 16%, with no similar mode shapes. The tetrahedral mesh was also used for this cavity, but created larger errors of up to approximately 19%.

Mode shapes for the irregular cavity are difficult to determine experimentally, so they cannot be compared with the FEA results. The resonant frequencies values for the FEA are in good agreement for the first six modes, with an error of up to 4%. The next four modes

are less accurate, with an error of up to 10% (see Figure 11 for the first mode). FEA is an especially good tool for calculating resonant frequencies for irregular cavities at low frequencies. At higher frequencies the errors are increased due to the high modal density and damping factors.

Real vehicle interior

Measurements of sound pressure level and mode shapes were taken in an interior of a Ford Fiesta. A speaker was set up in the foot well of the front passenger and a microphone was placed in four locations in the vehicle interior: the driver's right ear; the front passenger's right ear; the back left passenger's left ear; and the back right passenger's right ear. Each position was measured in the same way as in the quarter scale models, but with the frequency range quartered, therefore 25Hz-525Hz in 100Hz bands. Mode shapes were plotted of the first four peaks from the frequency response, across the horizontal plane of the car in head position.

Figure 12 shows the frequency response curves for the four positions of the microphone in the vehicle interior. It can be seen that the front passengers have the largest peaks in sound pressure, at around 200Hz. Figure 12 shows the average of the four microphone positions, showing few prominent peaks below approximately 200Hz, and then a fairly flat response up to 525Hz.

There are only a few peaks in the sound pressure level in the vehicle interior. This is due to high frequency sound being absorbed by the trim, including the seats and fabric in the vehicle. The prominent peaks are approximately at 50Hz, 100Hz, 147Hz and 210Hz. The lowest peak is probably due to electrical mains noise. The last three do not give an accurate mode shape, but do however give significant peaks and troughs across the plane of the car.

When compared with the irregular quarter scale mode (with quartered resonant frequencies), it can be seen that the SPL in the real vehicle is considerably lower (see Figure 13). Also the peaks of the vehicle interior are shifted in comparison and also have a flatter response. This is mainly due to the larger volume

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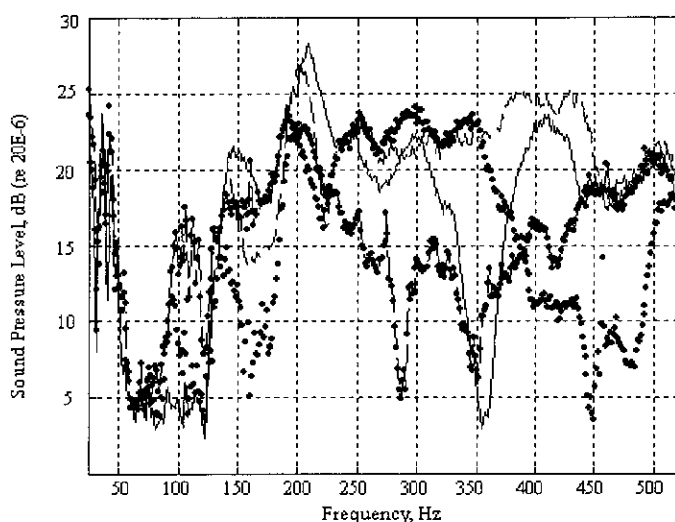


Figure 12: Frequency response of the Ford Fiesta at four different positions: rear left passenger's ear (solid curve); rear right passenger's ear (dashed curve); driver's ear (dotted curve); and front passenger's ear (dashed and dotted curve)

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of the real vehicle compartment (by $4^3 = 64$ times, which corresponds to 36 dB). Since the volume of the enclosure is present in the denominator of the acoustic Green's function, the average theoretical SPL of a real vehicle should be by around 36 dB lower. Also, the trim may cause additional correction to SPL. There are also more irregular surfaces in the real vehicle interior, allowing for more reflections and dissipation of sound energy.

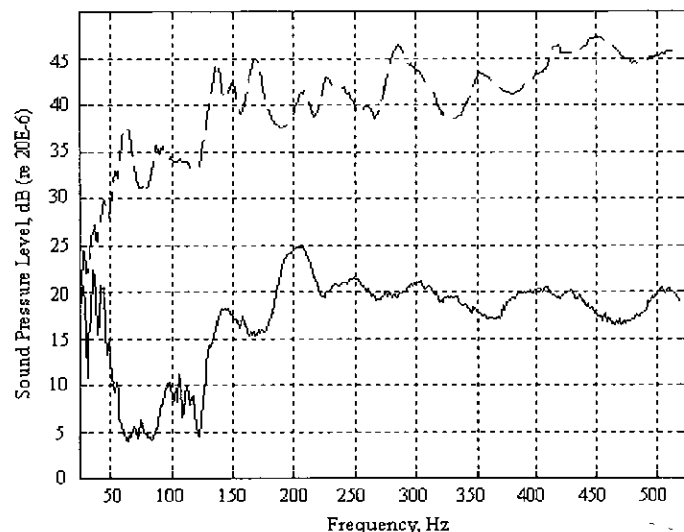


Figure 13: Frequency response of the Ford Fiesta compared with the response of the irregular cavity with added felt, solid and dashed curves respectively

Conclusions

From the investigations of the first model (the rectangular cavity) it was concluded that the experimental results agree well with the analytical calculations, with errors of less than 2.66% for the first eight modes. The spatial distributions were accurate, even for higher frequencies. The second model (the octagonal cavity) has a frequency response which is similar to that of the rectangular cavity. The modes are less frequent and are also shifted to higher frequencies. The third model (the irregular cavity) has a frequency response of up to approximately 25dB lower than in the case of the rectangular cavity. The modes are shifted to lower frequencies, possibly attributed to the increase in effective length of the cavity (11). The spatial distributions of the modes vary, and are difficult to classify.

The addition of felt to the three cavities gave a reduction in SPL for all three cavities, although not greatly reduced for the irregular cavity. This is probably due to the added seats giving the largest contribution (see Reference 10), therefore the felt having little effect. The modes also seem to have shifted toward the left of the spectrum, in agreement with the results of Reference 12.

Finite Element Analysis (FEA) of all three cavities was carried. The results for the rectangular model agree extremely well, with errors of only 2% for the first 25 modes, when compared to analytical calculations. It was found that FEA agrees well with the experiments also for irregular shapes, but only at low frequencies. The errors are only up to 1% when compared to the experimental

results of the octagonal cavity for the first six modes, and the mode shapes were the same. Further mode shapes, when compared, were inaccurate though, and the error in frequency response increased to 16% for the next five modes. The error for the irregular cavity with added seats was up to 4% for the first six modes. As with the octagonal cavity, the error increases for higher frequencies, of up to 10% for the next four modes. Measured mode shapes of the irregular cavity are not accurate, so they could not be compared with the FEA results.

The results for the real car (Ford Fiesta) demonstrate that the frequency response of the cavity has few peaks, with a very smooth frequency response in the higher regions. When compared with the irregular cavity with added felt, it shows a great reduction in amplitudes and fewer peaks across the spectrum. This is mainly due to the larger volume of the enclosure and to the higher absorption by the trim in the real vehicle. Investigation into reduced scale models of more realistic shapes and materials should be made to add further knowledge of the acoustics properties of vehicle interiors.

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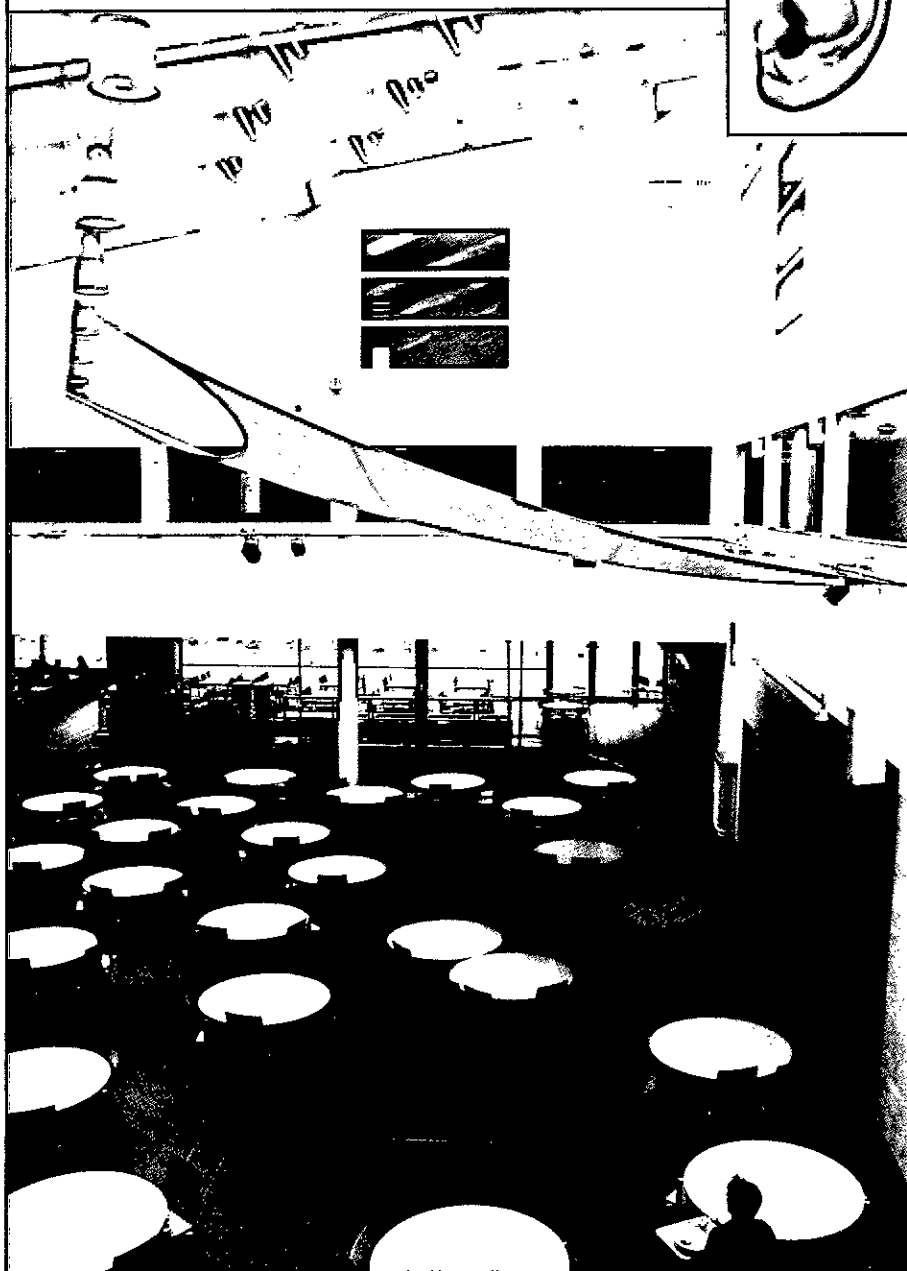
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Modelling the acoustic transmission of biological tissue at low frequencies

J A Hession and B A O McCormack

The structures of the human body emit a variety of acoustic and electrical signals - mechanical vibrations, noises and electrical current - as they perform their intended functions. Much of clinical medicine is concerned with understanding and interpreting these signals. In particular, when there is a medical problem, clinicians attempt to make a diagnosis based on an interpretation of the non-normalcy of these signals.

Palpation is one clinical method used where the patient's body is touched by hand to examine the size, consistency, texture, location, and tenderness of the underlying organ or body part (1, 2). With regard to the abdominal region, the examiner uses palpation to identify pathogens and to diagnose irregularities in the condition of abdominal organs by applying his/her hands on the abdominal wall. There is a question regarding the reliability and accuracy of palpation as a diagnostic technique and misdiagnosis has led to a significant number of unnecessary or inappropriate procedures (3).

Angtuaco *et al.* (4) reported that abdominal palpation did not itself influence gastrointestinal sounds. However the analysis for this study was carried out using band pass filtering between 100 to 1000Hz, which is above typical physiological frequencies of the abdomen (5). Other research (6) shows that a significant amount of bowel activity appeared in the lower range (ie. below 100 Hz). Bullock-Saxton *et al.* (3) reported on the unreliability of palpation. Lee (in Bullock-Saxton *et al.* (3) concluded that without knowledge of biomechanical parameters, such as size, weight and dimensions of body segments, or the use of imaging, it was not possible to rely on clinical palpitation data.

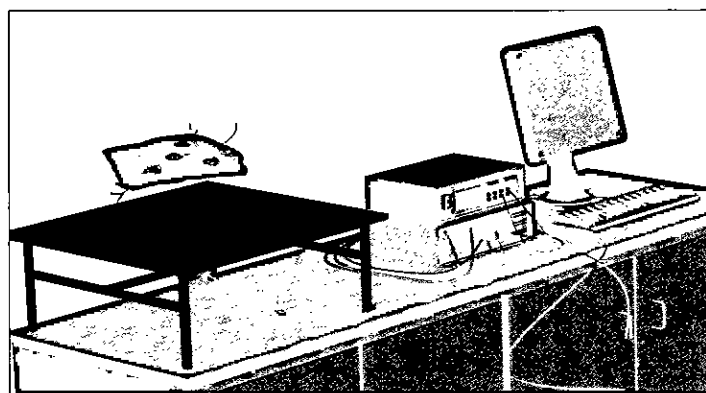
In practice, the accurate performance of manual palpation on the abdomen is limited to more superficial or larger organs, and may not successfully detect abnormalities if the condition resides deep in the abdomen or where small organs are obscured by overlying tissues (7, 8). Mechanical and acoustic properties, such as stiffness, absorption, attenuation and reflection, between the outer surface of the body and the underlying organ of interest will have an influence on the 'feel' observed by the clinician. What is missing in the literature is quantitative data on the transmission of a mechanical signal through tissue, and the influence that the tissue might have on the transmitted signal.

Bowel sounds have long been used as a means of identifying abdominal conditions (9, 10, 11). Abdominal

sounds are evaluated by listening to the abdomen with a stethoscope (auscultation) and they accrue from movement of the intestines as they push food through (12). The intestines are hollow, causing the bowel sounds to propagate throughout the abdomen. Sarr *et al.* (13) concluded that more than 30% of diagnoses of intestinal strangulation obstruction using auscultation, are incorrect and, in many instances, lead to unnecessary surgery and increased hospital costs.

A measure of the energy level of bowel sounds can provide a sensitive index of gastrointestinal activity, making it possible to quantify the effects of abdominal disorders. It was found by Politzer *et al.* (14) that the contents of the intestine influence the frequency content of the sounds as well as the energy of the sounds. In addition, it was found that different regions of the abdominal tract are likely to produce sounds with different characteristic frequencies and amplitudes (15). A study by Yoshino *et al.* (16) concentrated specifically on the frequency of sounds detected at a single location on the abdominal wall. It was reported that not only did the sounds recorded in all of the healthy subjects have similar constituent frequencies, but also that the peak frequency and constituent frequency range of the sounds were significantly different in the presence of many abdominal disorders. By categorising the bowel sounds according to their frequency content, it was reported that the objective diagnosis of several types of abdominal disorders was possible.

Tissue consistency and activity level also influence the values of the acoustic properties. One of the pioneering studies in this area was measurements of vibrations from a surface-mounted accelerometer attached to



Experiment 1

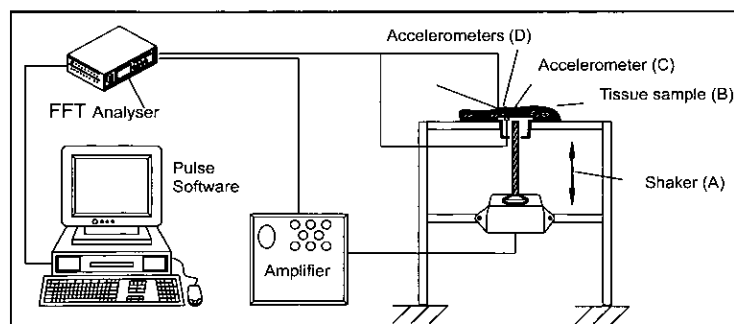


Figure 1: (Left) Vibration transmitted through tissue. The oscillating probe of the shaker (A) transmits a vibration of known characteristics to the internal (underneath) surface of swine abdominal tissue (B). An accelerometer (C) monitors the source vibration. Four additional accelerometers (D) monitor the vibration on the outer (top) surface of the tissue. These are attached to a face plate which is then attached to the tissue using double-sided tape. Data is recorded using a FFT analyser. The rig was located on a concrete floor in an acoustically isolated room in the basement of the research building

the skin overlying the quadriceps muscles of the leg (17). The acceleration signals indicated that the soft tissue oscillated with under-damped vibrations, and it was believed that the frequency and absorption of the vibrations are a function of the level of muscle activity. Research shows that running activity increased the median frequency of muscle from 60 Hz to about 90 Hz if the hardness of a running surface is changed from concrete to a softer surface (18, 19). Muscle activity in the lower extremity is used to damp soft-tissue resonance which occurs at heel-strike during walking. There are other studies in the literature on signals in the ultrasound frequency range being transmitted through tissue (20, 21). However, none of these studies reports on how the tissue type and thickness influence the quality of the transmitted signal at lower frequencies (ie. in the 0 - 100 Hz range of sounds typically generated from within the abdomen). Clearly, to understand the behaviour of biological tissue to vibration and sound, further tests need to be carried out on the properties of biological tissues themselves.

This study is concerned with investigating the acoustic transmission characteristics of abdominal wall tissue. The hypothesis is that, within typical physiological frequency ranges of vibrations and sounds, the level of transmission is significantly influenced by the physical dimensions of the tissue and its constituents. A sub-hypothesis is that, the difference between the characteristics of an acoustic signal detected on the body surface, from the actual transmitted source within the body is a function of the relative locations of the source and the detector/pick-up device.

Method

The first experiment was concerned with establishing the change in a signal that occurs as a vibration is transmitted through abdominal tissue of differing composition. An oscillating probe is placed against the inner surface of a sample of abdominal wall, and the resulting vibration on the outer surface of the abdomen is monitored.

An electro-mechanical shaker (Gearing-Watson Vibrator Model V.4) was located underneath a tissue sample, with the oscillating probe in contact with the tissue. The shaker was driven by power amplifier (model Gearing-Watson PA30), which received its signal from a pulse analyzer (Brüel & Kjaer), which generates a sine wave over a wide band of frequencies. An array of four accelerometers (Brüel and Kjaer Type 4507 B 005) was placed on the upper surface of the tissue. The accelerometers were miniature high sensitive piezoelectric element (type PZ 27, 4.3 gram) with an in-built preamplifier.

A mounting plate (UA1564, 5.7 gram) was attached to the accelerometers, to increase the surface area of contact with the tissue, which was in turn attached to the tissue using double-sided tape.

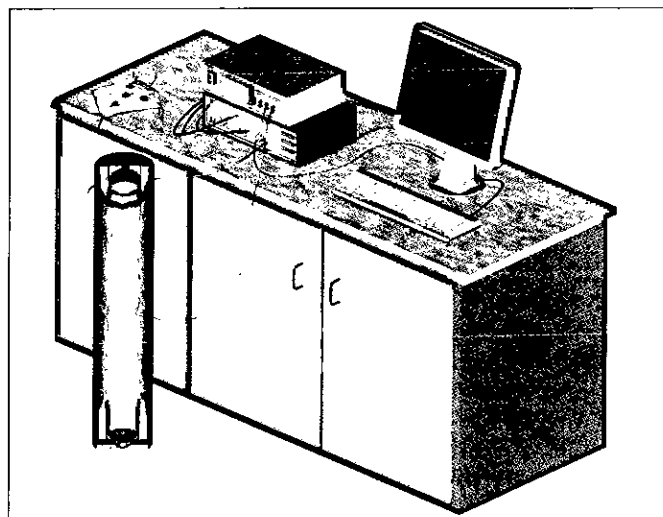
Signals from the accelerometers were received in the time spectrum and transformed into the frequency domain using a fast Fourier transform analyzer (PULSE 3060C 6 channel analyser). The signal intensity was displayed in dB as a ratio of the applied force on the sample relative to gravity.

The analyzer has a 24-bit A/D converter and covers the frequency range, 0 - 25.6 kHz. The data was analysed using Brüel & Kjaer Pulse software (V 7).

The tissue was subjected to continuous oscillating motion against the inner wall of the tissue (see Figure 1). Fresh underbellies of swine carcasses (unfrozen and

unsalted) were used, as they are similar in composition to human abdominal tissue and are readily available. Samples were harvested from the lower side of the abdomen of the pig between the ribcage and hind quarter (ie. the front wall covering the intestines). The specimens contained the major components of the abdominal wall, including fascia, major muscle groups (external oblique, internal oblique, transversus abdominis) and extra-peritoneal fat.

The outer layer of skin was removed as it was found to be significantly tougher than human skin. Samples were kept moist and all experiments were carried out at room temperature. The sample was supported by a thin rubber membrane located over the oscillating probe, with the internal surface of the tissue face down. An accelerometer was attached to the membrane near to the probe, in order to record the source signal applied to the tissue (this was necessary because the shaker was open loop control). Measurements were taken at four different locations on the upper (skin) surface of the tissue. Tissue vibration transmissibility was calculated by dividing the acceleration at each point on the surface of the sample by the acceleration at the membrane. All experimental measures were repeated several times to ensure consistency of the data.



Experiment 2

In the second experiment, a 100 mm diameter, vertically mounted standing wave tube was fitted with a Sony loudspeaker which was rated 25 W, with a peak of 110 W and a sensitivity of 88 dB/W/m, up to 22,000 Hz. The speaker was mounted at the bottom end of a standing wave tube. A slab of swine tissue, from the underbelly (see experiment 1) was placed at the opposite end to the loud speaker, directly on top of the tube. The sample was prepared so that it had uniform thickness across the full outlet of the tube. The outlet diameter of the tube was reduced to 22 mm, in order to restrict the flow of the sound to a specific location on the tissue. The loudspeaker was driven by a Brüel & Kjaer ZE 0769 amplifier. A sine wave was produced by a computerised signal generator (Brüel and Kjaer portable PULSE 3060C) and transmitted through the amplifier to the speaker.

Four accelerometers were mounted on the outer surface (skin side) of the sample at equal radial distances from the centre of the tube (as shown in Figure 2 overleaf). The distance was then varied. Data was recorded using a six channel FFT analyzer (see experiment 1). A comparison was made between the signal received at the

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different absorption at different frequencies. Certainly, this warrants further investigation.

It should be noted that there are limitations as to what clinically relevant conclusions may be drawn from this work. In order to demonstrate more completely the relationship between frequency, level of signal transmission, and tissue composition and thickness, more data is required on the behaviour of the separate biological constituents of tissues and for a greater range of tissue thicknesses. Also, a more physiologically representative model and source signal could be used in order to investigate the change in acoustic characteristics for real-time changes in frequency and amplitudes of signal under more anatomical accurate conditions (eg. sounds generated from within the intestine, within the abdominal cavity).

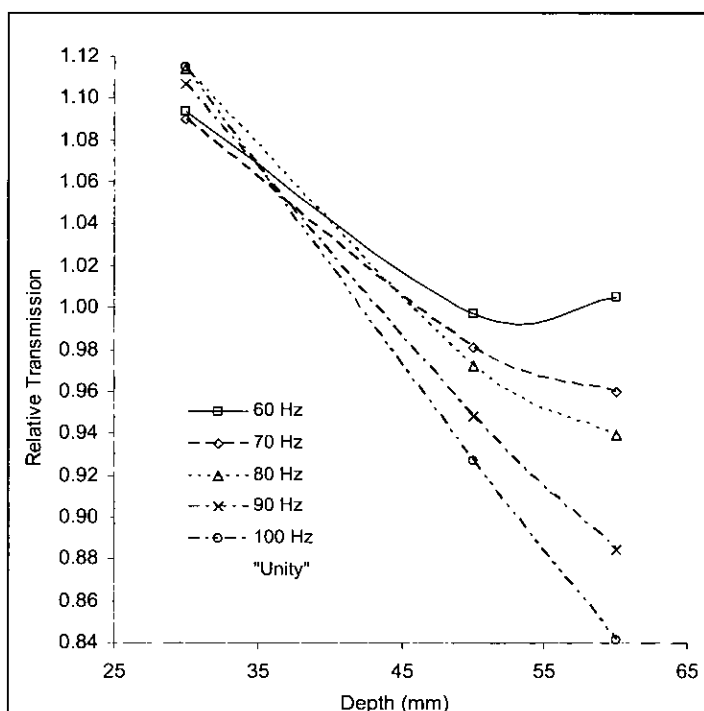


Figure 6: Comparison of vibration attenuation/absorption between tissue samples of different thickness. The data has been normalized with respect to the source signal

Conclusion

Two experiments were proposed to investigate the transmission of vibrations and sounds through biological tissue. In particular, the relationship between frequency of the transmitted signal and the tissue composition and thickness were investigated experimentally. It was found that tissue tends to attenuate signals at frequencies up to 50 Hz, while it may dissipate signals at higher frequencies. Such absorption increases with the thickness of the tissue. In general, thicker tissues will dissipate/absorb a signal, however, signal attenuation did occur for tissue in the range of 10 to 40 mm thick. Finally, quantitative data was reported indicating the rate of loss of sound passing through tissue, which is detected at increasing distance from the source of the sound.

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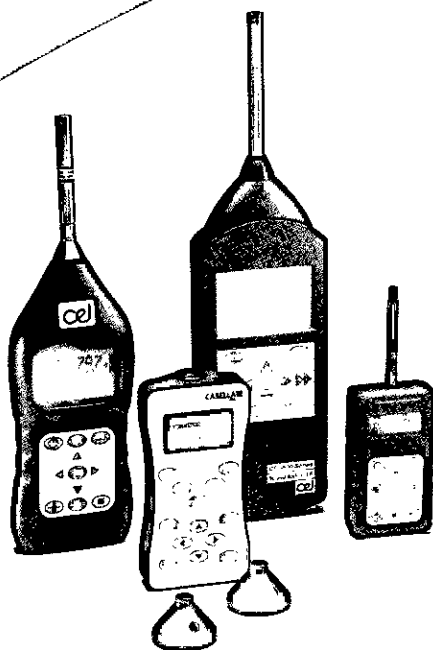
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Acoustic limiting in telephony headset systems

A M W Bayley

This article reviews European acoustic limiting legislation, and discusses how telephony headset systems meet the prescribed limits. The primary means of protection is acoustic limiting devices that are integrated into the headset, which regulate the maximum sound pressure level that the headset can produce. There are several different design approaches, described in detail below. However in practice they all provide the same protection for the end user, and no one limiting circuit has significant advantages over the others. Other signal processing techniques can enhance the headset user's comfort, for instance by preventing sudden large increases in volume that may startle the user, or by automatically adjusting the volume to compensate for loud or quiet callers. Some of these techniques are discussed. Finally, the time-weighted average workplace noise exposure of headset wearers is considered.

European legislation for acoustic limiting

Continuous and peak limits

In Europe the legislation governing continuous and peak noise exposure is the general product safety directive (1) (GPSD), or the low voltage directive (2) (LVD). These directives state that products shall not endanger safety when properly installed and maintained, and used in applications for which they were made, but they do not give any specific acoustic limits. Various product-specific standards, and the national legislation and guidelines that pre-date the introduction of the European directives, specify acoustic limits for telephones and headsets. These documents provide the basis for declarations of compliance with the product safety and low voltage directives.

One such standard is TBR8 (3). Annex C specifies continuous and peak noise exposure limits for telephone terminals and states that in the absence of any relevant safety standard, a supplier's self-declaration may be based on them. These limits, summarised below, are equally applicable to telephony headsets.

- ☐ For continuous signals, the sound pressure level in the artificial ear shall not exceed 24 dBPa (rms unweighted).
- ☐ Peak signal level in the artificial ear shall not exceed 36 dBPa.

These limits are for sound pressure levels measured in an ITU-T Recommendation P.57 (4), type 1 artificial ear, which measures sound levels referred to the Ear Reference Point (ERP). Measurements using an ITU-T recommendation P.58 (5) head and torso simulator (HATS) more closely simulate real-life usage for most lightweight headsets. HATS is a life-size manikin fitted with artificial ears that provides an acoustic model of a 'typical' adult human. It uses P.57 type 3.3 artificial ears, which measure sound level referred to the Eardrum Reference Point (DRP). A standard DRP to ERP correction factor is applied to measurements made on HATS when comparing them to the TBR8 limits.

Other UK documents that provide useful guidance on headset acoustic limiting requirements and test procedures are DTI 85-013 (6) and BS6317 (7). Both these documents, like TBR8, specify a continuous sound pressure level limit of 24 dBPa (118dB SPL). To put this into context, speech at a distance of 1m has a sound level of about 60dB SPL, a chainsaw at a distance of 1m has a sound level of about 100dB SPL and a jet aircraft at 150m is about 120dB SPL (10). Limiting at 118dB SPL prevents immediate permanent hearing damage, but 118dB is significantly louder than normal headset listening volume.

Prolonged exposure to this sound level is uncomfortable and the headset wearer would quickly remove the headset!

Time-weighted average exposure limits

The current European legislation on workplace noise exposure is the Noise at Work Directive (8). However new legislation, the Physical Agents (Noise) Directive (9), will be incorporated into law in EU member states on or before 15 February 2006.

These directives specify certain action levels, each with a limit on both continuous and peak sound level. If a telephony headset complies with the GPSD or LVD, it will automatically satisfy the peak limits specified in the Noise at Work and Physical Agents (Noise) Directives. In the context of workplace noise exposure legislation, continuous noise exposure is a time-weighted average (TWA) measurement, normalized to a standard 8-hour working day. The TWA calculation method is defined in the Noise at Work Directive, and takes account of both sound level and duration of exposure. The two action levels defined in the Noise at Work Directive are shown in Table 1.

	Continuous sound exposure maximum limit	Peak sound pressure level maximum limit
Lower action level	85 dB(A)	200 Pa
Higher action level	90 dB(A)	200 Pa

Table 1: Maximum sound levels defined in the Noise at Work Directive

The physical agents (noise) directive defines two action levels, which are 5dB lower than the action levels in the noise at work directive. It also defines limit values that may not be exceeded under any circumstances. These are shown in Table 2.

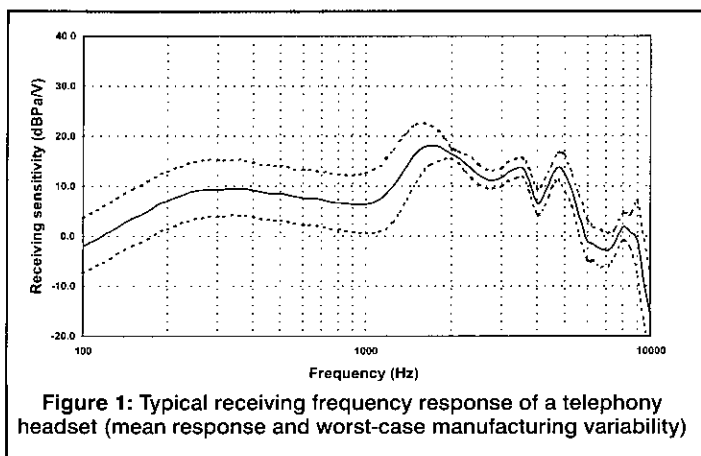
	Continuous sound exposure maximum limit	Peak sound pressure level maximum limit
Lower action level	80 dB(A)	112 Pa (135 dB(C))
Higher action level	85 dB(A)	140 Pa (137 dB(C))
Limit values	87 dB(A)	200 Pa (140 dB(C))

Table 2: Maximum sound levels defined in the Physical Agents (Noise) Directive

The measures that must be taken when the lower action limit is exceeded include making ear defenders available to workers. This is impractical for headset users, so effectively headset noise exposure must not exceed the lower action level.

Headset receiving characteristics

To understand the effects of acoustic limiting devices it is necessary to know something about headset characteristics - in particular the receiving frequency response, which describes the relationship between electrical drive voltage and the sound pressure level generated by the headset. Figure 1 is the receiving frequency response of a typical headset. The solid line is the average frequency response for this headset model. The dotted lines are the bounds of manufacturing tolerance (± 3 standard deviations), within which 99.9% of headsets of this particular model lie. The telephony bandwidth is 300 Hz to 3.4 kHz, so this is the frequency range of greatest interest. Both the average frequency response and the manufacturing tolerance vary for different headset models.



Telephone and headset acoustic limiting strategies

High intensity voltage transients can occur on telephone or data networks and cause audible noise spikes. This phenomenon mainly affects corded telephones (analogue, digital or Voice-over-IP) and is less of a problem with cordless or mobile phones that are not directly connected to a network cable. Fax and DTMF tones, acoustic feedback or network faults generate loud sounds of longer duration and malicious callers may also make loud noises deliberately. All these noise sources affect both corded and cordless telephones equally. Therefore acoustic limiting is necessary in all telephones and telephony headsets to protect users against excessive sound levels.

Although acoustic limiting devices could be fitted either in the telephone, the headset, or a headset adapter unit, they are usually incorporated into the headset itself. This ensures consistent limiting performance when the headset is used with a range of different telephones and accessories. Indeed, for this very reason, DTI 85/013 (6) required headsets to contain intrinsic acoustic shock protection, and not depend solely on protection circuitry within the associated telephone or PBX. Most reputable manufacturers of headsets for office and call-centre applications use in-headset acoustic limiting devices as the primary protection against excessive sound levels.

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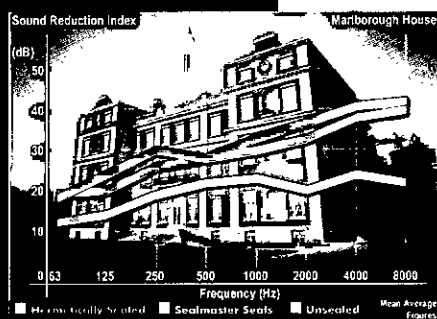
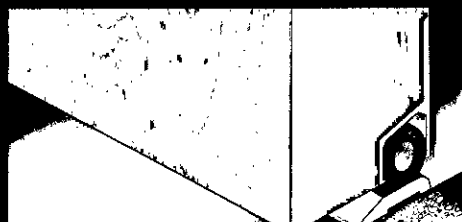
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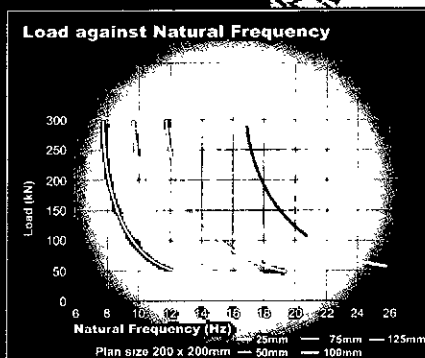
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Acoustic limiting in telephony headset systems

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Mobile and cordless telephone handsets, or wireless headsets, are not subject to the high amplitude line-transients that affect corded telephones. Their battery voltage determines the maximum headset drive-level. Therefore they can adopt a simpler acoustic limiting strategy, relying on the limited voltage drive capability of the circuit. For example, consider a telephone receiver with the same frequency response as the headset shown in *Figure 1*. The maximum sensitivity (upper 99.9% confidence interval) is 23 dBPa/V. Therefore the receiver cannot generate sound levels in excess of 24 dBPa if the drive voltage is limited to 1 dBV rms or less.

This limiting strategy is acceptable for a telephone's built-in receiver, since the manufacturer can select a transducer with appropriate sensitivity to match the power amplifier circuitry. However, it may not be appropriate for a headset that can be used with many different telephone models. If the telephones' drive levels vary significantly acoustic limiting will be inconsistent, and in some cases the statutory requirements for acoustic shock protection may not be met. Notwithstanding this, some headsets intended for use with mobile phones do not have acoustic limiting devices fitted.

In-headset acoustic limiting

Several types of acoustic limiting device can be built into headsets, although they all use the same basic principle. They limit the electrical signal that drives the headset transducer, which in turn limits the sound level generated as defined by the headset's receiving frequency response. In general there is no power source available in a headset other than the transducer drive signal, so in-headset acoustic limiters are either passive devices or very low power active circuits.

The headset's receiver characteristics determine the required limiting voltage. To ensure that the sound level is limited below 24 dBPa for all headsets under all operating conditions we use the worst case: sound pressure level produced by the most sensitive headset, at its most sensitive frequency. For the headset whose receiving frequency response is illustrated in *Figure 1*, the maximum sensitivity (99.9% confidence interval) is 23 dBPa/V. Therefore the voltage applied to the receiver must be limited to 1 dBV rms or less to limit the sound level to a maximum of 24 dBPa.

Referring again to *Figure 1*, note that the average receiving sensitivity varies by more than 10dB over the frequency range 300 Hz to 3.4 kHz, and that the manufacturing tolerance of receiving sensitivity is up to ± 6 dB at many frequencies. Therefore fixed-voltage limiting results in acoustic limits that vary by more than 10 dB, depending on the signal frequency. Also the acoustic limiting levels vary ± 6 dB between different headsets of the same model, due to manufacturing tolerances. The result is that some headsets, at some signal frequencies, limit somewhat below the statutory 24dBPa threshold.

Figure 2 is the transfer function of the ideal limiting device. Output voltage rises linearly with increasing input voltage until the output reaches 1 dBV. The output voltage then remains clamped at this level as the input continues to increase.

Telephones and headset adapters typically drive the

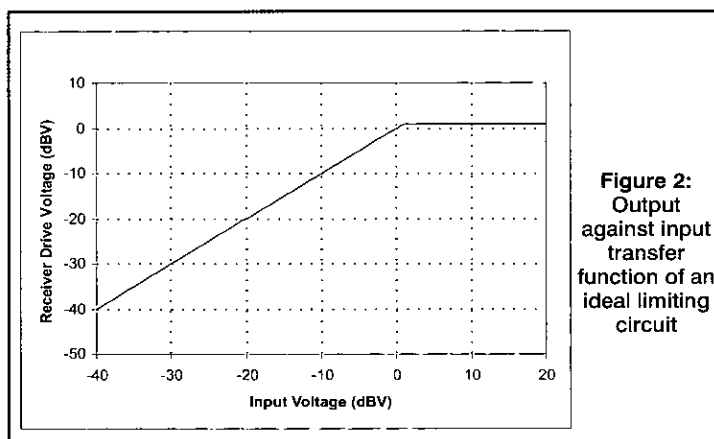


Figure 2: Output against input transfer function of an ideal limiting circuit

headset from a source-impedance in the range 50 to 600 Ω , although a few have higher or lower impedances. The acoustic limiting device is connected in parallel with the headset receiver. It has a non-linear current vs. voltage characteristic, such that its impedance changes from high to low when the limiting threshold voltage is exceeded. The limiting device works in conjunction with the telephone's source impedance to limit the drive voltage applied across the receiver's terminals.

Figure 3 shows the circuit configuration for three different types of limiting device commonly used on headsets: diodes (a), an active limiting circuit (b) and varistor (c). SPICE simulations of these circuits' transfer functions (V_{out} vs. V_{in}) are also shown, for source impedances of 50, 100 and 150 Ω . Practical implementations use extra components to 'fine-tune' the limiting levels and the shape of the transfer functions to suit particular receiver transducers, and some variants exist - for instance the active limiting circuit may use MOSFETs instead of bipolar transistors. However the simplified circuits of *Figure 3* illustrate the main features of each type of limiter. The key point is that all the circuits prevent the maximum sound pressure level exceeding 24dBPa, and they also all have a linear input/output characteristic at normal telephone listening levels below -20dBV (which equates to about -10dBPa or 84dB SPL for

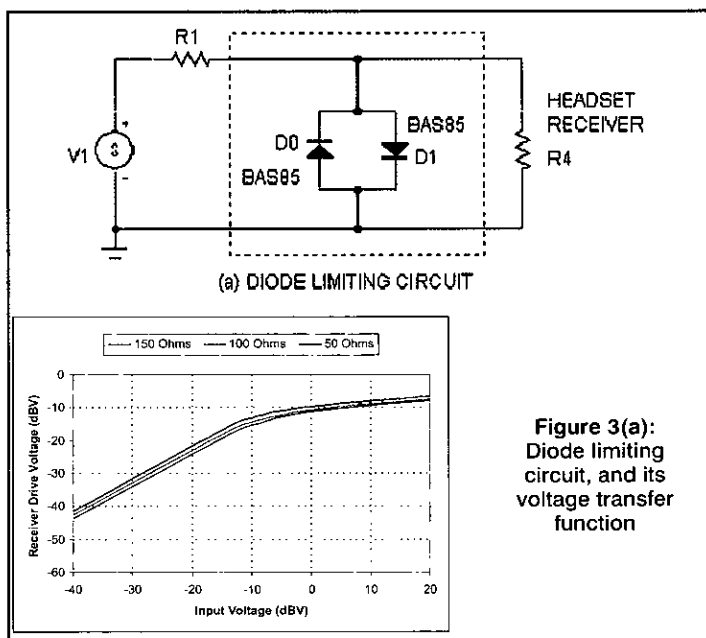
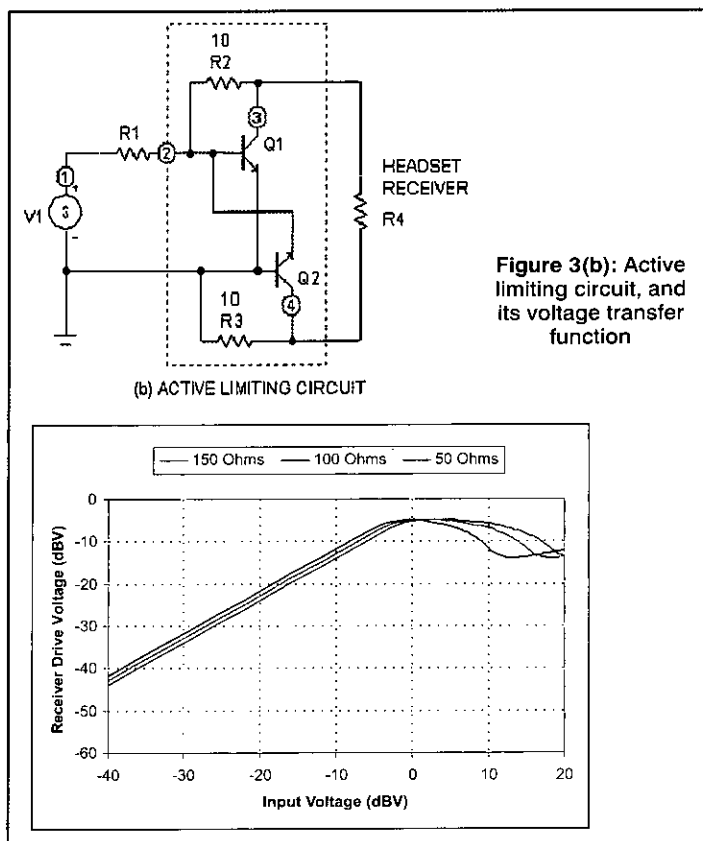


Figure 3(a): Diode limiting circuit, and its voltage transfer function

the headset we have been using as an example) so will not cause distortion of speech in normal use.

The diode limiter of *Figure 3(a)* approximates to the ideal limiter characteristics shown in *Figure 2*, and can be implemented at low cost. Furthermore, the circuit's simplicity makes it rugged and reliable. Limiting depends slightly on the source impedance. Schottky, silicon, and zener diodes are available with different forward 'knee' voltages, so can be used as limiting devices for receivers with different sensitivities. The transition from non-limiting (below 1dBV) to limiting regions (above 1dBV) is relatively gradual, when compared to the 'ideal' limiter of *Figure 2*, which causes distortion slightly below the 24dBPa limiting threshold. The output continues to rise slowly with further increases in input voltage, but limiting is maintained below 24dBPa for all signal levels that can occur on a telephone network. The distortion and creeping increase in sound level above the limiting threshold are not apparent to the user. The distortion only occurs for signals so much louder than normal telephone speech that the user would have removed the headset.

The active clamping circuit of *Figure 3(b)* may either be implemented as a discrete transistor circuit or as an



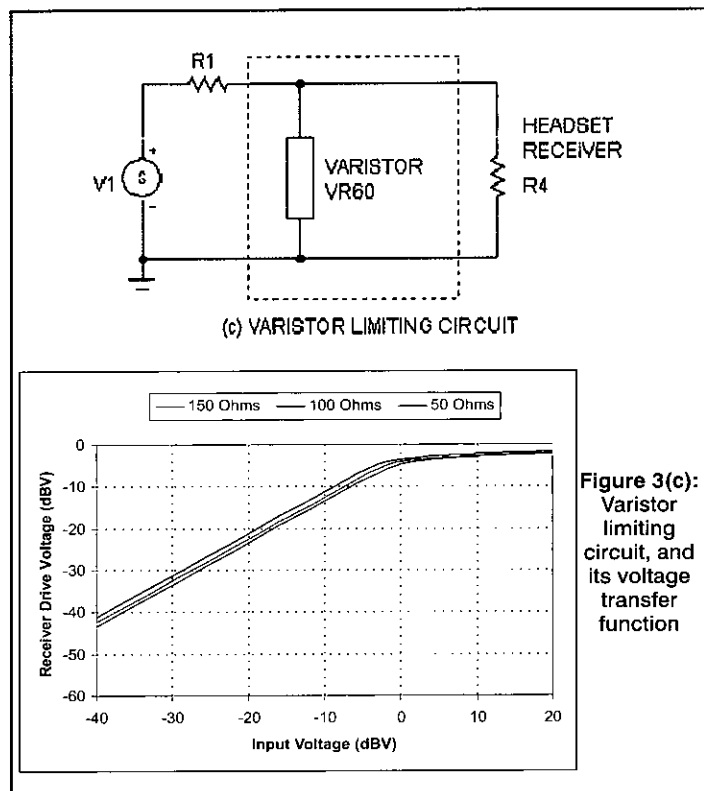
integrated circuit, and some manufacturers use variants based on MOSFETs rather than bipolar transistors. This circuit has a sharper transition from non-limiting to limiting than the diode circuit. When the input voltage exceeds the threshold the output voltage 'folds-back' to a lower voltage, preventing an increase in sound level with further increases in input voltage.

The highest output voltage is at the point where the transition from non-limiting to limiting occurs. At that point there is very little variation of output voltage with source impedance, although it varies significantly at higher and lower input voltages. The sharper transition to limiting and fold-back characteristic may appear beneficial, and some manufacturers highlight these features in their sales

literature, but they are no more important than choosing the colour of air-bag on your car - interesting to know, but totally irrelevant! These effects occur at sound levels so much louder than normal telephone speech, that they provide no tangible benefit for headset users.

The varistor limiter shown in *Figure 3(c)* is similar to the diode circuit, but has a faster transition from non-limiting to limiting region and exhibits harder clamping in the limiting region. Varistors are available with a range of clamping voltages to suit different receiver sensitivities.

Receiving sensitivity varies slightly with amplitude as well as with frequency, and the onset of limiting generates



a series of harmonics at multiples of the input frequency. It is therefore essential to verify the performance of limiting devices by directly measuring sound pressure level with a wide range of input conditions, and not just rely on performance predictions from frequency response measurements like *Figure 1*. Frequency should be varied in 1/3-octave or closer steps. Input voltage should also be varied because, as *Figure 3(b)* illustrates, the maximum output voltage does not always occur at the maximum input voltage.

BS6317 (7) specifies a test voltage of 24 dBV rms from a source impedance of 600 Ω , applied at the telephone line interface, for acoustic shock tests on analogue telephone terminals. It is appropriate to test headsets with a lower maximum voltage (15dBV) and lower source impedance (150 Ω) to more closely represent the electrical signal at a typical telephone headset or handset port.

Professional-grade headsets are robustly constructed to withstand the rigors of regular use in a call-centre. However, periodic maintenance is recommended to optimise performance. Call-centre managers may also wish to audit the performance of their headsets' acoustic limiting devices at regular intervals. To enable this, Plantronics manufactures the '✓-box' (tick-box) headset confidence checker, which quickly and simply tests whether the acoustic limiting devices are fitted and functioning correctly.

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Acoustic limiting in telephony headset systems

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Advanced acoustic limiting techniques

In-headset acoustic limiting devices simply clip the headset drive signal when it exceeds a certain voltage. They limit almost instantaneously, but at an uncomfortably high sound level. They should be regarded in the same way as an electrical fuse - a reassuring last line of defence, but ideally one that will never be used! It is better to prevent the sound level ever reaching the 24 dBPa limiting threshold. Simply restricting the maximum volume setting is not the answer because telephone speech signal levels vary, and sufficient volume control range is needed to make quiet signals loud enough to hear above normal call-centre and office background noise.

More sophisticated signal processing techniques are used, as described in the following paragraphs. Such processing cannot be integrated into a headset that has no power source available. It is usually implemented in headset adapters that connect between a telephone and

adjusts the volume control once to set their preferred listening volume, but does not have to adjust the volume control to cope with quiet or loud callers since the compression mechanism adjusts all calls to the same level. Any abnormally loud signals are also limited to the same comfortable level.

The disadvantage of compression is that it acts slower than in-headset limiting devices. This allows short bursts (tens to hundreds of milliseconds) of high level sound through before the AGC reacts and reduces the volume. It is therefore best used as an adjunct to in-headset limiting devices rather than as an alternative. More sophisticated compression schemes, using knowledge of speech signal statistics, can provide faster compression attack time in the presence of sudden loud noises.

Digital signal processing

Digital signal processing (DSP) makes possible a range of advanced limiting and intelligibility enhancement techniques. With DSP it is feasible to compensate for the headset's frequency response and provide more precise acoustic limiting at all frequencies. Frequency-dependant limiting may also be implemented, for instance to preferentially limit high frequency non-speech signals such as acoustic feedback howl, or whistles and air-horns used by malicious callers.

Workplace noise exposure limiting

Adequate control of workplace noise exposure in call-centres and offices demands a holistic approach, considering not just the headsets and telephone infrastructure, but also such issues as acoustic design of the buildings, layout of agents' workstations, shift-patterns worked and equipment maintenance.

Employers are responsible for carrying out a risk assessment and when necessary measuring noise exposure levels in the workplace. Compliance with acoustic shock legislation (1, 2) is largely guaranteed by selecting headsets incorporating acoustic limiting devices and using them with a compatible telephone system. However compliance with noise exposure legislation (8, 9) depends upon multiple factors such as volume setting, length of working day, frequency and duration of telephone calls. Equipment using advanced DSP techniques is now emerging, which can help manage compliance, but care should be taken to ensure that such devices are compatible with the existing telephone system and headsets.

Noise exposure of headset wearers can be measured in their normal working environment. The equipment required for such noise assessments is costly, and accurate results demand both knowledge of acoustic measurement techniques and a good understanding of headset systems. Several commercial and academic organisations, including Plantronics, provide headset noise assessment services.

Some headset adapters, such as Plantronics' DA60 USB adapter for IP softphones (Figure 4(b)), continuously monitor the sound level in the headset and provide TWA noise exposure calculations and graphs of sound pressure level versus time. Other adapters limit daily personal noise exposure below the 85dB(A) lower action level, under certain operating conditions (restrictions on headset model, hours usage per day, etc). However

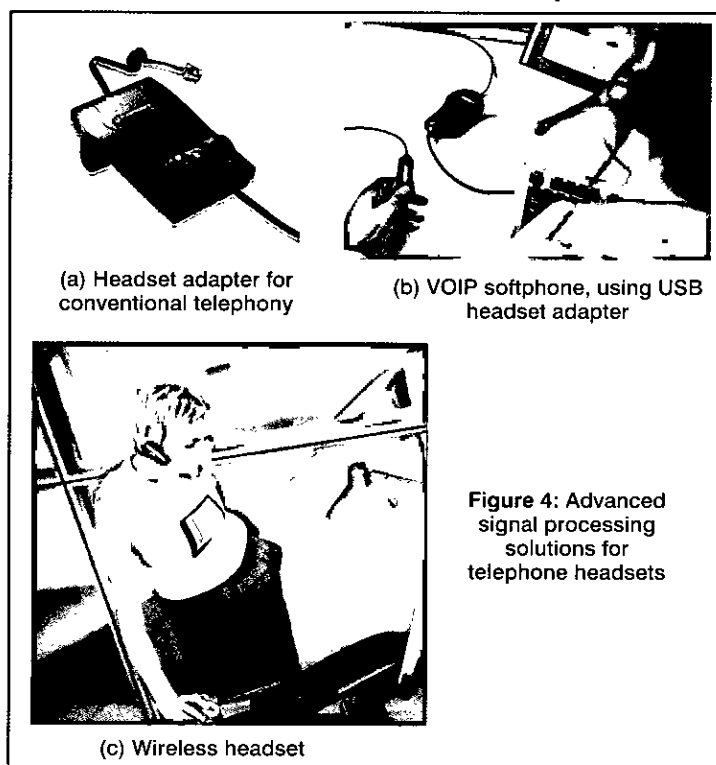


Figure 4: Advanced signal processing solutions for telephone headsets

headset (Figure 4(a)), between a PC and headset (Figure 4(b)) for calls made on a VOIP softphone, or in devices such as Bluetooth or DECT wireless headsets (Figure 4(c)).

Compression

Compression, or automatic gain control (AGC), seeks to maintain a nearly constant output sound level for widely varying input level. It works by measuring the headset signal level over a relatively long time period (tens to hundreds of milliseconds) and adjusting the volume of the headset amplifier to maintain a constant output. Too short a compression time-constant interferes with speech dynamics and reduces intelligibility, and too long a time constant reduces the effectiveness of the compression.

Compression maintains sound pressure level at a comfortable listening volume well below the mandatory 24dBPa limiting threshold. An optimally designed compression algorithm provides fast, accurate limiting with no noticeable distortion of speech. The headset user

care should be taken to ensure that TWA noise exposure limiting does not result in inadequate listening volume. Simply capping the maximum volume setting can achieve compliance with noise exposure legislation but may not provide adequate listening volume so that callers can be heard clearly in noisy environments such as call-centres.

Conclusions

Acoustic limiting devices that are integrated into the headset itself provide the primary protection against excessive sound levels. They ensure compliance with continuous and peak sound level limits required by European legislation. All telephony headsets designed by reputable manufacturers for call-centre and office applications contain such limiting devices, although some mobile-phone headsets do not have acoustic protection devices fitted. Several different limiting circuits are used, but their performance is indistinguishable for the user.

Other signal processing can enhance the headset user's comfort. Compression amplifiers have been available for some time, but the advent of DSP considerably extends the possibilities for headset signal processing.

Careful selection of headsets and associated headset adapters can help to ensure compliance with workplace noise exposure legislation, but may be only part of the solution. Time-weighted average noise exposure of headset wearers is affected by factors other than the telephone and headset equipment used, such as the length of shifts worked, background noise level and the number and duration of calls. Therefore additional procedures for sound level monitoring and control may be required.

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Support mathematics for acoustics research training

K Attenborough and M C M Wright

Mathematical methods are important for research in many aspects of acoustics. Currently, fundamental mathematical methodologies taught at undergraduate level are often advanced through independent learning by individual researchers. Students develop their mathematical skills as appropriate rather than being made aware of the potential of advanced mathematical tools at the onset of their research career. Furthermore, most researchers in acoustics do not have access to Masters-level courses to broaden their postgraduate study.

A first attempt to remedy this was made at a summer school held at the University of Southampton on 14-18 July 2003, which aimed to address the mathematical needs of UK postgraduate research students in engineering and physical acoustics. It took the form of an intensive residential week

Table 1: Prerequisite topics

TOPIC
Differentiation and integration
Basic definition of rate of change and slope of graph
Derivatives of simple algebraic functions, polynomials, exponentials, logarithms and trigonometric functions
Rules including product, quotient and function-of-a-function
Maxima and minima
Functions of more than one variable
Elements of partial differentiation
Integration as the limit of a sum
Integration as the reverse of differentiation
Indefinite and definite integrals
Numerical integration including rectangular, trapezium and Simpson's rules
First order ordinary differential equations and linear second order with constant coefficients, solution methods including integrating factor
Definition of imaginary unit (square root of minus 1)
Argand diagrams
Complex conjugate and modulus
Addition and multiplication of complex numbers
Polar representation including De Moivre's theorem
Complex roots and functions
Matrices, determinants and vectors
Matrix addition and multiplication
Matrix inverse
Determinants
Matrix representation of systems of equations
Vector algebra including vector addition and scalar and vector products
Intersection of lines and planes
Vectors in three dimensions

for 40 postgraduate students drawn from across the UK, supported by a high staff/student ratio. The school benefited from lecturing contributions by leading mathematicians and acousticians from several universities, including Chris Linton, Maureen McIver (Loughborough), Chris Howls, Rod Self (Southampton), Trevor Cox, Philip Duncan, Yui Wei Lam (Salford), John Chapman (Keele), Nigel Peake (Cambridge), John Elliott (Hull) and Trevor Esward (National Physical Laboratory). It was coordinated by Professor Keith Attenborough, on behalf of the Institute of Acoustics Research Coordination Committee, and Dr Matthew Wright at ISVR.

Although publicity was widely distributed, analysis of the students indicates that they were recruited mainly from the pre-1992 universities, the newer universities being under-represented. The course introduced important mathematical techniques in acoustical contexts using lectures, examples classes, tutorials and one-to-one 'surgeries'. The objective of the course was to convey the essential mathematical tools and concepts that will enable the attending research students in physical and engineering acoustics to make a rapid impact in their research. The emphasis was on how mathematics is used in acoustics rather than on mathematics for its own sake.

During the summer school preparation, Lyn Leventhall (Learning Technology Group, School of Computing and Information Systems, Kingston University) approached the organisers concerning her PhD research on mathematical communication. At the school she took video and audio recordings during some of the lectures and held focus group evaluations.

A relatively small amount of time was available between confirmation of the funding of the summer school and its proposed date. The lectures were arranged by balancing a number of constraints:

- ☐ the topics which were felt to be important to current acoustical research;
- ☐ the subjects which could be taught in the time available without unbalancing the programme;
- ☐ the subjects falling into suitable themes so that lectures could be arranged in a suitable order; and
- ☐ those who had volunteered, or could be asked, to teach particular topics.

The week began by revising important mathematical techniques (vector calculus, complex variables, integral transforms) on the first day. The other four days were devoted to the mathematics of waveguides, signal processing and aeroacoustics. These were augmented by tutorials, computer (MATLAB) sessions and evening 'surgeries' during which there were opportunities for individual interaction with tutors on topics (both mathematical and acoustical) chosen by the participants. A distinction was drawn between lectures, which took place during the day and fell within the day's theme (often being linked and having associated tutorial questions), and 'talks', which were given at the end of the day on a subject of the speaker's choice, with no tutorials. The final morning consisted entirely of such talks.

Apart from competence in algebra, trigonometry, and geometry it was assumed that registrants would have some familiarity with topics listed in Table 1. Potential attendees were requested to identify any topics from the list in which

they would appreciate assistance. In the event few of the registrants responded to this. Moreover the range of previous mathematical ability among the registrants was very wide, ranging from a degree in Music Technology to the second year of a PhD in mathematics! Some *ad hoc* arrangements were made for extra tutorials on topics in demand. These included matrices and Z-transforms.

The students worked and ate together each day, from 9:00 to 18:30 in the Mathematics Building, followed by a communal meal at the University Staff Club, and stayed together in rooms at one of the University Halls of Residence. An additional benefit to the summer school beyond the imparting of mathematical education was the opportunity for networking among future acoustics researchers, and exposure to ideas outside their own projects.

Feedback

Student feedback

Thirty responses to a feedback questionnaire circulated and completed on site were analysed. Post-school surveys produced seven further responses. Student response concerning the extent to which the school had met their needs was mainly positive. Some of the student responses to the question *'To what extent did the summer school meet your needs?'* were as follows:

'Well, ... now aware of maths in acoustics in a general sense'; 'to a great extent'; 'helped quite a lot'; 'needs met to a highly satisfactory level'; 'fairly well'; 'Monday pm, parts of Tuesday and Wednesday excellent, Thursday particularly good'; 'quite well, revision and extension'; 'learned some techniques useful for my work'; 'it has been good to remind me of what I studied before'; 'very good event, informative and useful'; 'I have lots of new ideas on my project now'; 'has given a broad idea of what kind of maths might be required in the future'.

A comment made via a supervisor three months after the school: 'has prepared (me) well for questions in recent (acoustics-related) job interviews'.

A selection of comments responding to *'Which sections did you find particularly useful and not useful?'* follows:

'Very useful'; 'very useful (DSP and Monday/Tuesday)'; 'all, particularly DSP'; 'maths of generalised functions'; 'all but particularly waveguides and DSP'; 'good reference base'; 'aeroacoustics very useful'; 'Monday not useful'; 'most useful aeroacoustic theory but general maths useful'; 'evening tutorials on matrices and Z-transforms were the most useful'.

Responses to *'What changes do you suggest we make in future?'* included:

'Advance circulation of lecturers' notes'; 'more applications and computer sessions'; 'more time for exercise sessions at cost of fewer lectures (eg Wiener Hopf)'; 'better accommodation'; 'more engineering and computational aeroacoustics'; 'more practical examples'; 'reduce scope'; 'more realistic exercises'; 'make clear the minimum level of background knowledge required'; 'more computer simulations, paper copy of every presentation'; 'more (optional) basic lectures'; 'less flexible timetable'; 'streaming'; 'social event earlier'; 'more and better-planned surgeries'; 'knowing that this is not necessarily feasible, I believe that a more 'modular' schedule with one or two days with parallel course-sessions could help the school be more attractive to a wider range of students (for example the mathematics of the first day could have one 'entry' and one 'advanced' version)'.

Staff feedback

Several tutors found it rewarding to work with such excellent students. Tutors have suggested also that periods for private study followed by graded tutorials would be desirable. Lyn

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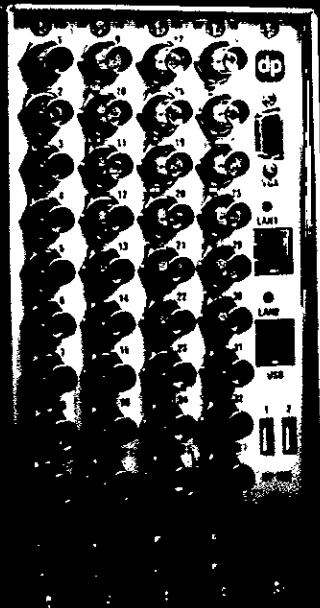
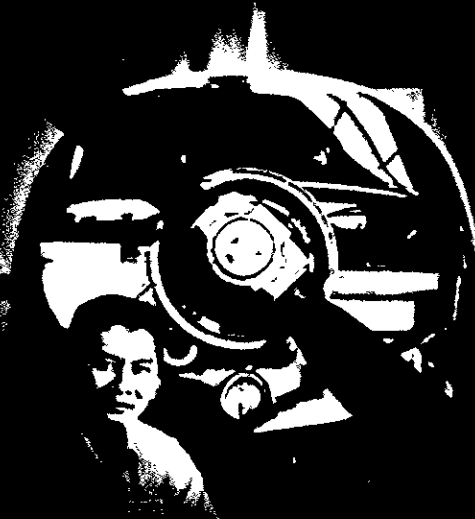
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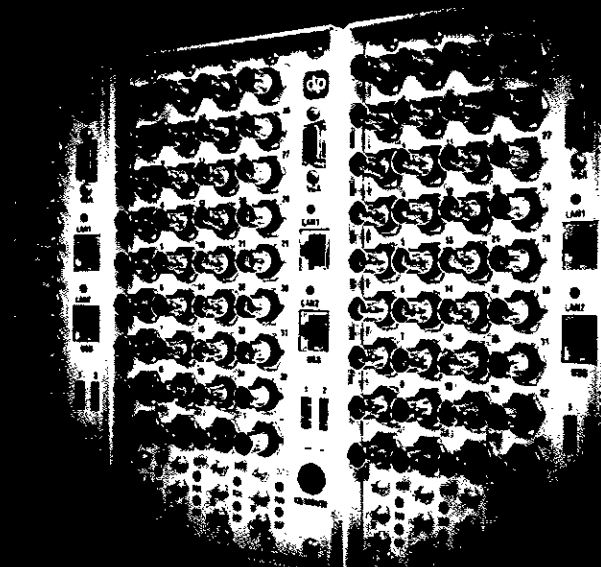
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Support mathematics for acoustics research training

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Leventhall has suggested that a future school should include five-minute presentations on their research by each registrant. This would help participants identify useful colleagues and help with their training in presentational skills.

Suggestions for future activity

Future summer schools

In respect of the minimum level of background knowledge required, it is suggested that the HELM (I) workbooks and CAL be made available to applicants for any future *Mathematics for Acoustics* school and that applicants be required to complete a pre-test based on these materials. In view of the wide range of mathematical background encountered this year and the obviously overburdened first day, a possible way forward would be a 'streamed' summer school with a common first day on basic techniques (a significantly reduced content compared with this year) and subsequently two parallel sessions, one more advanced than the other. This would give scope for the inclusion of more 'basic techniques' for some students, graded tutorials, and coverage of more topics such as statistics (including handling experimental data) and computational acoustics (CFD, BEM, FEM). One week with parallel sessions is preferred to a two-week school. A proposed structure for a future school is shown in Table 2.

	stream 1	stream 2	all
day 1	basic techniques session 1	basic techniques session 1	tutorials & surgeries
day 2	basic techniques session 2	waveguides	tutorials, surgeries & lectures
day 3	signal processing & statistics	mathematics of digital signal processing	computer session 1, surgeries & lectures
day 4	computational acoustics I		computer session 2 & guest lecture
	lectures on applications	aeroacoustics (matched asymptotic expansions or green's functions)	
day 5	revision tutorials	computational acoustics II	

Table 2: Proposed format for future Mathematics for Acoustics school

Book of lecture notes

Several students expressed a wish that they be given the lecture notes in advance. This need should be met for a future school by a book currently being edited by Dr Wright and based on this year's lectures, to be published by Imperial College Press. Each author has been invited to revise and expand where appropriate their material and notation conventions have been standardised as far as reasonable



Lecturers and students at the Summer school in support mathematics for acoustics research training

among chapters. This was an issue that there was not time to address in the relatively short preparation time for the summer school itself. It is hoped that the paperback edition will be available at a price that will put it within the reach of graduate students, and that copies could be provided to future students on registration.

The planned chapters of the book are:

Part I: Mathematical Methods

- 1 Vector Calculus - *J W Elliott*
- 2 Functions of a Complex Variable - *J W Elliott*
- 3 Integral Transforms - *J W Elliott*
- 4 Asymptotic Evaluation of Integrals - *R H Self*

Part II: Wave Motion

- 5 The Wiener-Hopf Technique - *M C M Wright*
- 6 Waveguides - *M McIver & C M Linton*
- 7 Wavefield Decomposition - *M C M Wright*
- 8 Acoustics of Rigid-Porous Materials - *K Attenborough & O Umnova*

Part III: Aeroacoustics

- 9 Generalised Functions in Aeroacoustics - *N Peake*
- 10 Monopoles, Dipoles, and Quadrupoles - *C J Chapman*
- 11 Corrugated Pipe Flow - *J W Elliott*

Part IV: Signal Processing

- 12 Digital Filters - *P J Duncan*
- 13 Measurement of LTI Systems - *T J Cox*
- 14 Numerical Optimisation - *T J Cox*

Conclusions

The experiment made in July 2003 at Southampton has confirmed the need for additional training in mathematics for early researchers. A plan for a future school in 2005 is underway. The contributors to the 2003 school would be grateful for suggestions and support for the organisation of future similar events.

Acknowledgment

The summer school was made possible by EPSRC GR/S47021/01.

Reference

1 FDTL4 project, *Helping Engineers Learn Mathematics*, consortium led by Loughborough.

K Attenborough is from the University of Hull and **M C M Wright**, the University of Southampton

The Making of a Sound Meter

Jim Weir

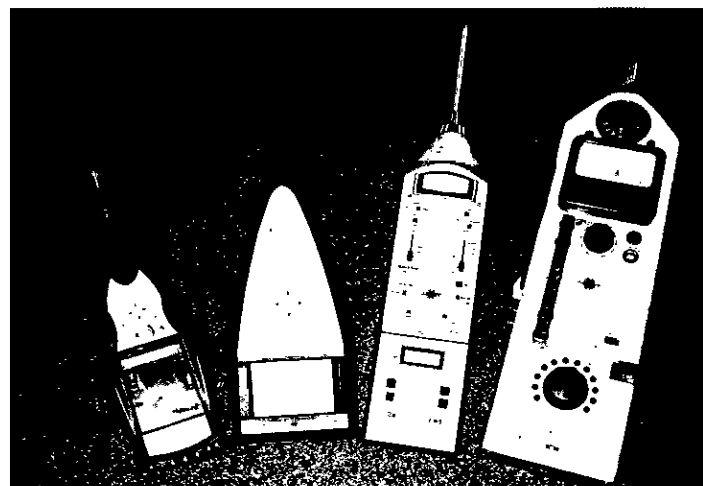
Do you remember the first time you were asked to measure how noisy something was? If you do, you'll more likely recall pulling a sound level meter out of the equipment cupboard. You may have skimmed through the manual, and twiddled a few knobs. You probably stared at an analogue meter needle bouncing up and down, and I bet you whistled...

My first experience as a young avionics engineer at the Learjet Company was just like this. I was asked to evaluate some cockpit noise levels. My visit to the equipment cupboard brought me face to face with a pale green instrument that was a bit intimidating, if only by its size. It barely fitted in my large hands, and two hands were definitely required. The sturdy instrument offered a tapered top to minimise reflections that may disturb the accuracy, and had only two knobs, making it easy to figure out. The top 'range' knob was a clever double attenuator that allowed me to set the measured level so that it fell into the instrument's massive 20dB display range. It wasn't long before the measurement was complete, with the stepped octave filter determining that the highest noise level was in the 500Hz octave frequency band, and according to Beranek, loud enough to interfere with speech communication in the cockpit.

History

The instrument I used was the first generation sound level meter by Brüel & Kjær, the *Type 2203*, which in 1965 changed the way sound meters looked, and in many ways how we used them. Massive grey boxes with gooseneck microphones, usually from General Radio, were its predecessors.

I joined Brüel & Kjær in 1983, when the second generation of sound level meters was being introduced, and the first microprocessor controlled model, the *Type 2230*, came onto the market. Just a few years later, the programmable *Type 2231* followed. The shape of the meters was similar to the older meters, though now they fitted readily in one hand, letting you use your other hand to move the controls to display the many parameters stored in the SLM's memory. Start a measurement and you could switch between



maximum, minimum, and Leq - the real average level.

Technology, like rust, never sleeps. Along with that technology, the knowledge of the acousticians started to creep into standards, and the requirement for sound measurements grew in scope and scale. By the mid 1990's, statistical parameters like L_{DN} , L_{10} , and L_{90} became common measurement requirements, and no longer was it sufficient to measure values over a fixed time period. Noise monitoring was now a function of the sound level meter, not just a noise terminal. At Brüel & Kjær, Multi-D™ measurements of level-v-time-v-frequency was born in the *2260 Investigator* platform almost a decade ago. Now a digital signal processor and a microprocessor collaborated to fill up megabytes of information the noise consultants could use for diagnostics and analysis.

Interestingly, Brüel & Kjær used this third generation of product to introduce the first new shape in sound meters. The display section was moved to the more practical user end of the meter, closer to the failing eyes of ageing acousticians! The control buttons moved towards the middle of the unit so it could be gripped and operated by one (large) hand. The sleek distinctive sweeping shape let the sound waves flow towards it as smoothly as an America's Cup sailing boat slips through the ocean.

Brüel & Kjær used the latest available technology when introducing the *Type 2260 Investigator*. This, coupled with flexibility of application-based measurement technology, has enabled the instrument to persevere in a competitive market, with sales growing in each successive year. In 2003, *Type 2260* platform sales achieved their highest growth ever worldwide.

Planning ahead

As innovative as a company can be, it is useful now and then to get a reality check as to the direction you are moving. Sometimes, this comes from a competitor introducing a new technology, waking you and customers up to 'the new thing'. The reality check may also come from an unexpected drop in sales, when customers' needs drift away from the products and services you provide.

A few years ago, the environmental market group at Brüel & Kjær initiated a reality check of our own. We called it

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the Handyman Project. New technologies such as laptop computers and palm PC's were now capable of serving in the portable sound measurement market. We asked ourselves what our customers wanted to have in a sound measurement analyser to perform their jobs.

More important, actually, is that we went to the customers and asked them that question. We enlisted sixty customers considered to be expert users of sound meters and interviewed them about their job function and work processes. In small groups we mediated discussions about platform type, workflows, integration and reporting... asking for example: 'Do you want to bring your laptop into the field?'

We then engaged in a brainstorming session with these users, letting them come up with ideas, characteristics and features. We made a feature puzzle, with each expert using a stack of tiles, each one representing a feasible instrument feature or characteristic (such as 'colour screen'), and a



Getting the grip right
- indents made by
the combined holds
of various hands in
a soft clay prototype
were modelled in a
computer-aided design
system that could
also perform acoustic
calculations

playing area. They then had to fill the playing area with tiles. Easy enough, except that there were more tiles than space on the playing area, so a choice had to be made. The result was a set of chosen features. The playing area was then halved, and the process repeated (using the same set of tiles). The playing area was halved once more and the tiles placed again. The result for each member was therefore a description of three instruments representing the 'nice to have', 'should have', and 'must have' features.

Time to start

About the time we were wrapping up the Handyman research project, we were getting one of those unexpected reality checks. We discovered that whilst a vast number of our customers were happy with their existing noise measurement analysers, others were asking for additional features such as real time frequency analysis and a wide 100dB dynamic range. Now was the time to put the Handyman research into practice.

During this project, a re-occurring set of descriptors continued to show up in our discussions. We would hear: 'It has to be easy to ... (hold, use, set up, calibrate, etc.) or: 'Our (data, measurement, use,) has to be safe'. 'It would be clever

if it could... (record sound, use standard memory cards, accept sound and vibration transducers, etc')'. The words 'easy', 'safe', 'clever', became the mantra for the development of the new meter.

When designing *Type 2250* every idea and feature was tested against the question: 'Is it easy, safe or clever?'. If the answer was 'no', then the idea was either modified until a yes was achieved or scrapped.

The feature set chosen by the experts in the Handyman project allowed rapid acceleration of the design and development of the new meter. We knew what features we had to include, and we had a guideline to use to define the technologies customers were expecting for the next mid-range platform sound meter/analyser.

An instrument takes shape

For example, the panels of experts said *Type 2250* should be safe to hold, so an instrument with a pre-formed handle like that on a power-tool would be ideal. Unfortunately, this is not acceptable acoustically. You can wave goodbye to Class 1 rating if you stick a pistol grip on a sound level meter. There was obviously a conflict here, so instead, a streamlined model of the proposed instrument was made in soft clay, and then given to a large number of people to hold.

Over time, the combined grips of big and small hands, with long, short, wide or narrow fingers, made indents in the model (see picture). This gave an average grip shape which was then modelled in a computer-aided design system that could also perform acoustic calculations. These showed where the grip shape caused the frequency response to fall out of tolerance. By iteration, the shape was modified to make the frequency response correct. When done, a real solid model was made from a polythene block, and tested on

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Technical Sales Engineer

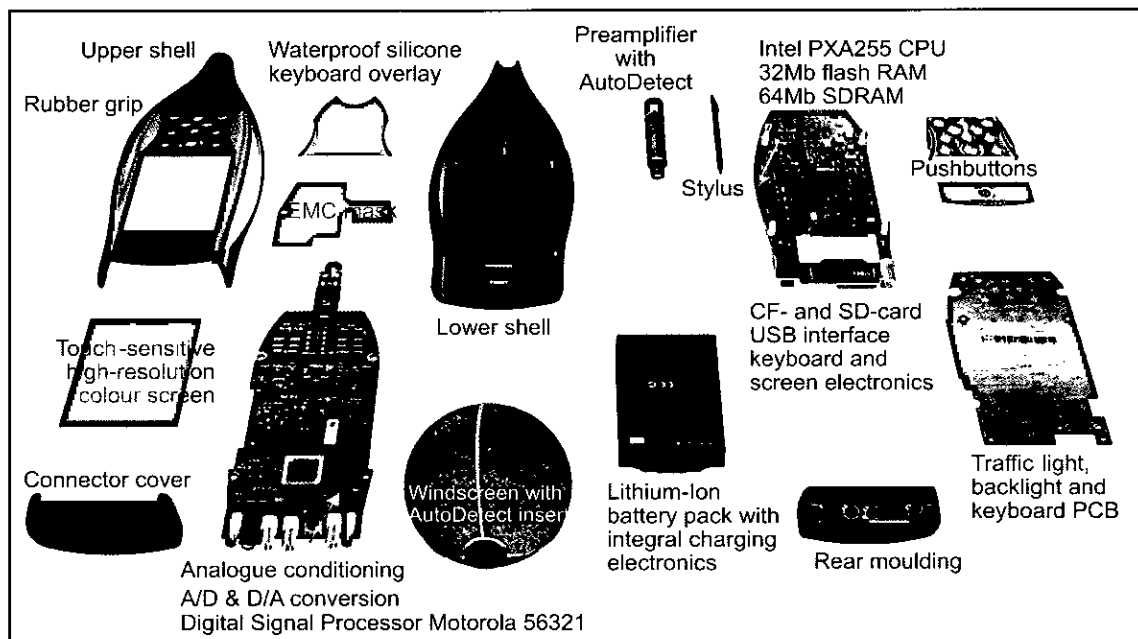
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The Making of a Sound Meter

continued from page 33

the same people. This revealed that the grip was good, but still suffered from small aberrations. So the whole process was repeated, the final result being the shape that *Type 2250* is clothed in today.

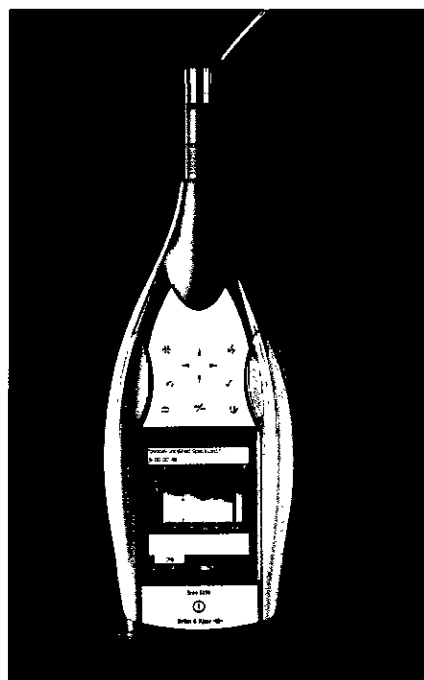
Sandy McDonnell of the renowned McDonnell Douglas Aircraft Company, once said of the development of a new aircraft: "When the weight of the paper matches the weight of the aeroplane, it will fly."

Well, a sound meter isn't a DC-10, but we had a weight of features to fit into our little SLM-to-be. And it had to be *Easy*, *Safe* and *Clever*. From the experts' input it was obvious that a dedicated handheld platform was preferred over hybrid Palm-PC or Laptop data acquisitions formats, because we can make it environmentally rugged, and we could control the way the user operates the device.

It was decided early that a colour touch screen was a convenient user interface. It would be clever to include screen formats with high contrast for daytime measurements, and a low contrast night vision mode for measurements in the dark. Also, you may need to be one-handed to control the instrument, so buttons can be used to navigate the functions of the touch screen, and it is clever to allow you to backlight those buttons for easy night-time operation.

Technological developments allowed us do some things nobody has done before to make data safe. We can now measure from the standard microphone's noise floor to 140dB for broadband measurements filters (A, C, Z) and also maintain that same dynamic range for the octave and third-octave measurement bands. Now you are unlikely to overload or under-range your measurement by mistake. Technology also brought us the latest low power consumption DSP and μ Processors to give extended battery life, while the latest battery technology allows thousands of recharge cycles from a single battery.

One unique feature that came from the Handyman project was the *Type 2250* user login that lets you customise and save the set-ups and measurement templates you use, while colleagues can use their own personalised meter configurations. As the experts requested, the instrument is easily set-up and synchronised with a PC using the included software, making it even easier to download and upload measurements and settings.



Above: these are the components packed into the *Type 2250* sound meter (pictured left)

What's inside the Type 2250?

Perhaps the most daunting task was that of the hardware designers to fit all this 'stuff' into the marketing teams' easy-to-hold compact sound analyser package. USB, Compact Flash interface, SD memory slot, signal input (with accelerometer power supply), trigger connector and a standard headphone mini-jack all had to fit on the rear face alone. The *Type 2250* had to be water resistant, retain its look and feel over a wide temperature range, and meet the demanding standards of your next generation Brüel & Kjær sound level meter.

Turn the meter on, touch your log in ID, press ►/||. That's it! You are measuring the way you want - *Easy, Safe, Clever!*

You can take a tour of the new *Type 2250* at www.type2250.com

Acknowledgements: Julian Simpson and the rest of the 35+ member Brüel & Kjær Denmark Marketing and Development team for their information, support and pictures.

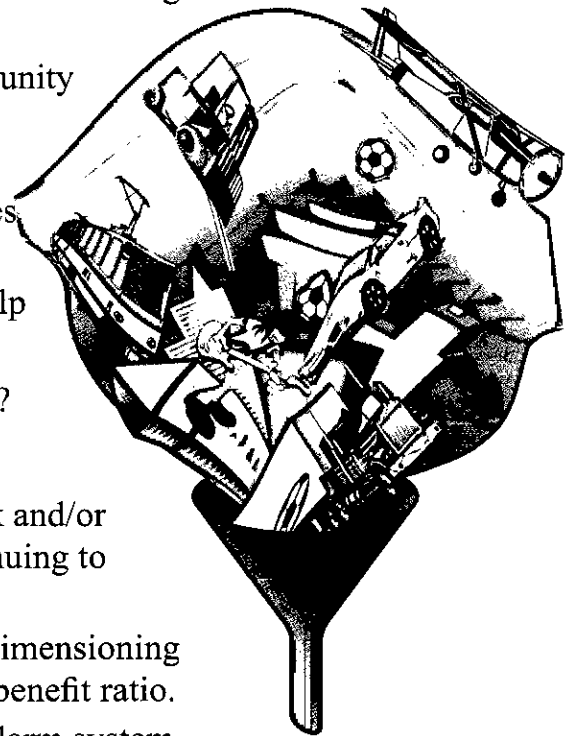
About the author: Jim Weir is Product Manager representing the environmental products line of Brüel & Kjær in North America. During his 21 years with the company he has been involved in sales, application support and management activity.



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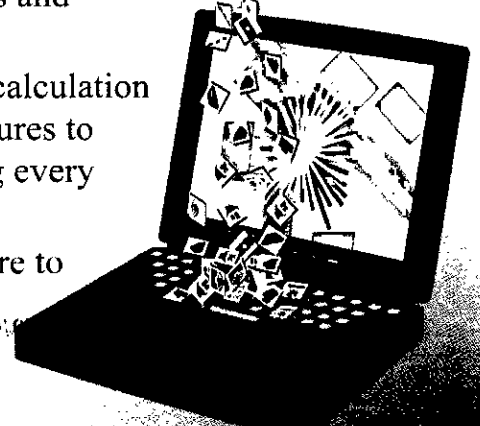
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- ☐ How loud is it inside a building? Which sounds dominate?
Can the noise breakout be minimized with new doors, gates or window applications?
- ☐ Can I document my data sufficiently? Will the software help me comply with ISO 9000 quality control?
- ☐ Will I get the hotline support I might need in my language?



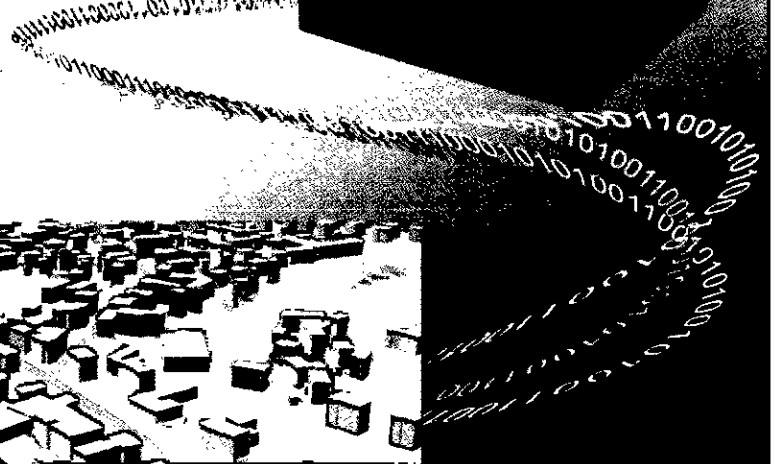
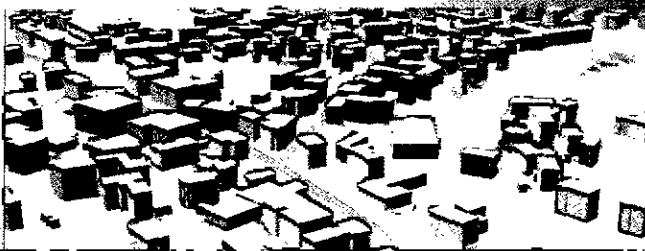
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Harvey Fletcher

1884-1981

John W Tyler FIOA

'As I looked across the Utah valley, I thought that the tops of the mountains that I could see in any direction marked the end of the world where people live. On the other side of these was the great ocean. There were cracks in the wall that held the ocean back so that the water from the ocean leaked through and formed the various streams that come down from the mountains.'

So thought the boy Harvey, born and brought up in Provo, a small town in the then relatively unexplored mountain country of eastern Utah, situated near a freshwater lake surrounded by high mountains. Those readers familiar with the Fletcher/Munson loudness curves will need no reminder that Harvey Fletcher made his mark in the field of acoustics. The route that he followed to achieve his contributions to this subject and also to engineering, medicine and physics, is the subject of this article.

Here, for much of the information about Harvey Fletcher, I must acknowledge my dependence on his son Stephen, whose memoirs of his father were published by the US National Academy of Sciences. These memoirs contained many fascinating extracts from the autobiography (unpublished) of Harvey Fletcher.

This story interfaces at one point with the history of Alan Blumlein (*Acoustics Bulletin* Vol 28, Sept/Oct 2003).

Background

Harvey Fletcher was born on 11 September 1884; his parents were of pioneer stock, loyal members of the Church of Jesus Christ of Latter-Day Saints, his father built houses and his uncles ran grocery stores in Provo. He had no

ambitions to be a scientist and, working with his father building houses and with his uncles delivering groceries, he wanted nothing more in life.

However this changed when, after a good basic education in local schools, he entered Brigham Young Academy, the only school in Utah Valley offering education at a higher level. Here he was taught physics, mathematics and chemistry, not by choice but because the Academy provided these subjects at a lower cost than the commercial subjects he wanted to follow. After seven years he graduated with a B.S. degree and was hired by the school to teach physics and mathematics courses. During summer vacations he put his newly acquired knowledge to practical use by working on local government projects, such as surveying the unexplored mountain country of eastern Utah and supervising the building of water mains to supply the town of Provo.

By this time his ambitions had changed from pursuing a business career to a commitment to science and teaching science subjects. To this end he decided that, to be successful in teaching physics, he would need to obtain a PhD, choosing to do this at the University of Chicago. Before making the move to a strange city he persuaded his girlfriend, Lorena Chipman, to marry him and thus join him in this major career step. Soon after marrying on 9 September 1908 they moved to Chicago.

However, his plans to enter the University were thwarted by the fact that Chicago did not accept much of the curriculum at Brigham Young and because his degree there only involved three years of study; the University required him to take four years of undergraduate courses in order to move on to the graduate programme. This was beyond his means and he would have had to give up his plans had it not been for the intervention of Robert A Millikan, then assistant professor. Millikan proposed that Fletcher enrol as a special student in the courses that were usually taken in the first year of the graduate physics course and if he was successful he might then be admitted to the graduate school. He was and, once in the graduate school, discussed a possible subject for his PhD with the professor.

Robert Millikan, who was working with Professor Louis Begeman on measuring the charge of an electron, outlined to Harvey Fletcher the research they had been conducting at Chicago and also similar work being done at Cambridge University by J J Thompson and Regener. Millikan was using water droplets for his experiments, essentially repeating the work done by Regener in England, but these evaporated too rapidly to obtain reliable results. Harvey Fletcher redesigned the experiments using oil droplets which enabled more accurate results to be obtained and also led to a modification of Stokes' Law. One of the five papers written to describe these experiments was Fletcher's thesis for his PhD, obtained in 1910.

Teaching

In 1911, although offered a position with the Western Electric Company (Bell Telephone Laboratories) Harvey Fletcher returned to Provo to resume his teaching career at Brigham Young University, as it had now become, and was the only faculty member with a PhD. He was appointed chairman of the physics department and taught there for five years.

Although the equipment and facilities at BYU were more limited than at Chicago, Harvey continued research on the electron charge by designing and building another oil drop experiment. This resulted in his publication of two more papers on the subject.

Every year he was approached by Western Electric to join

them and each time he rejected the offer through loyalty to the University and his commitment to building the physics facility and attracting potential scientists to Brigham Young. However, after five years teaching he finally accepted the offer in 1916 and moved with his family to New York City to work in the Western Electric Company's research and development department.

Telephones

In his biographical memoirs of his father Stephen describes: *'my father's first year with the Bell System (See Note below) was spent getting acquainted. He climbed telephone poles, operated switchboards and installed telephones. At the end of the year he began formulating a plan for research that he felt was needed by his new employer. Since the business at that time was largely the transmission of speech from the mouth of one person to the ear of another, he felt that a thorough understanding of the characteristics of speech and hearing should be fundamental to the Bell System. He thus embarked on a study of the physical mechanisms of the body used in this form of communication. I can remember as a boy seeing my father with a bellows under his arm connected by a tube to a vibrating reed, which he placed in his mouth to form various speech sounds. He would repeat them until he was sure he understood the position of the tongue and lips that characterised the sound. His first publication on this new research was 'On the Relative Difficulty of Interpreting the English Speech Sounds', appearing in Physical Review, in August 1920.'*

(Note: The Bell System, aka 'Ma Bell' or simply 'THE telephone company', was not a 'company' but rather an aggregate term for AT&T, eventually encompassing 24 Bell operating companies providing local exchange phone service, the AT&T Long Lines Division providing long distance connections, an equipment manufacturing arm known as Western Electric, and a research and development arm known as Bell Laboratories. The American Telephone and Telegraph company (known today as simply AT&T), Western Electric (which became Lucent), Bell Labs, and the 22 local Bell operating companies (which became the so-called 'Baby Bells') made up a huge and complex corporate system providing telecommunications equipment and service to the majority of people living in the US prior to divestiture).

At this time, many friends who knew of his work with Millikan on the electron charge, attempted to discourage him from leaving this promising field for research in the world of acoustics. After all, they told him, all that there is to know about acoustics has already been discovered. Fortunately, however, he felt a sense of commitment to explore acoustics and particularly the production, transmission and recording of sound.

Telephones and hearing

In his first ten years with Western Electric Harvey Fletcher contributed to the greatly improved quality of speech in telephone communication and designed the 2-A audiometer, a development of earlier models, which was used extensively by audiologists and schools for hearing measurement. He also worked with the hard of hearing, developing early forms of hearing aid including the first using vacuum tubes (valves in the UK!).

In 1921 Harvey Fletcher began publishing some of his findings about speech and hearing. His first article, *The frequency sensitivity of normal ears*, appeared in the Proceedings of the National Academy of Sciences in 1921.

This was followed by several articles throughout the 1920's, leading to the publication of his well known book, *Speech and Hearing*, in 1929.

By this time Harvey's work in acoustics was considered by his company to be of sufficient importance to appoint him - in 1928 - director of acoustic research, part of the Physical Research Department in the newly formed Bell Telephone Laboratories. By 1935 he was made director of all physics research at Bell Systems.

Around this time, Harvey Fletcher became aware that a small number of deaf people whose hearing had been assisted by hearing aids were further afflicted by having their larynx surgically removed, usually as a result of cancer. Since he had already devised a vibrating reed mechanism to study speech sounds in his work on telephone clarity, it was a relatively simple matter for him to devise an artificial larynx for surgical insertion into sufferers, which was subsequently manufactured and sold by the Bell Company. According to Stephen Fletcher, his father received much world-wide publicity for this invention.

By now his fame had spread outside the confines of

Bell Telephone Laboratories. In 1920 he was elected a fellow of the American Physical Society and in 1921 a fellow of the American Association for the Advancement of Science. In 1922 he became a member of the American Institute of Electrical Engineers and in 1926 a member of the Board of Managers of the American Federation of

Organisations of the Hard of Hearing. He developed a multiple hearing aid for the latter organisation so that attendees at meetings of the federation could hear the proceedings. He described the first use of this equipment in his autobiography:

'As I remember it small strips were made with five or six jacks and attenuators wired in parallel. Any number of these strips could be connected together by simply plugging connecting cords into the end jacks. There were about 20 of these strips so that about 100 head pieces could be connected in parallel to the amplifier. As the hard of hearing person sat down he could reach for a headset and then turn the attenuator until he obtained the loudness with which he could best understand. The first installation was at the Hotel Astor at the annual convention. When everyone became quiet for the beginning of the meeting, they asked me to talk and explain how to use these sets. Some of the people could hear and helped the others to adjust the headbands. When they all had finished fussing with the headband I started to talk slowly in a normal volume and greeted them and told them to adjust the attenuator if they needed more volume. Most did not and sat with tears running down their cheeks crying, "I can hear! I can hear!" It was the first time most of them had ever heard a public speech. After they had quieted down I turned the microphone over to the president and he carried on the conference.

The Bell Labs donated the system to the national organisation and it was used for many years after that time. The officers of the Federation took their group hearing aid all over the USA for meetings in various localities.

In 1929 Harvey Fletcher was elected president of this organisation. He also contributed greatly to the design of smaller hearing aids for individuals and was able to help a number of well-known sufferers, for example Thomas Edison.

continued on page 38

Harvey Fletcher 1884-1981

continued from page 37

In the same year he co-founded the Acoustical Society of America and became its first president. In 1949, in recognition of his work in the field, he was made an honorary member of the Society.

In the early 1930's Fletcher worked with Wildon Munson to produce a set of graphs which correlate sound intensity and loudness, now referred to as the Fletcher-Munson Curves. (H F Fletcher and W A Munson, Loudness, its definition, measurement and calculation, *Journal of Acoustics Society of America*, Vol. 5 1933, pp. 82-108). Although measured over 60 years earlier, the contours published by Fletcher and Munson were still the standard for earphone listening in 1998, according to Bertram Scharf (*Handbook of Acoustics*, edited by Malcolm J Crocker, John Wiley and Sons) and may well still be (in the USA anyway).

Sound recording and stereophony

Harvey Fletcher became involved in sound reproduction with the advent of film with sound. He rejected offers from the film companies to help them engineer the systems and stayed with Bell Telephone Laboratories. However, for a number of years many of the sound pictures were made under Bell System patents. We now come to the stage of the story which interfaces with the work on binaural sound and sound on film carried out in the UK by Alan Blumlein. In 1931 Harvey Fletcher and Arthur Keller of Bell Labs, together with Leopold Stokowski, used improved electrical recording equipment in the Academy of Music in Philadelphia to record and transmit monaural and binaural sound. At about the same time - in December 1931 - Blumlein filed the provisional application for his famous patent on stereo sound.

In 1933, as Alan Blumlein in the UK was patenting several two-channel devices including a disc recording system using sum and difference and 45 degree/45 degree principles and also a recording microphone technique that still bears his name, Harvey Fletcher and Arthur Keller of Bell Telephone Laboratories were patenting and demonstrating three-channel sound systems. In the USA the experiments transmitted the sound from three microphones in the Academy of Music in Philadelphia to three loudspeakers on stage at Constitution Hall in Washington. The music was played by the Philadelphia Orchestra conducted by Alexander Smallens while Leopold Stokowski in Washington manipulated the controls to provide the results to satisfy him!

In 1934 Alan Blumlein recorded Thomas Beecham at the Abbey Road Studios, in stereo, conducting Mozart's Jupiter Symphony and in 1936 developed a system for two optical tracks in the space of the usual single track on 35mm film.

In April 1940 Harvey Fletcher and Stokowski made another stereophonic demonstration at Carnegie Hall with three channels using sound on film with a frequency range of 30 to 15 kHz and a dynamic range of 120 dbA. The *New York Times* reported 'Sound Waves Rock Carnegie Hall as Enhanced Music is Played' and 'The loudest sounds ever created crashed and echoed through venerable Carnegie Hall last night as a specially invited audience listened, spellbound and at times not a little terrified'.

By this time Britain was at war and Alan Blumlein had moved on to vital work on the development of radar.

Not much is known about the military work that Harvey Fletcher became involved in when America joined in World War II; he makes light of it in his autobiography and the general belief is that it concerned underwater acoustics.

In his time as Director of Physical Research at Bell Laboratories from 1935, Harvey Fletcher supervised the work of several important researchers, including Shockley, Brattain and Bardeen in the development of the transistor and Dean Wooldridge in the development of magnetic tape.

After the war Fletcher worked hard on two projects he wanted to finish before his impending retirement from Bell Laboratories at the age of 65. The first was to develop an empirical theory of telephone quality. The second involved the dynamics of the cochlea. His research on both subjects and developments since the publication of his first book in 1929 led to his second book in 1953, *Speech and Hearing in Communication*, also published by D van Nostrand.

When he retired he accepted a position as professor of electrical engineering at Columbia University. During his three years there he organised a department of acoustics and persuaded Bell Laboratories to donate to Columbia some of the stereophonic apparatus which had been used in his demonstrations.

Harvey Fletcher moved again in 1952, back to his old school Brigham Young University where, as director of research, he was able to increase the amount of grants for research given to the University. In 1953, at the request of the president, he organised an engineering course and became chairman of the new Department of Engineering Science; this ultimately became the College of Physical and Engineering Sciences. In 1958 he was able to hand over some of his administrative responsibilities to enable him to teach mathematics for two years after which he again returned to research, this time to actively pursue his study of musical tones. He analysed the sounds of the piano, organ, cello, violin and base drum to further his vision of inventing completely new instruments.

His loyal wife Lorena bore him seven children of whom six survived to maturity. She died in 1967 and he then married her sister Fern Eyring; this marriage lasted until both their deaths in 1981. As Stephen Fletcher records in his biographical notes on his father: 'He never felt any insoluble conflict between science and his religious beliefs... He was a working scientist until the very year he died at the age of ninety-six. The curiosity that propelled him as a boy, a young student, a researcher and leader of others continued to the very end. His influence will continue to be felt for years to come by those who knew him and for those following in his very large footsteps'.

Dr Harvey Fletcher had an enviable record of achievement and honour. In his career he published 51 papers, was awarded 19 patents and published two books.



Fletcher's work on binaural sound and sound on film interfaced with Alan Blumlein's in the UK



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24 June 2004

Estimates 2004–05: Highways Agency Department for Transport

Mr Jamieson: While I have concentrated on the way in which the agency is meeting the needs of the road user, I can assure the House that its activities are balanced so that the needs of communities and the environment are not ignored.

As the hon. Gentleman said, the Highways Agency is the second largest planter of trees in England. At many road openings, I have seen special arrangements made to enable badgers to cross the road in tunnels. On one of the sites that I visited, I saw that about 59 water voles had been temporarily removed and sent in a charabanc off to north Devon; I think that I passed them when I was travelling down to my constituency, tootling along with their swimming costumes and with their surf boards on the roof. They will also be brought back. That shows the meticulous care that the Highways Agency takes in respect of livestock, birds and other animals, as well as trees.

We have set the agency challenging targets to ensure that the environment is properly respected. For instance, the agency is reducing traffic noise by resurfacing concrete roads with quieter surfaces, and at least 50 lane-km of concrete roads will be treated this year, bringing a welcome reduction in noise. My hon. Friend the Member for Stafford asked about noise attenuation measures. We have put aside a ring-fenced budget of £5 million per year, and we are examining sites where we can put in noise attenuation measures, such as fences, bunding or whatever is appropriate. Obviously, we are dealing first with those sites where the number of people affected and the noise are the greatest, which has provided relief to certain communities. On procurement, the agency delivers the majority of its services through third parties such as contractors, managing agents and consultants. Buying in such services is therefore an integral part of the agency's business, and it is at the forefront in that particular field. The agency's procurement strategy benefits the supplier industry, because it provides continuity and certainty, which was not available in the past, by allowing companies to plan effectively and, importantly, to train and retain skilled staff. The agency's procurement strategy also improves health and safety for workers and develops sustainable working practices.

Adjournment debate

8 June 2004

The Parliamentary Under-Secretary of State for Transport (Mr Tony McNulty):

The White Paper entitled 'The Future of Air Transport', which was published on 16 December 2003, is recognised by many people as breaking new ground. In the history of policy papers on aviation, it is the first to make a comprehensive and integrated attempt to put in place a strategic framework with a 30-year horizon.

Other White Papers, whatever the nature of the Government who produced them, were largely concerned with catching up with prevailing conditions. They did not look to the future or the 30-year vista established in



the present White Paper, which shows that the Government is prepared to take difficult decisions and see that they are followed through. It recognises the importance of aviation in our economy and shows that we understand fully the critical balance between aviation and the environment. The strategic vision for airports includes a programme of action to ensure that key policy objectives are met.

People who would make sloppy, rather than intellectually rigorous, criticisms of the White Paper might dismiss it for taking a predict-and-provide approach. That, however, is an easy canard, as early drafts of the White Paper gave three graded demand curves on future aviation ranging from 400 to 600 million passenger movements. Total capacity will be nowhere near the higher end of that demand structure. Unless people have degrees in futurology or far-sightedness, they should not dismiss the White Paper for taking a predict-and-provide approach. That is not helpful, and we need a mature debate about the future of our air transport industry and aviation in general.

We have already had the opportunity to debate specific recommendations in the White Paper, including those on Scotland and the midlands. I should like to show where we are six months after its publication and update the House on the way in which the Government and others are developing some of its recommendations in advance of the progress report that we intend to publish in 2006. It is important that the Government hears people's views six months after the publication of the White Paper, when they have had time to reflect and resist any early knee-jerk reactions.

Our priority is to focus on realising the objectives set out in the White Paper; to ensure that the best use is made of existing airport capacity and that regional airports, where appropriate, continue to grow; and to follow up the commitment to increase capacity in the south-east of England. We have not been idle in the six months following 16 December, and work is already in hand. I shall set out what has been achieved so far and, more importantly, what we expect to happen next. I have been encouraged by the airport operators' positive response to the White Paper and their quick reactions in taking the policy forward. I hope that that will continue. I fully accept that communities close to all airports, not simply those earmarked for expansion, should have clear information about their development in the next 10, 15 or 30 years. We have asked every airport to produce a master plan by the end of the year, and we will consult on their form and timetable. Airports that will undergo lesser expansion, as well as those seeking to achieve significant increases in capacity, should explain how they might expand

and, within their region, grow in spatial and economic capacity.

The ensuing debate occupied half a day, and covered a large number of environmentally sensitive issues not least of which was noise.

Commons written answers

22 June 2004

Transport

Acoustic Barriers (M1)

Mr Robathan: To ask the Secretary of State for Transport what assessment he has made of the effectiveness of acoustic barriers on the M1 near Junction 21.

Mr Jamieson: A recent report into noise from this section of motorway confirmed that noise levels could be reduced by the installation of acoustic barriers. However, the carriageway here is nearing the time when it needs to be resurfaced and the Highways Agency considers that the use of lower noise surfacing would provide a sufficient reduction in noise levels in this location.

12 July 2004

Micro-light Aircraft

Mr. Drew: To ask the Secretary of State for Transport (a) if he will investigate the noise nuisance caused by micro-light aircraft; (b) what complaints his Department has received about noise problems caused by the operation of micro-light aircraft in rural areas.

Mr. McNulty (holding answer 13 July 2004): The Department receives very few complaints about noise nuisance from micro-light aircraft. The Government has no plans to commission specific work into noise nuisance caused by micro-light aircraft. The policy on noise from micro-lights is the same as that for other light aircraft, local solutions for local problems.

20 July 2004:

Hearing Loss

Ms Atherton: To ask the Secretary of State for Defence what research he has conducted on the comparative levels of hearing loss suffered by (a) those suffering from age-related hearing loss and (b) veterans suffering from hearing loss which is both age-related and attributable to wartime noise.

Mr. Caplin: Neither the Ministry of Defence, which is now responsible for veterans' matters, nor the former Department of Social Security, has commissioned research on this specific comparison. However, we recognise that, particularly in the past, noise injury arising from service in the Armed Forces has been a significant contributor to hearing loss among service personnel. The Government has therefore taken a close interest in the medical understanding of the causes of and prognosis for hearing loss, including instigating the 1997 Caiman review.

The current scientific understanding of noise-induced sensorineural hearing loss is that it does not get worse on removal from the noise giving rise to the injury and that, in the context of the War Pensions Scheme, hearing loss due to noise and that due to subsequent effects of age are not more than additive. The aim remains that policy and individual decisions should reflect the latest published peer reviewed scientific evidence and, to that end, we carry out a regular scrutiny of emerging relevant scientific literature.

Accuracy in predicting traffic noise levels

I refer to the article about noise from the A34 (*Acoustics Bulletin*, May/June 2004, page 40). The penultimate paragraph states planners (what, no engineers or acousticians?) predicted that noise from the road would generate no more than 60 dB. It later states that the actual levels proved to be as high as 78 dB, equivalent to a quadrupling of the traffic volume. Quadrupling traffic would produce a noise increase of 6 dB, not 18 dB.

This statement does, however, raise a further question. We can all be slightly out in predicting traffic noise levels, but by 18dB? Even substituting a concrete surface for an asphalt one, there would not be such a tremendous difference. This is, incidentally, something over which the promoting highway authority has no control, the type of surface being a choice made by the contractor for the works. The figures look as if comparisons are not being made like-for-like. Is someone confusing predictions at different distances, free-field and façade levels, or L_{10} and L_{max} levels? It would be interesting to see an explanation of the facts about the noise from this road if there is someone within the Institute able to come up with the information.

The article also raises another point regarding the Noise Insulation Regulations in that once eligibility has been decided, an unexpectedly large growth in traffic with the concomitant noise increase cannot be

a reason for reconsideration. This is not the case in Scotland or (I believe) Northern Ireland.

Under the Noise Insulation (Scotland) Regulations (*Regulation 6 and paragraph 5 of the relevant Scottish Development Department Memorandum*) insulation eligibility is reconsidered 5, 10 and 15 years after the road is first opened and, if the traffic has grown more than predicted, additional properties may be deemed eligible. This is one of the many improvements that could be incorporated into the badly-needed revision of the English Noise Insulation Regulations.

Bernard Rochester

Encyclopaedia Britannica ready reference Errors in entry for the Decibel

The entry for the decibel (dB) on the CD of *Encyclopaedia Britannica Ready Reference* reads as follows:

'One decibel (0.1 bel) is defined as 10 times the common logarithm of the power ratio and is roughly equal to the faintest audible sound. Because the scale is logarithmic, doubling the intensity means an increase of a little more than 3 dB. A 90-dB, or 9-bel, sound is 109, or 1 billion times more intense than a barely detectable sound of 1 dB. Decibels are also used to express the ratio of the magnitudes of two electric voltages or currents; in this usage 1 dB equals 20 times the common logarithm of the ratio'.

Apart from the typographical errors '... sound is 109, or one billion ...' where the 9 should be superscript ie 10^9 , and the lack of a capital 'B' in Bel, this passage contains two other errors.

1. The reference to a 'barely detectable sound of 1 dB' is not correct. In the definition of sound pressure level in dB, the reference sound pressure (corresponding to the minimum pressure that is normally audible at 1 kHz) is $20 \mu\text{Pa}$. Since the ratio of this pressure to itself is 1, it corresponds to 0 dB.

2. While it is true that any other given quantity (including voltage and current) can be given a decibel value, the statement 'in this usage 1 dB equals 20 times the common logarithm of the ratio' is incorrect also. According to the definition of sound pressure level, 1 dB corresponds to a ratio of 1.122.

A letter about these errors was sent to *Encyclopaedia Britannica* in 2003 but has not resulted in any response.

We hope that readers of the *Bulletin* will agree that these errors and the lack of response do no credit to the reputation of *Encyclopaedia Britannica*. If anyone is able to tell me of an appropriate contact, then we can follow up the opportunity to make the encyclopaedia's editorial staff aware of these errors and the existence of the IOA as a means of checking their 'acoustics' entries.

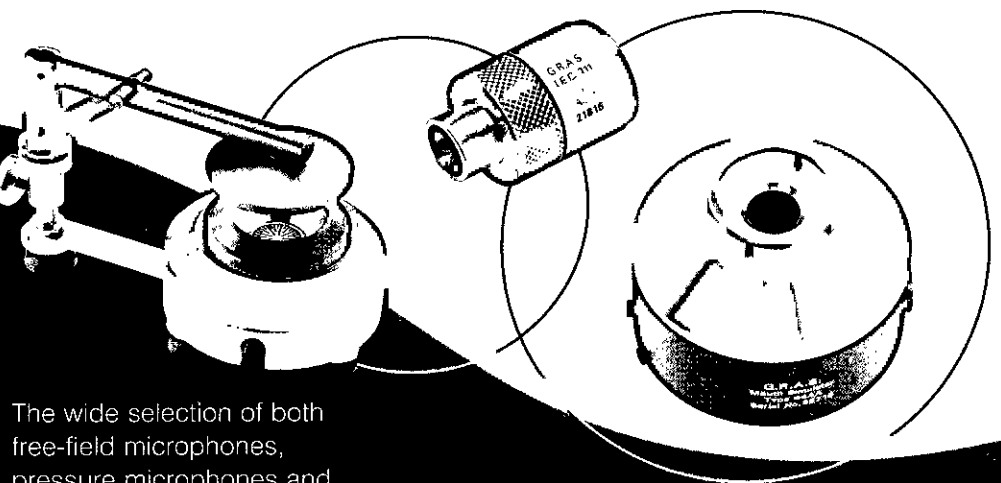
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Transforming London's South Bank

Royal Festival Hall's best and most flexible acoustics

A £90 million transformation of the Royal Festival Hall and its surroundings, now under way, will achieve the finest and most flexible concert acoustics in London, finally enabling the RFH to accommodate the full range of classical and popular contemporary music.

As Michael Lynch, chief executive of the South Bank Centre explained: "The Royal Festival Hall is a wonderful music venue, popular with musicians and audiences, but for classical music its acoustics leave room for improvement: the acoustic aspirations of its original designers were never fully realised. Now we have the opportunity to complete the job, with the benefit of twenty-first century technology and with financial support from the National Lottery and from private donors and sponsors."

The task of enhancing the acoustic has been entrusted to acoustician Larry Kirkegaard and his firm, Kirkegaard Associates of Chicago. They are working alongside Royal Festival Hall architects, Allies and Morrison, to make significant improvements to the acoustics as part of the major refurbishment of the auditorium and foyers of the 53-year-old hall. Kirkegaard Associates has developed a scheme intended to create a fine natural acoustic for classical music, while introducing facilities to accommodate popular amplified performances.

Larry Kirkegaard said: "Audiences have enjoyed great music performed by the world's most accomplished musicians. Yet most listeners have been unaware that musicians were struggling to make music in the Royal Festival Hall's profoundly unsupportive acoustic. London's audiences have not experienced the quality of performances that are possible in the world's great concert halls."

The renovation programme will achieve improvements such as:

- ☐ increased warmth and low-frequency support;
- ☐ strengthened early reflections for both performers and audience;
- ☐ increased reverberation time;
- ☐ increased loudness for listeners while avoiding excess loudness for performers;
- ☐ enriched high frequency response and reduced harshness;
- ☐ a new sense of envelopment while maintaining intimacy and presence for the audience;
- ☐ performers will be able to hear each other;
- ☐ increased responsiveness of the hall for performers;
- ☐ flexible control of reverberation and unwanted reflections for amplified performances; and
- ☐ reduced background noise to near silent levels.

There are many unseen changes, where wall and ceiling surfaces will be stiffened and made more massive in order to reduce bass absorption and achieve longer reverberation and greater envelopment. More apparent changes will be to the reconfigured concert platform and a new over-stage canopy which has been carefully designed to reflect just the right amount of sound directly to both players and listeners.

Additional acoustic flexibility will be provided with the ability to retract the woollen tapestries during classical concerts when they are acoustically detrimental, and to extend them during rock pop concerts to make the hall acoustically more 'friendly' during amplified performances. A new, quieter, more comfortable air conditioning system will be introduced to eliminate

any interfering noise that would diminish appreciation of quiet musical moments, both in live performance and in recording uses of the hall. Doors will be sealed to preclude noise passing from the foyers.

Notwithstanding its unfavourable acoustics, the Royal Festival Hall auditorium is one of the world's best-loved performing arts venues, seating up to 2,900 audience members. During its first half-century it has attracted international artists of the highest calibre from every genre of music, dance and spoken word, and works in partnership with its resident orchestras, the Philharmonia Orchestra and the London Philharmonic Orchestra, and associate ensembles, the Orchestra of the Age of Enlightenment and the London Sinfonietta.

Speaking as chief executive and artistic director of the London Philharmonic Orchestra, Timothy Walker welcomes the planned refurbishment as "a move that will place the Hall at the forefront of the world's greatest concert venues." He added that: "A particular emphasis on improving the acoustic qualities of the hall will enhance the experience for musicians and audiences, inspiring a new era in great music performances at the South Bank Centre." As David Whelton, managing director of the Philharmonia Orchestra stressed: "The South Bank Centre is home to a world class and vibrant artistic community. Refurbishment of the Royal Festival Hall will allow audiences to experience its rich programme in an environment and an acoustic that matches the quality of its performers. The Philharmonia is proud to have the Royal Festival Hall as its home and is looking forward to being part of its restoration as London's great cultural flagship."

Preserving the character

The RFH is a Grade 1 listed building of great architectural significance. Considerable care has been taken to respect the building's architectural integrity and meet conservation requirements. With support from English Heritage, Lambeth Council has granted Listed Building approval for the refurbishment of the auditorium and foyers. The character of the original 1951 auditorium will be upheld. The main work in the auditorium and foyers begins in July 2005, and the hall will re-open in January 2007. During the closure period a full arts programme will continue in Queen Elizabeth Hall, the Purcell Room and the Hayward Gallery. Work is already underway on creating a new building alongside Hungerford railway bridge to house arts facilities, arts-related shops, cafes and restaurants, and provide accommodation for staff, freeing up to 35% more space for public use in the Royal Festival Hall. Improvements are also underway on the riverside of the hall at ground level.

The project is receiving £25 million from Arts Council England Lottery funds and £19 million from the Heritage Lottery Fund. So far £9 million has been raised from trusts and private donors and from 12,000 members of the audience who have given more than £1 million. A further £19 million was raised from the London Development Agency, the Waterloo Project Board, the Cross River Partnership and commercial sources.



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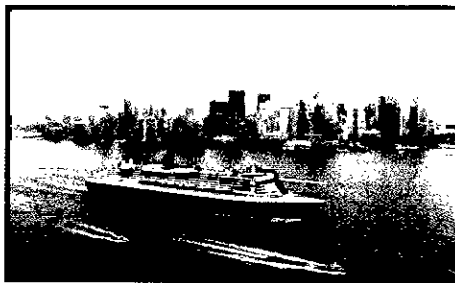


IAC Boet Stopson

QM2 flies the flag for silencers

Passengers and crew aboard the Queen Mary 2 are benefiting from a quiet environment thanks to **IAC Boet Stopson's** exhaust gas silencers that have been fitted to the two GE LM 2500+ gas turbines on the ship. Measuring 354m from stern to prow, the Queen Mary 2 is the world's largest transatlantic liner and her electricity requirements are naturally considerable. These two turbines supply energy required for the ship's propulsion as well as generating onboard electricity. Each produces 25MW of electricity, and the exhaust gas has a flow rate of 75kg/second, with a maximum temperature of 542 degC.

The silencers supplied had to adhere to strict performance criteria, both acoustically (important for a luxury ship) and aerodynamically. In addition the installation's overall weight had to be



kept to a minimum to comply with limits specified in the contract.

Malcolm Hewitt, IAC's sales manager (industrial), said that passenger liners as well as naval vessels and military ocean-going craft had long been a strong market for the group. This QM2 project was actually undertaken by French subsidiary, IAC Boet Stopson, which leads the silencers market in that country.

For more information on IAC silencers and other noise control technology visit www.iacl.co.uk or email malcolmh@iacl.co.uk

Phoenix Inspection Systems

Assisting the Prestige clean-up

Phoenix Inspection Systems is taking part in a pioneering project to recover oil from the tanker *Prestige*, which sank off the coast of Spain in autumn 2002.

The company has achieved a world first in creating transducers that can carry out reliable ultrasonic testing at 4,000 meters below sea level, the depth at which the *Prestige* lies on the seabed. The transducers, along with the other equipment, have been operating under a demanding workload in extreme conditions as part of a recovery project due for completion by the end of this summer.

The *Prestige* was carrying around 70,000 tonnes of oil when it sank and some 13,800 tonnes remain in the hull. The recovery operation - described as 'environmental science's moon shot' by one journalist - is designed to prevent any further environmental damage. The underwater engineering and operations company Sonsub, is the main contractor to Repsol YPF, which was appointed by the Spanish government to design, develop and manage the recovery project.

Working from their survey ship, the *Polar Prince*, positioned above the wreckage, Sonsub sent down remotely operated vehicles (ROVs), initially to carry out ultrasonic scans of the *Prestige's* deck, and later to drill through and position valves. During the next phase, the valves were opened to release the oil,

which rises upwards and is captured in 300-ton shuttle tanks in the same manner that a balloon captures hot air.

ROVs have only recently been able to operate at such depths and Sonsub upgraded models specifically for this purpose. It commissioned Phoenix to design probes which could be mounted on the robots and operate in the same exacting conditions.

John Turner, Phoenix's special projects manager explains: "Ultrasonic testing is a crucial part of the recovery operation as it reveals the best places to drill. The ship's deck was strengthened by metal beams running along the underside. These have to be located by ultrasonic sensors since the valves have to be sited carefully between them."

Inspection results can be analysed in real time as data is fed back through the umbilical cord which links the robot to the ship above. At the same time, a video camera on the front of the ROV feeds back live views of the whole operation.

John Turner added: "The biggest problem was designing transducers that could withstand the tremendous pressure which, at 4,000m underwater, is equivalent to 400 bar or 6,000 lb per square inch. We believe it is the first time that ultrasonic transducers have successfully operated at this depth. The devices had to be proven to operate at 500 bar, and we know that the concept is good for 650 bar or more."

For more information: tel +44 (0)1925 826000 or see www.phoenixisl.co.uk

Frogbox Company

Retail system noise control

With the development of a unique patented acoustic enclosure system, **The Frogbox Company (UK)** claims to have overcome the problem of noise pollution associated with refrigeration and air conditioning equipment. Designed for convenience stores and forecourt retailing applications, the system also offers a cost-effective housing solution for a wide range of noise generating equipment.

The industry approved system achieves significant noise reductions in comparison with other solutions for refrigeration and air conditioning equipment. The enclosure has been tested to noise levels of below 30dB(A) at 10m, meeting the most stringent local authority requirements. Where visual appearance is a consideration, it can be camouflaged in a range of finishes including mock brickwork.

The enclosure, which is robust and weatherproof for outdoor installation, also incorporates secure locks on service access panels to prevent tampering and vandalism. The modular design means it can be tailored to meet specific application requirements. For locations where available space is at a premium, the compact service footprint offers considerable space saving over traditional indoor plant rooms and other remote equipment solutions, allowing greater scope for valuable storage space.

The enclosure's internal configuration provides a stable environment, optimising temperature and airflow efficiencies for condensing equipment and air conditioning units, whilst promoting energy efficiency and increasing the equipment's service life.

For more information: tel: 01622 772433 fax: 01622 772434 or visit www.frogbox.co.uk



Sound Reduction Systems

Maxiboard maintains a healthy level of peace and quiet

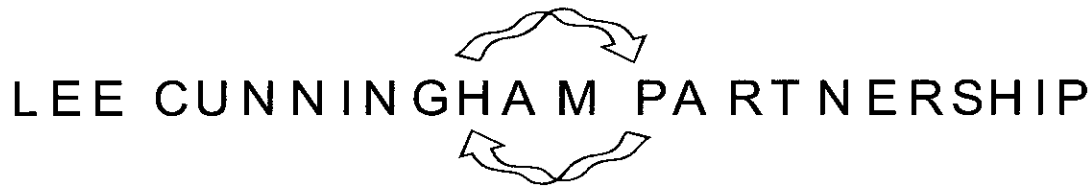
Making sure students and researchers are not distracted by external noises was a key priority for a recent installation using **Sound Reduction System's** multi-purpose acoustic building board, *Maxiboard*.

Dry lining and suspended ceiling specialists Quad Building Services (Southern) Ltd used the board as an integral part of the internal skin of the cladding on a new

building for the London School of Medicine in Whitechapel. On a job of some 10,000 square metres, the product has been used to reduce sound transmission through the walls separating new laboratories, lecture theatres and observation decks, and further to enclose noisy machinery including generators. Significantly, it has also been used in outside walls to exclude

unwelcome sound, such as helicopters landing and taking off from the adjoining Royal London Hospital. Maxiboard is suitable for use wherever the passage of sound needs to be attenuated, and at only 17mm thick offers maximum performance for minimum thickness.

Further details: tel: 01204 380074 email info@soundreduction.co.uk or visit www.soundreduction.co.uk



The **Lee Cunningham Partnership**, is a small friendly practice currently looking to increase its design team with the addition of two acoustic consultants.

The practice specialises in a diverse range of disciplines, including the following areas of expertise:

- Environmental Noise & Planning Assessments
- Building Acoustics
- Mechanical Services Acoustics
- Architectural Acoustics

The practice has developed a loyal and expanding client base, with a computerised in-house business management system developed over the past ten years. In order to maintain the current standards of good service provided to our clients, we are seeking to recruit the following personnel:

Experienced Acoustic Consultant (circa £40k)

The candidate having a minimum of 5 years experience, shall be a member of the Institute of Acoustics, and qualified to Degree or HND standard, either in mechanical engineering or an appropriate acoustic related subject.

The successful applicant shall be self-motivated and will be expected to run projects, undertake surveys and prepare reports.

Trainee Acoustic Consultant circa (£22k)

The candidate shall be dynamic with good communication skills, and qualified to Degree or HND standard either in mechanical engineering, or an appropriate acoustic related subject.

The challenging job role will include environmental noise monitoring, field-testing, and shall provide general technical support to the consultant team. Previous experience is not essential since training will be provided, and an option will be given after the completion of 1 year, to undertake the MSc course "Acoustic & Noise Control".

oo00oo

Applicants for either position will need to be proficient in the use of Microsoft software including, *Word*, *Excel* and *Coral Draw*. In addition, the successful candidate will be required to travel throughout the UK and a full driving license is therefore essential.

The salary and benefits package offered for both positions is negotiable, commensurate with age, qualification and experience.

Applications should be sent to Martyn Cashmore, accompanied with a detailed CV, and addressed to:

Lee Cunningham Partnership Ltd
Parkside House, 258 Shinfield Road, Reading, Berkshire, RG2 8EY
Tel 0118 987 9300. Fax 0118 987 9320.

Casella CEL**New technology removes range adjustment errors in acoustic measurement**

The latest technology developments from **Casella CEL** are playing a significant role in eliminating the most common cause of acoustic measurement errors - range adjustments.

The new 400 series of competitively priced sound monitors that offer real time frequency analysis and a new software package have a single measurement range of 140dB to remove range adjustment problems. Simultaneous measurement reduces measurement time and associated cost while ensuring a high standard of data. Designed for ease of use, the **CEL-450** incorporates the latest technology, bringing real time frequency analysis to the work place for hearing protection assessment, while the **CEL-490**, with its emphasis on environmental monitoring and community noise investigations, measures all necessary statistical parameters, even in frequency modes.

Both of these point-and-shoot logging instruments with an easy to use menu structure greatly reduce analysis time



through the production of a time history of the noise levels at selectable time intervals, as well as real time frequency analysis. As both of the products are upgradable, a customer can buy for current needs knowing that the instrument can be changed to meet future requirements. The new dB23 software incorporates a full graphics package and extensive reporting capabilities, giving quick and easy access to data in an intuitive system.

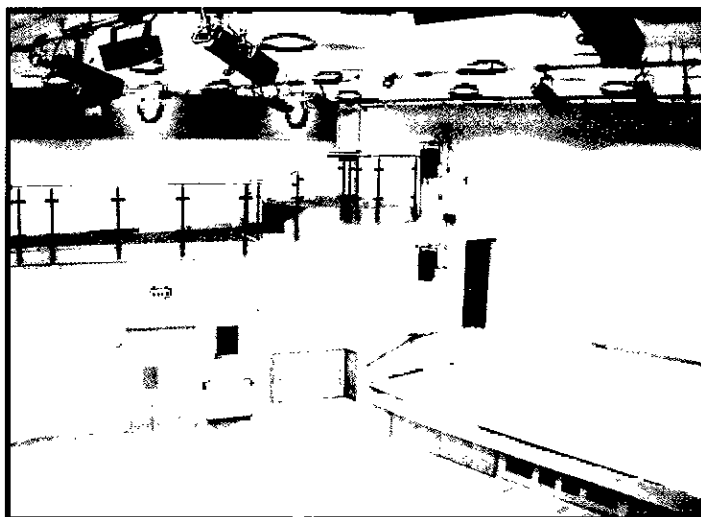
Further details: Rebecca Williams, tel 01234 844100 fax 01234 841490
email rebeccawilliams@casellagroup.com

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and his e-mail address is
dbioa@hotmail.com**

**Autograph Sales
Equips UK schools**

Professional audio distributor **Autograph Sales** has supplied a wide range of equipment to some of the UK's leading education centres, including Dauntsey's School in Wiltshire, which specialises in music and drama performance.

The company first supplied and installed an extensive sound and communications system three years ago. This included various Meyer Sound loudspeakers, AKG radio microphones, a Clear-Com communications system and an HSA Rolltop desk, which houses an Allen & Heath GL3300 mixing console. A further quantity of AKG radio microphones was added in the summer of 2001.

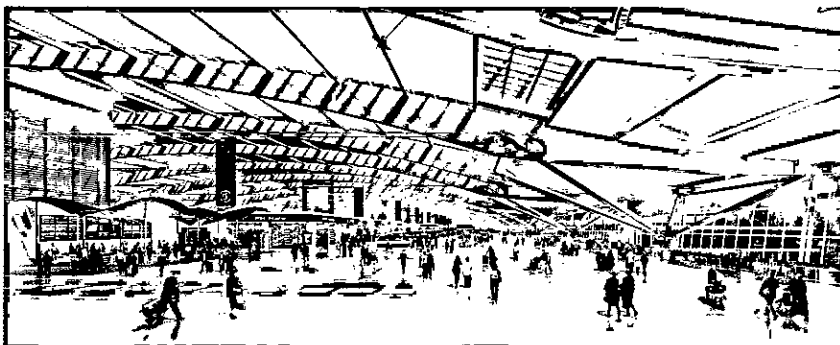
Director of Music, Chris Thompson, returned in June 2004 seeking to extend his radio microphone system. Autograph

Battersea, has also received some sound advice from the Autograph Group. Architect David Self, the creative force behind a new theatre at the school, wanted a high quality sound system to compliment his plans. He originally approached Lee Dennison, who works for the rental division, **Autograph Sound Recording**.

After many hours working on a sound system, Lee specified a range of audio equipment including various Meyer Sound cabinets, XTA DP224 crossovers, and an Allen & Heath GL3300 mixing console coupled with a Sennheiser UHF radio microphone system.

In addition, Kings House School in Richmond recently bought a Sennheiser wireless microphone system, while the Royal Scottish Academy of Music & Drama in Scotland is now enjoying the benefits of Clear-Com wireless communications.

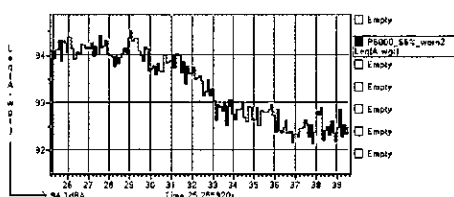
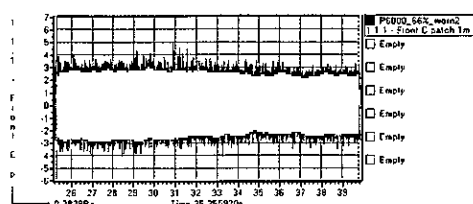
Further details: www.autograph.co.uk

**IAC****Controls noise at Heathrow Terminal 5**

A large HVAC attenuation contract from the British Airports Authority, for London Heathrow's Terminal 5, has been secured by **IAC**. From a starting value of £14m, as the construction project progresses, the design and scope of works are also increasing. Currently Europe's biggest construction project, the terminal will open in 2008. Dubbed an engineering masterpiece worthy of history's greatest, the terminal will be the largest single span building in the UK, with a roof 39 metres high and a total floor space equivalent to 50 football pitches! That means

a great deal of air conditioning plant. **IAC** is providing a range of noise attenuation solutions for the new terminal, such as acoustic panels and louvres around the plant rooms, and HVAC attenuators to reduce noise from air conditioning systems throughout the main concourses. A number of the HVAC plant rooms are 30m below ground level in the basement while the 'concourse chimneys' positioned throughout the large interior spaces bring conditioned air to the main public areas.

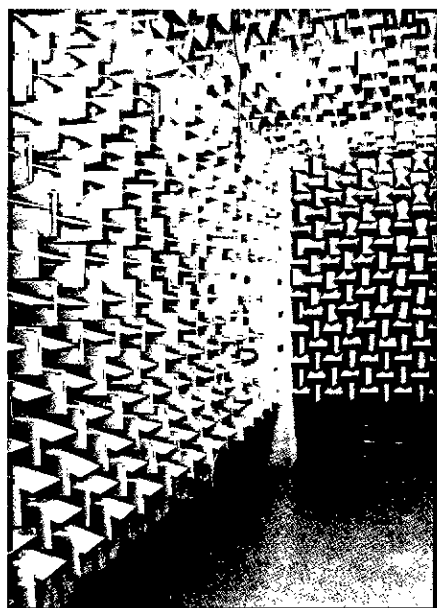
For further information: Gary Dawson, Business Manager on 01962 873059 or email garyd@iac.co.uk
<http://www.iac.co.uk>



Bay Systems

nVision Leq

Release 5 of *nVision*, the desktop noise and vibration analysis system with more than 300 currently installed worldwide, will be available this autumn (2004). The new release adds the L_{eq} weighting function and the noise exposure calculator to the system's standard features. The L_{eq} weighting will be included free of charge for all supported and warranty customers.



The new, simple to use, module enables time data set to be mapped for both A_{wt} and L_{eq} levels. Input data can be accepted from many different sources including PCScan and the new Sony EX multi-channel acquisition system. Easy access to the module should make it an attractive option for anyone wishing to use L_{eq} values to minimise noise exposure.

A total noise exposure calculator is also offered to make the job of calculating the overall exposure straightforward.

Semi-anechoic chamber

Regulatory pressure on reducing radiated sound power for all products is an additional cost and a potential benefit for companies. Provision of facilities suitable for measurement of sound power and simpler rooms that are quiet enough for diagnosis of problems and product benchmarking have always been expensive. Bay Systems has now designed and built four semi-anechoic rooms for educational and commercial companies in a variety of situations and on very tight budgets. The most recent project is pictured here at the stage of wedge installation. The chamber achieved the following performance: noise isolation from outside to inside: 68dB; reverberation time 50ms $\pm$ 10 from 200Hz to 12.5kHz. Further details: Alan Bennetts, tel: 01 458 860 393; fax: 01 458 860 693; mob: 07836 230 475 email: alan@baysystems.ltd.uk

Pure Distribution

Melua opts for Audix quality

Pure Distribution, a division of Stirling Audio, who became UK distributor for Audix microphones earlier this year, has supplied a number of VX-10 vocal condenser microphones to Katie Melua, one of Britain's hottest contemporary jazz artists. With a frequency range of 40-20kHz and being highly sensitive, it is able to reproduce vocals and speech with exceptional detail and realism, perfect for Katie's extreme vocal presence. Katie's sound engineer Matt Manasse requested Audix for her tour, after previously using its range of percussion microphones. After being sent a selection of vocal mics, Matt determined that the VX-10 was perfectly suited to her vocal style, handling everything from a whisper to a scream.



Autograph Sound Recording

Globetrotting with the shows

Theatre specialist **Autograph Sound Recording**, which recently celebrated 30 years of sound design and rental supply, has truly gone international, currently supplying or about to supply, large scale theatre productions in Athens, Berlin, Utrecht, Stuttgart, Madrid, Moscow and Tokyo. Having just designed the new *Miss Saigon* UK tour, the company's Nick Lidster, is now in Tokyo working on another new production of this popular musical, which opened in mid-August at the Imperial Theatre. Supplying the equipment for this Japanese version demonstrates how successfully the company has expanded its global market.

Another hit show to make use of Autograph's sound design and rental expertise is *Mamma Mia!* With one production already in full flow at Utrecht's Beatrix Theatre, the recent opening at Stuttgart's Palladium Theatre has added another European city to the list and in the pipeline is Madrid's Lope de Vega Theatre. Autograph is also supplying the International tour of *Mamma Mia!* that goes on the road this month (September). The show opens in Dublin at The Point, before moving to The Edinburgh Playhouse and embarking on a tour that will take it outside the UK and into many far-flung territories. Yet more international work comes via *We Will Rock You* - the company is supplying the new production of the Queen musical opening in Moscow in October.

For more information visit:
www.autograph.co.uk

PEOPLE NEWS

IAC expands industrial power sales operations

As part of an extensive growth programme, noise control specialist IAC of Winchester has recently expanded its Industrial Power team. Two new managers appointed to head up the UK operation will further fuel inroads being made into the UK market of silencers manufactured by IAC Boet Stopson, the group's French subsidiary and market leader in that country.

Through his new role as Business Development Manager - Power Products, **Gordon David** brings to IAC over 25 years' experience of the noise control market. In fact it is a 'welcome back' to Gordon, who spent 17 years with the company from 1980 to 1997. During his spell away he held sales director positions at IAC's major competitors, Sound Attenuators and Systems to Silence. In this last position he doubled sales turnover, developed a blue chip customer base and secured valuable partnership agreements in both the UK and the Middle East.

Well known in the industry, a strong team leader, and with unrivalled knowledge of the

sector, Gordon has ambitious plans for the new IAC Acoustic Container and Canopy product range, as well as for IAC Boet Stopson silencers in the UK. He has already clinched over £1m of new business since his return.

Malcolm Hewitt, who has been appointed Manager - Industrial Silencers, joins IAC from industry rival Industrial Marine Silencers, where he spearheaded a tripling of sales turnover in six years, with a high percentage of that in export sales. He has been involved in the industrial silencer market for over 13 years and has a strong background in application engineering across filtration, heavy automotive and industrial products.

Ted Mangan has joined IAC Ltd as Area Sales Manager, being responsible for developing Building Services business in the South West, handling sales of the company's wide range of acoustic products. Ted, who is a longstanding member of the Institute of Acoustics, is a well-respected figure in the acoustics industry and has a wealth of experience in the field of noise and vibration control in addition to his technical specification expertise. He joins IAC from AAT and previously spent 14 years with Sound Attenuators.

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Institute Diary 2004

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30 September Executive St Albans	20 October Publications Committee St Albans	25 November Medals & Awards & Executive St Albans
6-7 October Autumn Conference Sound 20	26 October Research Co-ordination London	7 December CCWPNA Examiners & Committee St Albans
8-9 October Reproduced	28 October Membership St Albans	9 December Council St Albans
14 October Council St Albans	9 November CCENM Examiners & Committee	

Noise Research Strategies for a Quieter Europe

This CALM conference takes place at MCE (Management Centre Europe) in **Brussels** on **19 October 2004**

The conference aims to present results of the CALM network to the general public and increase the awareness of environmental noise and related research. The programme will include the following sessions: Hot topics of environmental noise; CALM - the noise research strategy plan; Implementation plans of European research advisory councils; and National contributions to the European research area. No conference fee but registration required. Visit www.calm-network.com

Note: CALM is a thematic network within the 5th Framework Programme of the European Commission.

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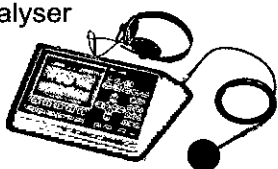


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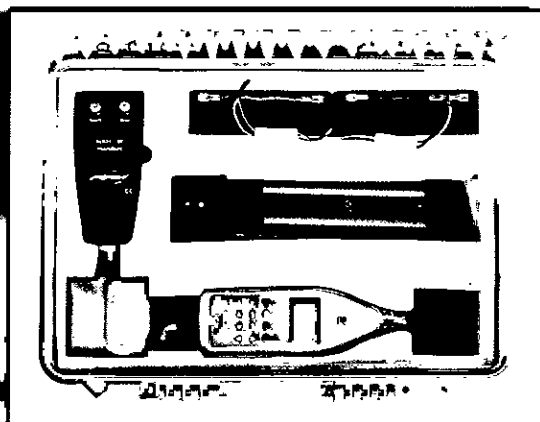
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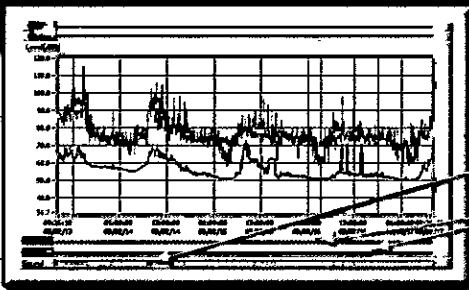
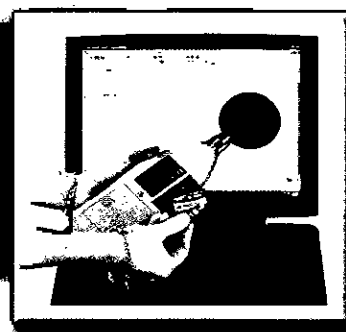
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