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From the President

Noise Created By Moon Orbiting Earth Found To Breach Acceptable Limits!

Ok, so that was a bit of a misleading headline, but it obviously got your attention, which I hope will be the consistent theme of these messages during my time as president. First of all, I'm very excited about becoming president. There's a genuine buzz around the industry at the moment – you can hear it can't you – and my goal is to inject some of that into this column over the next few issues to give you a sense of what's hot and happening in the industry right now.

You all know that Acoustics Australia is a splendid journal with a stellar reputation, but in the course of my work I've had my ear to the ground, and have been feeling a lot of vibrations that many of you would enjoy some lighter content about our industry – why should gossip columnists in magazines and newspapers have all the fun? So while I'm around I'm going to try and dig up as many interesting or amusing stories about our profession as I can (or you can email to me). Hopefully some of them will contain a few rich pearls of wisdom for us all.

This is also the right time to say a big thankyou from all of the members to the editorial team (Neville, Marion and Joseph) for their hard work and dedication in producing the journal.

So I can hear you all wondering who on earth is Neil Gross and how did he become president? Well I became president because of an upset stomach – at the National Council meeting I ducked out to go to the bathroom and when I got back discovered I'd been voted in – there's a lesson there for all of us – stay in your seat! I would also like to take this opportunity to thank Ken Mikl for his work as president over the last 2 years. The society has been gaining momentum in this period and Ken's energy is a big part of the growth, particularly in securing the ICA conference in 2010.

My career started in the UK where I studied mechanical engineering, completed a Masters in Acoustics through a research project and then worked in consulting for a few years. I first set foot in Australia in 1991 and was immediately hooked. My first job here was with a brilliant, enigmatic firm called Wilkinson Murray. At the time they were one of the few consultancies in Australia to recognise true genius, but times were hard and they gave me employment. Because I am terrible in job interviews I decided to stay with WM where I am now one of three directors.

Naturally, since my background in acoustics is almost entirely consultancy based I am keen to encourage membership growth in this area, that doesn't mean I'm not going to be gunning for a broad range of activities in the society – I think it's critical that we have as diverse a range of membership as possible. You should remember there are 13 "fields of interests" which you can select from in the annual review, so I'm keen to hear (now) from any members in each of these fields, eager to promote further discussion amongst members with common interests. Just send me an email (president@acoustics.asn.au) and we'll try and get something started.

So with the introductions out of the way, let's get back to that industry buzz. As those of you who were there already know, the recent AAS conference in the Gold Coast was a corker, with spectacularly high attendance and heaps of excellent papers. The conference dinner was a great event attended by over 240 people. A big thanks to the organisers and also the presenters for making it such a success.

I have found my membership of AAS and my role on both the NSW and National committee has allowed me to meet most people practicing in acoustics. I am convinced that any sort of collaboration is positive for our profession, given how specialised and relatively small it is in Australia. Being able to put a face to a name, get advice from your peers, share knowledge or equipment can only really occur if people get together on a regular basis and take part in Society functions. You know what they say, knowledge is power so let's all keep on sharing as often as possible because if we are perceived as a profession where reasonable consistency in advice is given and practical solutions or compromise can be found, the whole profession gains respect which will be beneficial for all of us. And speaking of sharing, don't forget, if you have any great stories and anecdotes that you want to share then let me know.

Neil Gross

From the Editor

This issue of *Acoustics Australia* is the last to be produced by the present editorial team in Canberra. Our journal has a long and proud history, from the time it was established in 1972 as the *Bulletin of the Australian Acoustical Society* with an editorial team based in Melbourne. In 1982 the *Bulletin* editorial headquarters moved to Sydney and Howard Pollard took over as Editor, with Marion Burgess, who had also been involved in the early stages of the journal, as Associate Editor, and a new higher-quality format. In 1985 the title was changed to *Acoustics Australia.* Howard and Marion continued to edit the journal until 1993 when Howard retired as Editor and a new editorial committee, Neville Fletcher, Joseph Lai and Marion Burgess, was established in Canberra. So now, after twelve years of editing the journal, we are preparing to hand over to a new team based at the University of New South Wales in Sydney and under the Editorship of Joe Wolfe from the School of Physics. The other members of this group are John Smith, also from the School of Physics, and Emery Schubert from the Department of Music and Music Education. Marion has agreed to continue editing the News and Notes section of the journal for a transition period.

Editing the journal is, of course, only part of the task. Joseph Lai has kept careful track of our finances, and we have had an excellent business manager in Leigh Wallbank and a highly efficient production team at Cronulla Printing under Scott Williams, all these arrangements having been inherited from the previous committee under Howard Pollard. Although Cronulla Printing has now merged with Cliff Lewis Printing in Caringbah, all the production arrangements remain essentially unaltered. We are immensely grateful for the help of Leigh and Scott over the years.

Looking back over our time at the helm, it is clear that we inherited a journal that already had a well established editorial reputation and production format, and we hope that we have enhanced the interest and status of the journal while it has been under our care. In accord with international practice, the papers published in *Acoustics Australia* have always been formally peer-reviewed. We do not aim, however, to be a "primary research journal" but rather to concentrate on publishing material that is of interest and importance to the Australian acoustics community. With this in mind we also regularly publish less formal articles, comments and news items. We hope that we have achieved a balance that is attractive to members of the Society.

Now, as we pass the baton on to Joe and his team, we wish them all the best. While editing a journal is often hard work, and deadlines loom with distressing regularity, it has been a source of great satisfaction to all of us to have continued the tradition. We wish Joe, John and Emery all the best in the years to come, and hope that they enjoy the work as much as we have done.

Neville Fletcher
Joseph Lai
Marion Burgess

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VISUALIZATION/AURALIZATION OF SOUND FIELDS FOR ROOM ACOUSTICS*

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ABSTRACT: The first step of architectural and acoustical design of a concert-hall/theatre is to choose the fundamental room shape. Secondarily, the shapes of walls and ceiling are designed so as to realize proper reflections and diffused (blended) sound field. As a basic study to investigate these points, 2-dimensional numerical analyses by the finite difference time domain (FDTD) method were performed for typical room shapes, rectangular, fan-shaped, elliptic, etc., with and without diffusive room boundaries. In this presentation, the differences of sound wave propagation and sound diffusivity in the rooms with different shapes and diffusion treatments are visualized by computer animation and the room impulse responses are compared by auralization technique. A new idea to simulate a sound field by combining the FDTD calculation and 4-channel reproduction system is also introduced.

1. INTRODUCTION

The first step of architectural design of concert halls and theatres is to decide the basic room shape. As the basic room shapes, rectangular, horseshoe-shaped, fan-shaped, hexagonal, circular, semi-circular, and elliptic shapes are generally taken. Among them, rectangular shape is often used for classical concert halls represented by Musikvereinssaal in Vienna. Horseshoe-shaped, circular, semi-circular and fan-shaped types are often used for theatres. Elliptic shape is also often used for various kinds of halls. By the differences of such room shapes, the sound propagation characteristics should be much different.

As the second step, the shape of the wall and ceiling is considered. Usually, they are designed irregular to make the sound in the rooms diffused (blended). These room shape design works are very essential in architectural design not only from aesthetic viewpoint but also acoustical viewpoint.

In the author's laboratory, such fundamental studies on acoustical design of halls have been performed using scale modeling and computer simulation techniques. In this paper, some examples of basic investigations made by visual and aural simulation techniques using finite difference time domain (FDTD) method are presented. (In the aural presentation, these results are demonstrated by computer animation and auralization techniques.)

2. NUMERICAL SIMULATION BY FDTD METHOD

Calculation by FDTD Method.

For the purposes of sound field analysis and visualization of room acoustics, such computer simulation techniques as ray-tracing and image-source methods have been developed and being widely used. This kind of techniques based on geometrical acoustics are effective for rough estimation of sound reflection and absorption in a room but it is impossible to exactly deal with such complicated phenomena as sound reflection, diffraction and scattering. To overcome this problem, the "Finite Difference Time Domain (FDTD) method" [1,2] to transient acoustic phenomena has been investigating in the author's laboratory [4-11]. The outline of this calculation method for 2-dimensional space is as follows.

In a 2-dimensional sound field, the sound wave is expressed by the following partial differential equations. Equations (1) and (2) are the momentum equations in x- and y-directions, respectively, and Eq. (3) is the continuity equation.

$$\frac{\partial p(x,y,t)}{\partial x}+\rho\frac{\partial u_x(x,y,t)}{\partial t}=0 \tag{1}$$

$$\frac{\partial p(x,y,t)}{\partial y}+\rho\frac{\partial u_y(x,y,t)}{\partial t}=0 \tag{2}$$

$$\frac{\partial p(x,y,t)}{\partial t}+\kappa\left(\frac{\partial u_x(x,y,t)}{\partial x}+\frac{\partial u_y(x,y,t)}{\partial y}\right)=0 \tag{3}$$

where p is the sound pressure, u_x and u_y are the particle velocities in x- and y-directions, respectively, ρ is the density of the air and κ is the volume elastic modulus of the air.

By expressing these equations in the central finite difference forms by applying a staggered grid system with square-grids ($\Delta_x = \Delta_y$, see Fig.1), the following equations are obtained.

$$u_x^{n+1}(i+1/2\,,j)=u_x^{n}(i+1/2\,,j)-\frac{\Delta t}{\rho\Delta h}\left\{p^{n+1/2}(i+1,j)-p^{n+1/2}(i,j)\right\} \tag{4}$$

$$u_y^{n+1}(i,j+1/2)=u_y^{n}(i,j+1/2)-\frac{\Delta t}{\rho\Delta h}\left\{p^{n+1/2}(i,j+1)-p^{n+1/2}(i,j)\right\} \tag{5}$$

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$$p^{n+1/2}(i,j) = p^{n-1/2}(i,j) - \kappa\Delta t \left\{ \frac{u_x^n(i+1/2,j) - u_x^n(i-1/2,j)}{\Delta h} + \frac{u_y^n(i,j+1/2) - u_y^n(i,j-1/2)}{\Delta h} \right\} \quad (6)$$

where Δh is the size of the square-grid and indices n, n+1/2, n-1/2 and n+1 denote time steps. In the calculations mentioned below, Δh=1 cm for the spatial grid size and Δt=0.02 ms for the discrete time step were set.

As the initial condition assuming an impulse source, a smoothly continuous distribution of sound pressure described by the following equation was set (see Fig. 2).

$$p(r) = \begin{cases} 1 + \cos \pi \dfrac{r}{12\Delta h} & (r < 12\Delta h) \\ 0 & (r > 12\Delta h) \end{cases} \quad (7)$$

where r is the distance of a grid point from the source position.

Based on the assumption that the boundary is locally reactive, the normal component of the particle velocity on the boundary is expressed as follows.

$$u_n\big|_{boundary} = \frac{p}{Z_n} \quad (8)$$

where $u_n\big|_{boundary}$ is the normal component of the particle velocity on the boundary, is the sound pressure and Z_n is the normal acoustic impedance on the boundary. Here, by assuming that a part of the boundary is approximated by the two sides of a square-grid as shown in Fig.3 and p can be represented by the sound pressure at the center point of the square-grid $p(M,N)$, the following expressions are derived for the x- and y-components of the particle velocity on the boundary.

$$u_x^{n+1}(M+1/2, N) = \frac{p^{n+1/2}(M,N)}{Z_n} n_x \quad (9)$$

$$u_y^{n+1}(M, N+1/2) = \frac{p^{n+1/2}(M,N)}{Z_n} n_y \quad (10)$$

where n_x and n_y are the x- and y-components of the unit vector normal to the boundary under consideration.

To simplify the problem, it was assumed that the normal acoustic impedance on the boundary consists only of real part in this study. In this case, the relationship between the normal acoustic impedance Z_n and the normal sound absorption coefficient α_n is expressed as follows.

$$Z_n = \rho c \frac{1 + \sqrt{1 - \alpha_n}}{1 - \sqrt{1 - \alpha_n}} \quad (11)$$

In the calculation mentioned below, it is assumed that α_n=0.2 (corresponding to Z_n=7357 Ns/m^3) for over all frequencies to simplify the boundary condition. Under these initial and boundary conditions, the sound pressure and particle velocities at each grid point were calculated successively using Eqs. (4), (5), and (6).

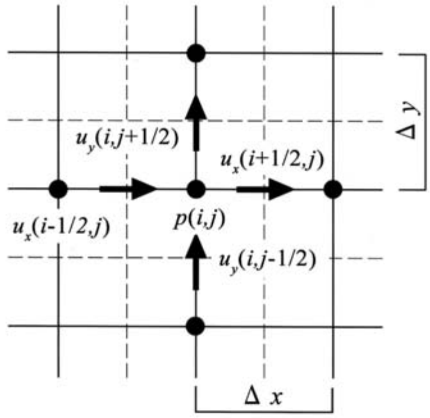

Fig.1 Discretization of the sound field by staggered meshes.

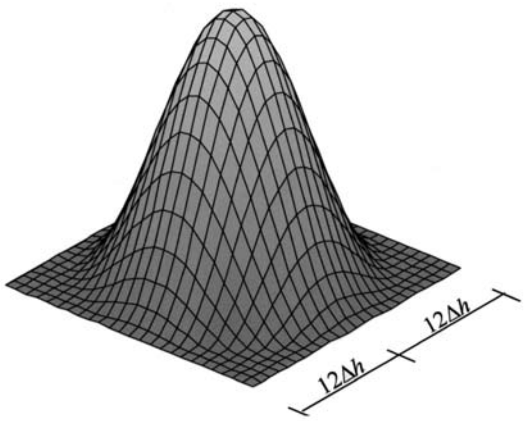

Fig.2 Sound pressure distribution around the source position as the initial condition of calculation

Visualization of Sound Propagation in Rooms.

As the typical room shapes for concert halls and theatres, rectangle (so called "shoe-box style"), fan-shape and ellipse were chosen and the sound propagation characteristics in these 2-dimensional rooms with the same area of 518.4 m^2 were examined by the FDTD method. The left hand sides of Fig.5 show the calculation results in the form of "snap shot" in the time lapse after the emission of the impulse source. (When demonstrating the results by computer animation, the successive propagation of the wave front of the impulse can be clearly visualized.) In each figure, the black circle indicates the source position and the white one indicates the receiving position for the calculation of impulse response mentioned later.

Comparison of these figures reveals that the propagation of the wave front is much different in each room shape. In the rectangular room, it is clearly seen that the number of wave front increases with the progress of time, whereas in the fan-shaped and elliptic rooms, a tendency that the wave front deflects and concentrates is seen. Especially, in the elliptic room, it is clearly seen the wave front focuses at around the source position and its symmetrical point alternately.

The impulse responses at the receiving point in each room are shown in Fig.6 (a). In these results, it is seen that the

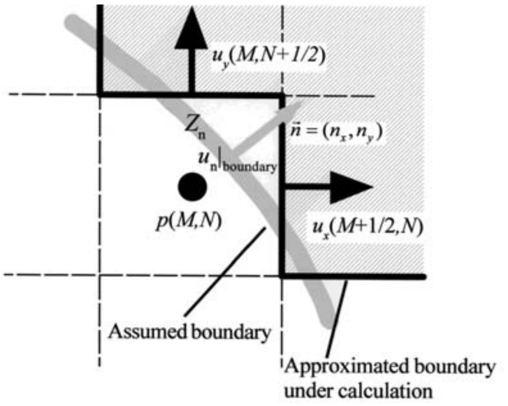

Fig.3 Discretization of the sound field near the room boundary

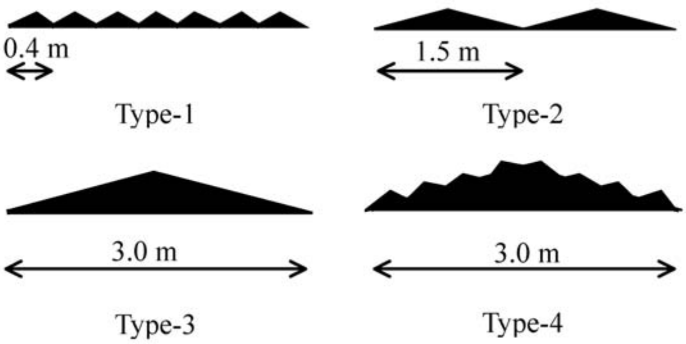

Fig.4 Shapes of diffusers under investigation

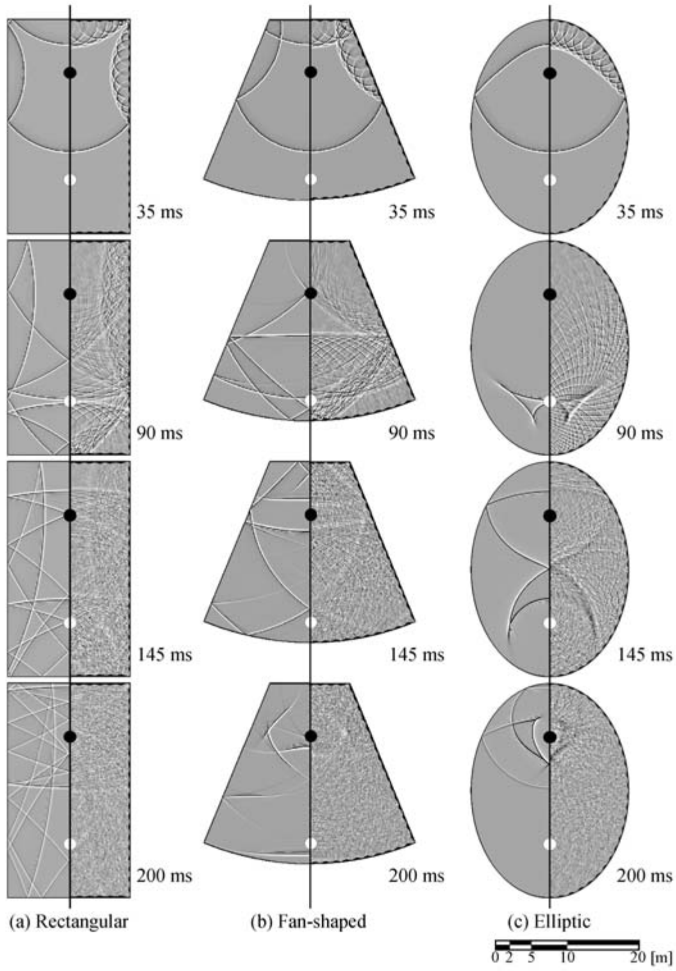

Fig. 5 Sound propagation in a rectangular (a), fan-shaped (b) and elliptic (c) rooms without diffusing treatment (left hand side) and with that (right hand side)

reflections are dense and smoothly diminishing in the rectangular room, whereas they are scattered and uneven in the fan-shaped and the elliptic rooms.

Basic Study on the Effect of Sound scattering by diffusers.

In concert halls and theatres, wall and ceiling are generally made irregular to increase sound diffusivity. To examine the effect of such diffusion treatments, the FDTD calculation was again performed for the three types of rooms by making their walls irregular. As the shape of irregular wall, a zigzag shape (Type-2 in Fig.4) was assumed. The snap shots of the calculation results are shown in the right hand sides of Fig. 5. By comparing the results with those in the case of no diffusion treatment shown in the left hand sides of Fig. 5, it is clearly seen that the distinct wave fronts have been much diminished and scattered in all of the three rooms.

The impulse responses at the receiving points in the three rooms were calculated in this case, too. The results are shown in Fig. 6(b) in comparison with those without diffusion treatment shown in Fig. 6(a). In these results, it is obviously seen that the impulse responses have become much denser and smoother than the case of without diffusion treatment. When hearing these impulse responses through a loudspeakers or headphones, it can be clearly judged that the reverberation decays have much improved to be natural and smooth by the diffusion treatment, although the early fluttering sounds caused by the sound concentration are still slightly remaining in the cases of the fan-shaped and elliptic rooms. This fact indicates that the general tendency of sound concentration caused by the fundamental room shape can not be prevented completely by this kind of diffusion treatment on the room boundaries.

In order to examine the effect of sound scattering by diffusers in more detail, a further study was performed on the rectangular room. In this study, four kinds of zigzag shapes shown in Fig. 4 were assumed. Among them, Type-1, Type-2 and Type-3 are similar in shape but the size was varied in three steps. The ratio of the height of the apex to the width of a triangle was set 0.15. Type-4 is a “two-way” diffuser composed of Type-3 and Type-1.

Figure 7 shows the calculation results. To compare these results with those in the case of no diffusion treatment shown in the left hand sides of Fig. 5, it is clearly seen that the sound is scattered after the first reflection on the diffusive boundaries and the space is filled with sound pressure fluctuation. In the results for Type-1, Type-2 and Type-3, it is seen that the scattering effect is dependent on the size of the diffusers. That is, in the case of Type-1, relatively strong and continuous wave fronts are still remaining, whereas they are much diminished in the case of Type-3. In the result for Type-4, the effectiveness of “two-way” diffuser can be observed.

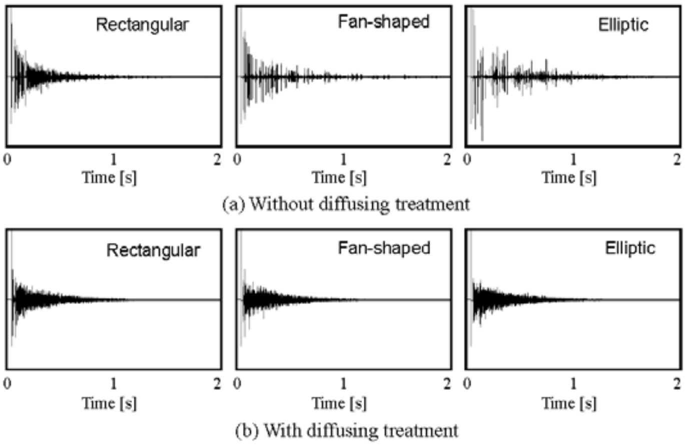

Fig.6 Calculation results of impulse responses at the receiving points shown in Fig.5.

In the calculation by the FDTD method, instantaneous sound pressure at every mesh point is obtained. By squaring the sound pressure, instantaneous potential energy distribution in the room can be obtained and consequently the time variation of acoustic diffusivity in the room can be evaluated quantitatively from a viewpoint of the spatial uniformity of sound energy [11].

The Effect of Sound Diffusing Treatment in an Elliptic Hall.

In the acoustic design of the Small Hall in the Kiryu City Hall, in Japan, we had a chance to apply the numerical simulation technique using the FDTD method [5]. At the first stage of the design of this hall, the architect proposed elliptic room shape. This shape is very dangerous and we proposed to make the walls zigzag-shaped with forward-bent surfaces in order to prevent acoustic defects caused by the basic room shape. To examine the effect of such diffusion treatment (and to make the architect be convinced), numerical simulation was performed.

In the calculation, spatial grid size of 5 cm and discrete time step of 0.08 ms were set and the sound absorption coefficients of the wall, forward-bent surfaces and floor were assumed 0.13, 0.50 and 0.12, respectively. The surface of the ceiling was treated as perfectly absorptive because high absorptive finishing was designed on the ceiling.

Figure 8 shows the calculation results for the two conditions, with and without diffusing treatment, in the form of "snap shot" in the time lapse after the emission of the impulse source. In the case of without diffusing treatment, successive sound focusing is clearly seen, whereas sound is much scattered and blended in the case of with diffusing treatment by the effect of the zigzag walls.

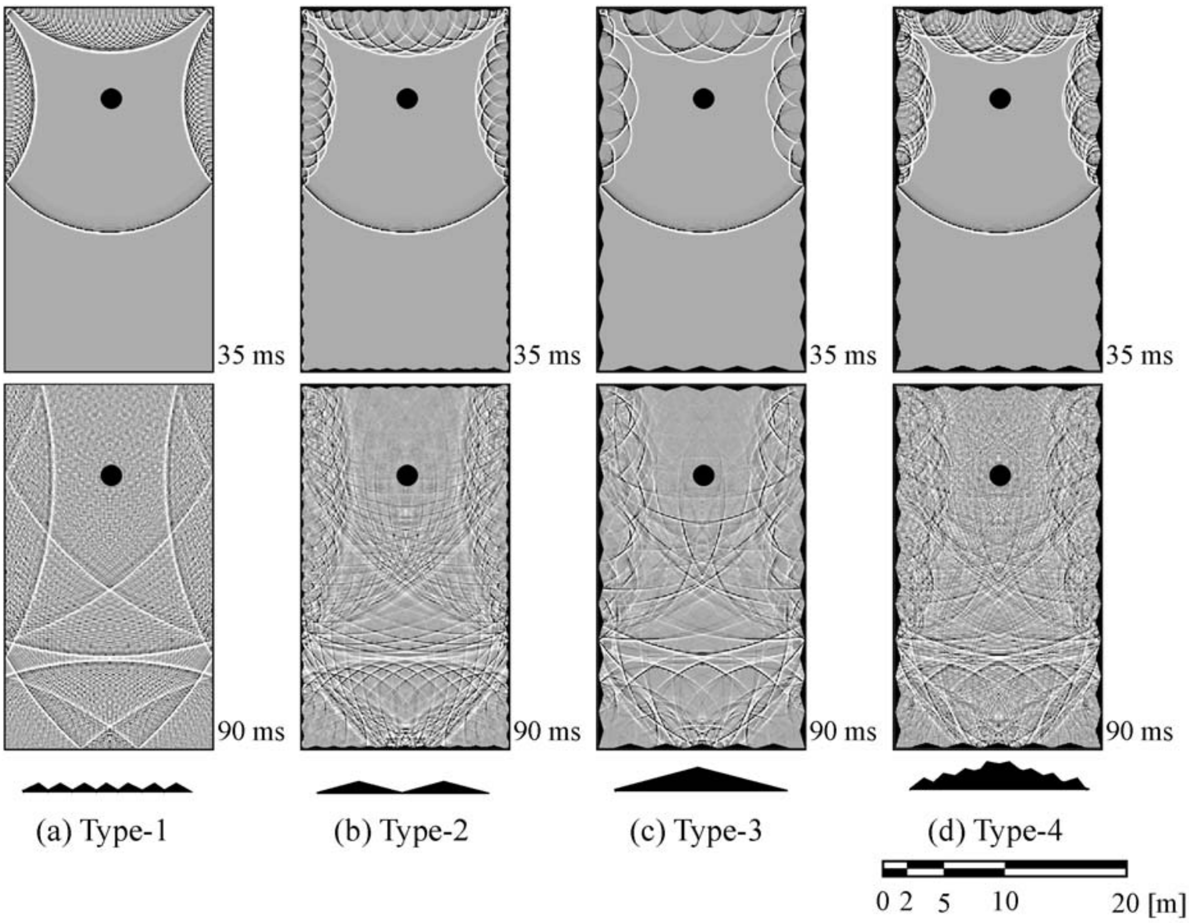

Fig.7 Comparison of sound propagation in the rectangular room with four types of diffusing treatments.

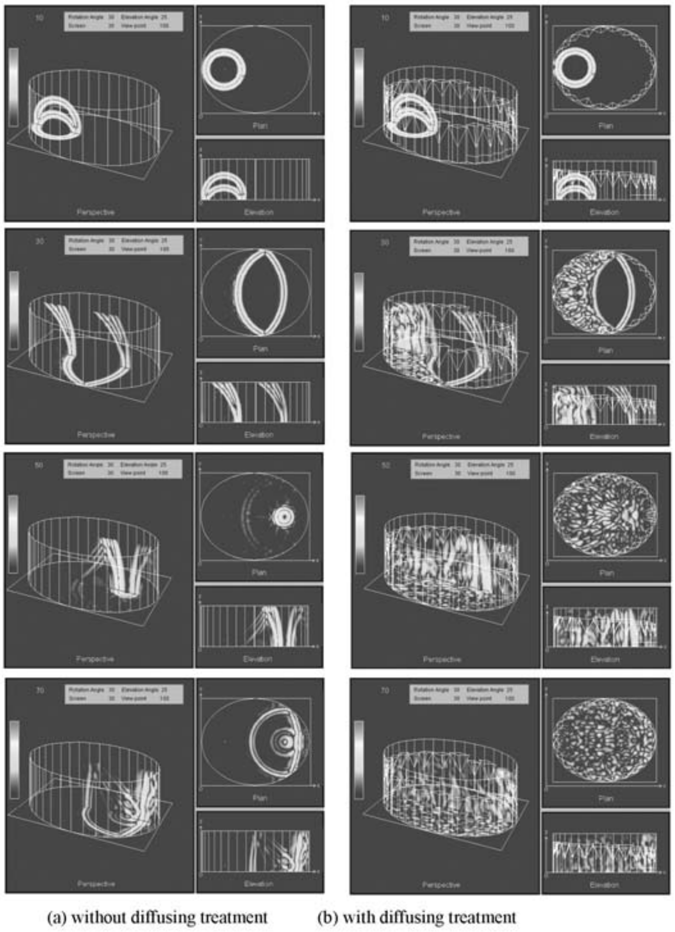

Fig.8 Comparison of sound propagation in a 3-dimensional elliptic hall with and without diffusing treatment.

After the construction of this hall, room impulse responses were measured and they were compared with those calculated by the FDTD method. Two examples of the comparison are shown in Fig. 9 and we can see a fairly good agreement between the calculation (upper figures) and the real measurement (lower figures).

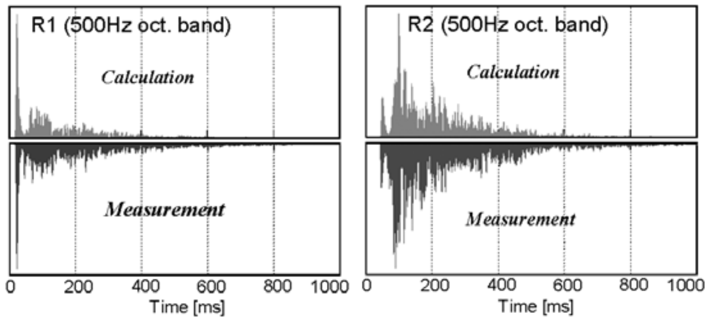

Fig.9 Comparison of impulse response between calculation and measurement.

3. TWO-DIMENSIONAL AURALIZATION OF ROOM IMPULSE RESPONSE

As a further application of the numerical simulation by the FDTD method, we are now developing a technique to auralize the calculated impulse responses with spatial information [8,10]. Figure 10 shows the principle of the "4-channel numerical sound field simulation system". In this system, the uni-directional impulse responses for four orthogonal directions are firstly calculated by the FDTD method as follows.

$$p_{directional}^{n+1/2}(i,j) = p^{n+1/2}(i,j)\cdot f(\theta) \tag{12}$$

$$f(\theta) = \frac{1+\cos\theta}{2} \tag{13}$$

where θ is the sound incident angle to the receiving point. The incident angle is calculated using the sound intensity components in x- and y-directions at the receiving point. In the staggered grid system, the sound intensity at the grid point (i, j) is calculated as follows and the incident angle θ can be calculated by Eq. 16.

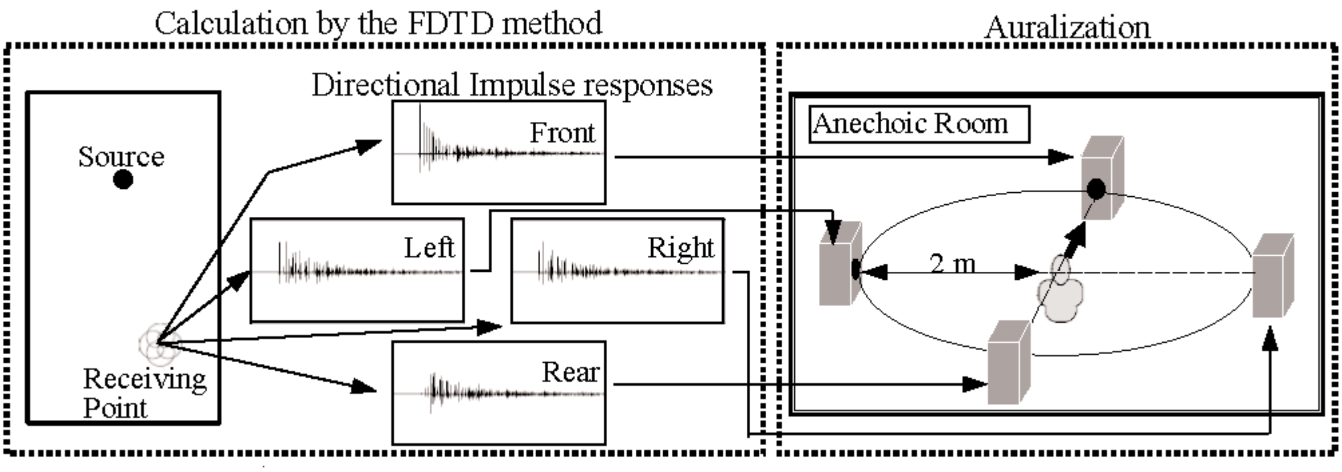

Fig.10 Outline of the 4-ch. numerical sound field simulation system

$$I_x^{n+1/2}(i,j) = p^{n+1/2}(i,j) \cdot \frac{u_x^n(i+1/2,j) + u_x^n(i-1/2,j)}{2} \quad (14)$$

$$I_y^{n+1/2}(i,j) = p^{n+1/2}(i,j) \cdot \frac{u_y^n(i,j+1/2) + u_y^n(i,j-1/2)}{2} \quad (15)$$

$$\theta = \tan^{-1}\left(\frac{I_y^{n+1/2}(i,j)}{I_x^{n+1/2}(i,j)}\right) \quad (16)$$

Next, the four directional impulse responses are reproduced from four loudspeakers set in an anechoic room as shown in Fig.9. At the center point or the simulated sound field, we can hear the impulse response with spatial impression. (At present, the system is for 2-dimension but it is easily expanded to 3-dimentional, in principle.) By applying this auralization system, we are now making subjective hearing tests on the effect of sound diffusing treatments on the walls of concert halls [10]. Of course, by convolving an arbitrary dry source with the 4-channel impulse responses, we can hear the sound with 2-dimensional spaciousness, in principle. At present, however, it is difficult to calculate the impulse response up to high frequencies enough for listening music.

4. CONCLUSIONS

As a basic study on visualization of room acoustics using numerical simulation technique, the sound propagation in rooms of different shapes and the scattering effect of acoustic diffusers have been investigated by applying the FDTD method. As a result, it has been found that this kind of sound field simulation technique is very effective to get intuitive comprehension of acoustic phenomena in rooms. It will be a useful tool for acoustic education not only for students and acoustic engineers but also for architects who design concert halls and theatres.

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RESONANCE THEORIES OF HEARING – A HISTORY AND A FRESH APPROACH

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ABSTRACT. This paper provides an historical overview of how a powerful acoustical principle – sympathetic resonance – has been applied to our organ of hearing. It focuses on the principle's virtues, drawbacks, and varying fortunes. Why did Helmholtz's resonance theory of hearing in the 1850s fall from universal acceptance to near total disregard? What were the factors favouring travelling wave theories, most notably that of von Békésy in the mid 20th century? Post-Békésy, however, thinking on cochlear mechanics has been radically changed by findings that the cochlea is an active transducer, not a passive one as previously thought. As Kemp demonstrated in 1979, healthy cochleas are highly tuned and continuously emit narrow-band sound … prompting the thought that something seems to be resonating. Maybe, then, it is worth re-examining resonance, even though travelling waves remain the centre-piece of the standard cochlear model. A fresh resonance formulation is described.

1. INTRODUCTION

If the ear were more sensitive, we would have to contend with the noise of air molecules raining upon our ear drums. The core of our multi-stage sound transducer is the cochlea, a spiral-shaped organ the size of a hazelnut buried in the solid bone of the skull.

Operating close to theoretical limits, the cochlea has a 10-octave frequency response, operates over a signal power range of a million million times (120 dB), and exhibits a noise floor close to thermal noise. It's electrically powered using supplies of a fraction of a volt, and operates underwater (the cochlea is filled with watery liquid). And while we have broad ideas of how it works, there's still a long way to go.

Because the cochlea is inaccessible and delicate, its experimental study is difficult, and so auditory science has relied heavily on theory, informed by anatomy, psychophysics, and sometimes inconclusive direct probing on animals (experiments which, from my ethical perspective, are regrettable). There have been a multitude of theories, and progress has often been slow.

But in 1978 a new window into the cochlea suddenly opened. English auditory scientist David Kemp [1] discovered that the organ not only detects sound but produces it. He placed a microphone in his ear and picked up the faint but distinct sounds of the cochlea at work.

His discovery of "otoacoustic emissions" has revolutionised the field and led to new diagnostic tools and methods. Most human cochleas produce an echo in response to a click and, more remarkably, constantly emit faint, narrow-band tones. We now know much about these energetic phenomena, but still remain largely ignorant of how they are produced and how they relate to the fundamental process of sound transduction.

Here I give a broad outline of the two major theories of hearing – the accepted travelling wave theory and the now virtually outmoded resonance theory. Following Kemp's discoveries, the hearing field has generally been content to build active properties on top of the passive travelling wave, but I have misgivings. There are certain unsolved problems associated with travelling waves, and I think a resonance picture may provide a way around them.

Starting afresh, I have been endeavouring to construct a new resonance model of hearing. The following sections provide a historical perspective on the development of resonance theories, describe the general principles on which they operate, and argue for why resonance deserves reconsideration. As part of this, a summary is given of how the newly constructed model works.

2. HISTORY

For most of recorded history, people have turned to resonance as an explanation of how we hear. The ancient Greeks held that "like is perceived by like" so, in order for the inner soul to perceive a sound, Empedocles (5th century BCE) said there had to be direct contact. In other words, the ear must contain something of the same nature as the soul, and this was a highly refined substance particularly tenuous and pure called "implanted air", and it was this that resonated to incoming sound. "Hearing is by means of the ears," said Alcmaeon of Crotonia in 500 BCE, "because within them is an empty space, and this empty space resounds."[2] Aristotle concurred and said that when we hear "the air inside us is moved concurrently with the air outside." Empedocles introduced the notion that in the same way as the eye contains a lantern, the ear contains a bell or gong that the sound from without causes to ring [3]; perhaps he noticed the ringing sound in his own ears, an experience we now call tinnitus (Latin for "tinkling bell").

Renaissance science recognised the importance of resonance and Galileo formally treated the phenomenon in 1638 [4]. Observation of stringed musical instruments showed that they readily picked up vibrations in the air around them. Importantly, they responded in a discriminating way, becoming alive only to like frequencies and remaining insensitive to others.

The first scientifically based resonance theory of hearing was that of Bauhin [4] in 1605. It was successively refined by others, all considering air-filled spaces as the resonant elements. DuVerney in 1683 thought the cochlea's bony but thin spiral lamina vibrated – with high frequencies at one end and low at the other – and the notion of spectral analysis by sympathetic resonance had been born. Soon the idea of vibrating strings emerged, and by the 18th century people were using the analogy of the sensory membrane being composed of strings as in a stringed musical instrument.

All of this thinking culminated in the immensely influential work of Helmholtz which he put forth in his landmark *Sensations of Tone* [5]. His resonance theory began as a public lecture in 1857 and within 20 years had gone on to become almost universally accepted. Helmholtz applied his scientific and mathematical skills to the simple analogy of the cochlea as a graded array of minute piano strings. Speak into a piano (with the dampers raised), said Helmholtz, and the strings will vibrate in sympathy, producing an audible echo; in like manner, the cochlea's arches of Corti will reverberate perceptibly in response to incoming sound. His presentation gave details of anatomy, number of resonators, and their degrees of coupling and damping, and it all seemed to fit nicely. He had to modify the theory to accommodate new anatomical findings, switching to the fibres of the basilar membrane as the preferred resonators, but the essence of his theory remained.

But then problems arose. The major one was a doubt that independently tuned stretched strings could exist in the basilar membrane. Anatomically, the structure shows a rather loose appearance and, since the fibres form a mesh, they must be closely coupled. It is therefore hard to see that the fibres could be finely tuned, that is, that they could have an appreciable quality factor, or Q, especially when the basilar membrane is immersed in liquid. And how could something no bigger than a nut have within it a structure able to resonate in sympathy with the throb of a double bass, for example?

The theory aims to explain how our keen pitch perception originates – we can easily detect changes in frequency of less than 1% – but if the Q of the fibres is low, this leads to the prediction that our pitch perception is correspondingly poor. On the other hand, if we nonetheless insist on retaining high Q, this invites another difficulty: a tone will take many cycles to build up and as many to decay, producing a hopeless blur of sound like a piano played with the sustain pedal always down. Something was amiss and the theory fell from favour.

Moreover, there were new alternatives. With the invention of the telephone, theories appeared likening the cochlea to a vibrating diaphragm. Some thought that the diaphragm was the basilar membrane; others thought the tectorial membrane a better choice.

3. TRAVELLING WAVE THEORIES

Towards the end of the 19th century another novel theory arose: that of a travelling wave [4]. It came in a succession of forms, the first being that of Hurst in 1894, who suggested a wave of displacement travelling down the basilar membrane (hence the name). Variants were put forward by Bonnier (1895), ter Kuile (1900), and Watt (1914). These theories made a positive virtue out of their low Q, explaining how sound perceptions could start and stop instantly. They also gave a useful role for the cochlear fluids, using hydrodynamics to help with propagation of the wave.

The wave is considered to travel along the basilar membrane like a wave in a flicked rope. Travelling wave theories are built on the idea that the cochlea is a coarse frequency analyser, leaving it to the nervous system (or perhaps some mechanical "second filter") to sharpen up the response.

The most famous travelling wave theory is due to Georg von Békésy who won a Nobel Prize for his decades-long efforts, beginning in 1928, to elucidate the mode of action of this wave. It is his name that we associate with the theory, for he was the first to actually observe a travelling wave in the cochlea, both in human cadavers and in animals, using intense sound stimulation and stroboscopic illumination [6]. He also built water-filled boxes divided by rubber membranes, and saw similar behaviour. He started his experiments expecting to rule out the basic place principle of Helmholtz [7] – that the sensing membrane in the cochlea maps frequency to distance along it – but was surprised to discover that, depending on the frequency of excitation, the peak of the wave shifted systematically from the base of the cochlea to its apex, offering a degree of frequency resolution. Again, the peak was supposed to be fine-tuned neurally so that, to quote Békésy [8] "very little mechanical frequency analysis is done by the inner ear."

As well as suitably low Q, the other attractive feature of his travelling waves was that they showed, in accord with observations, several cycles of delay between input and response. This seemed to be decisive evidence against the Helmholtz theory, for a simple resonator will give, at most, a phase delay of $\pm 90°$ between driving force and displacement. By 1948 the travelling wave theory seemed incontrovertible.

4. GOLD'S RESONANCE IDEAS

But not quite. In 1946 a young Cambridge graduate accidentally landed into hearing research after doing war-time work on radar. Full of electronic signal-processing knowledge, Thomas Gold became focused on how the ear could attain such high sensitivity and frequency resolution. He was dissatisfied with the travelling wave picture because it cast an impossible burden onto the neural system: no matter how sharp its discrimination may be in theory, in practice noise enters all physical systems and will throw off attempts to precisely locate the peak. He became convinced that the basis of our acute frequency discrimination must reside in the ear. But how was that possible when cochlear fluids alone are sufficient to assure high damping?

During a boring seminar, inspiration hit: if the ear employed *positive feedback*, he realised, these problems could disappear [9]. He knew all about regenerative receivers, which were simple circuits that used positive feedback to amplify a radio signal before it was detected, thereby achieving high sensitivity and narrow bandwidth. He reasoned that "surely nature can't be as stupid as to go and put a nerve fibre – that is a detector – right at the front end of the sensitivity of the system", and so proposed that the ear must be an active system – not a passive one as everybody had previously thought – and that it worked like a regenerative receiver. In this way, damping could be counteracted by positive feedback, and, given just the right level of feedback gain, the bandwidth could be made arbitrarily narrow.

Gold later framed the problem confronting the cochlea in terms of an evocative analogy [10]: the cochlea's strings – whatever they may be – are immersed in liquid, so making them resonate is as difficult as sounding a piano submerged in water. But if we were to add sensors and actuators to every string, and apply positive feedback, the "underwater piano" could work again.

He and Pumphrey, his colleague, designed experiments to test the hypothesis that there must be high-*Q* resonators in the ear. There were two ground-breaking experiments in 1948 [11,12], the first of which involved testing the hearing thresholds of listeners first to continuous tones and then to increasingly briefer versions. If hearing depends on resonators building up strength, like pushing a child on a swing, the threshold should depend in a predictable way on the number of pushes, or cycles. Their results accorded with this picture, and they calculated that the *Q* of the resonators must be between 32 and 300, depending on frequency.

Flowing from Gold's model was a startling prediction: if the ear were in fact using positive feedback, then if the gain were set a little too high, it would continuously squeal, as regenerative receivers (and PA systems) are prone to do. Daringly, he equated this state of affairs with the common phenomenon of ringing in the ear, or tinnitus. He caused his ears to ring by taking aspirin, placed a microphone in his ear, and tried to pick up a sound. The conditions and equipment weren't right, and the experiment failed.

Gold and Pumphrey remained convinced that Helmholtz was correct, and the abstract of their 1948 paper declares "previous theories of hearing are considered, and it is shown that only the resonance hypothesis of Helmholtz… is consistent with observation"[13]. Gold paid a visit to Békésy in Harvard and tried to convince him of the impossibility of relying on neural discrimination. He also pointed out the scaling errors that Békésy introduced by building a cochlear model many times actual size, but each side stuck to their views, and for many years – until Kemp's momentous discoveries – Békésy's ideas prevailed [14]. People just assumed that the high *Q*s that Gold and Pumphrey had found must have a neural origin, and the loop-hole in their second experiment (the extra cue) was leapt upon.

With Gold's ideas falling on deaf ears, he left the field and made a name in cosmology instead.

5. DISTINGUISHING TRAVELLING WAVE AND RESONANCE

Békésy made many mechanical models demonstrating how a travelling wave works, and he did important work clarifying the fundamental differences between travelling waves and resonance. To model the cochlea he built arrays of pendulums – bobs on strings of varying length – suspended from a common rod.

First he demonstrated that a bank of resonators (the pendulums) could behave like a travelling wave. If there were coupling between the resonators – such as by threading rubber strands between the strings – then after exciting the shortest pendulum, a wave motion would be seen progressing from this pendulum to the longest. If the coupling is light, then the wave progresses very slowly, giving large delays.

The other way of exciting what looks like a travelling wave is to suddenly jerk the rod. Even with no coupling, an apparent wave will be seen to move from the shortest pendulum towards the longest. In this case the wave carries no energy; it is just an illusion, an epiphenomenon, reflecting the fact that the shortest pendulum will accumulate phase faster than the longer ones. It's rather like the blinking lights outside a theatre which give the impression of movement.

It is important for later discussion to recognise that although they can give a similar result, there are fundamentally different physical processes driving them. In terms of physical understanding, we need to clearly distinguish these two mechanisms, for one marks a travelling wave theory and the other a resonance theory.

Travelling wave. The essence of a travelling wave theory is that the signal path through the resonators is *in series*. That is, the input to the system is via the high frequency resonator and the energy is passed sequentially (via coupling) to lower frequency resonators. The *Q* of the individual resonators can be high or low, but the key is that the signal energy is injected into the high frequency end, just as what happens in a tapered transmission line. Likewise, the classic travelling wave theory of Békésy is that the input applied to the stapes causes an immediate deflection of the basilar membrane at the high frequency end and this is then coupled (hydrodynamically and materially) to neighbouring sections until a peak is reached at the characteristic place (after which motion quickly decays).

Resonance. By way of contrast, what distinguishes a resonance theory of excitation is that the signal energy is applied to the system *in parallel*. Thus, when we jerk the rod suspending the pendulums, or lift the lid on a piano and yell into it, the excitation is applied to all the resonant elements virtually simultaneously. In the same way, Helmholtz called for an array of independent resonators that were excited by sound passing through the cochlear fluids. It is this idea that I want to reconsider.

The advantage of the pure resonance approach is that only that resonator with matching frequency receives energy (provided the *Q* is sufficiently high). Moreover, weak signals can, cycle by cycle, cause a resonator to build up an appreciable in-phase motion, like a child pumping a swing. In this way the cochlea would be able to hear sounds just above thermal noise.

The question, then, is can a resonance mechanism operate in conjunction with the travelling wave one? Perhaps the ear uses a hybrid of travelling wave and resonance to optimise performance. No one yet believes they have the perfect cochlear model, and maybe persistent anomalies in travelling wave models can be resolved by introducing resonance effects. Whatever the answer, it must accommodate the range of cellular-powered phenomena discovered by Kemp.

6. KEMP AND THE ACTIVE COCHLEA

David Kemp's experiments gave a clear demonstration that Gold was heading in the right direction and have changed the face of auditory science. In the same way as faint radio signals have opened an unsuspected window on outer space, his otoacoustic emissions have limned a new horizon into inner space. In 1978 he placed a microphone in his ear and picked up the faint signal that Gold had been searching for 30 years earlier. His equipment was better, and you didn't need to induce tinnitus to pick up a ringing sound.

We now recognise broad classes of acoustic emissions. As well as the striking spontaneous emissions, other continuous signals of cochlear origin can be detected: stimulus frequency emissions (where the sound coming out is at the same frequency as that going in) and distortion product emissions (where the modulation products of two input stimuli are detected). The most widely employed tools for diagnosis of cochlear function use transient stimuli: in response to a click, an echo will come back from the cochlea – Kemp's original experiment – and similarly a tone burst of a set frequency will lead to a similar answering echo.

These 'active' properties reflect the operation of a so-called 'cochlear amplifier' and they fade away once sound intensities reach 60–80 dB SPL. The active cochlea is highly tuned, and the relative bandwidth of spontaneous emissions, which show very stable frequencies, can be less than 1 in 1000.

When I first read a report of Kemp's findings in 1979, I was astonished. Surely travelling wave theory couldn't be right: how could a more or less slack membrane immersed in fluid sing? Helmholtz must be closer to the mark, I thought, and I have been intrigued by the cochlea and its micromechanics ever since. I have been searching for an explanation of spontaneous emissions: if something is constantly ringing, what are the resonating elements? Gathering clues to their origin, I studied the stability of these tones [15], and am now currently engaged in PhD research at the Australian National University investigating whether a resonance model of the cochlea is possible.

The auditory community has interpreted Kemp's work in terms of a travelling wave but with additional parameters. People accept Gold's incisive idea of an active cochlear process, but resist his call to reinstate simple resonance. Thus, the delay of the cochlear echo has been seen as the delay of the travelling wave as it propagates from the stapes to its characteristic place and then, by means of a "reverse travelling wave", returns to its place of origin. If the stimulus recirculates, the travel time for the loop defines the period of a spontaneous emission. To counter propagation losses, the basilar membrane has been ascribed negative resistance, a state of affairs presumed possible by some (unknown) sensing action of the outer hair cells – which are pretty certain to be the source of the mechanical activity detected by Kemp. We now know, for example, that when an outer hair cell is stimulated, it changes length cycle by cycle in step with the stimulus [16]. In other words, these cells are effectors as well as sensors.

7. TRAVELLING WAVES AND RESONANCE

This all adds up to a system that can be described by travelling wave equations and which mimics what happens in a tapered transmission line (provided the line also contains a travelling wave amplifier and can operate in reverse). There is no doubt that this class of model comes close to describing the measured responses of the cochlea. However, I think a resonance mechanism may play a significant, if not dominant, part at low sound levels.

But first, one should realise that there are two different, although related, signals in the cochlea. One is the usual acoustic pressure wave that, following back-and-forth vibration of the stapes, is communicated to the cochlear fluids at the speed of sound in water (1500 m/s). This wave creates, nearly instantaneously, a hydraulic pressure field, the size of the pressure being controlled largely by the compliance of the round window (which is the major point of pressure relief) since the rest of the cochlea, mostly water, is nearly incompressible. This hydraulic pressure is sometimes called common-mode pressure, for it occurs, in phase, on both sides of the sensory partition.

The second signal is the differential pressure, the difference in pressure between the upper gallery (scala vestibuli) and the lower gallery (scala tympani) caused by the presence of the partition itself. It is the differential pressure that causes a slow travelling wave of displacement to propagate from base to apex (because of the graded acoustic stiffness of the partition), and this motion is presumed to bend stereocilia and stimulate the firing of hair cells. The common-mode pressure has been thought to have no sensible effect on the cells and has been disregarded (after all, hair cells do bear distinctive stereocilia).

My idea is that this neglected compressional wave could stimulate outer hair cells – without requiring a travelling wave to bend stereocilia. This possibility fits in with how some water-dwelling animals hear: they need to detect the long-range (far-field) pressure component of an underwater sound, not the short-range (near-field) displacement component which rapidly fades. Sharks, for example, pick up distress calls over hundreds of metres (when displacements have shrunk to 10^{-12} m). Sharks have no swim bladder, and the auditory cells in their macula neglecta carry no otoliths, so how do they detect long-range pressure? Anatomy gives a clue: their auditory cells house many 'vacuities' within the cell body itself [17], suggesting they use an enclosed bubble to perform 'on the spot' pressure-to-displacement conversion.

In a similar way, I suspect that mammalian outer hair cells detect acoustic pressure. The direct pressure signal is fast and phase coherent, making a clean and clear signal for an organism to feed into a cochlear amplifier.

Such an arrangement may be able to explain behaviour that the travelling wave cannot. For example, cochlear echoes show a similar waveform as input signal strength is raised. Active travelling wave models have not yet replicated this behaviour and a recent paper announced in its abstract that this behaviour "contradicts many, if not most, cochlear models"[18]. Another prominent modeller noted the difficulty

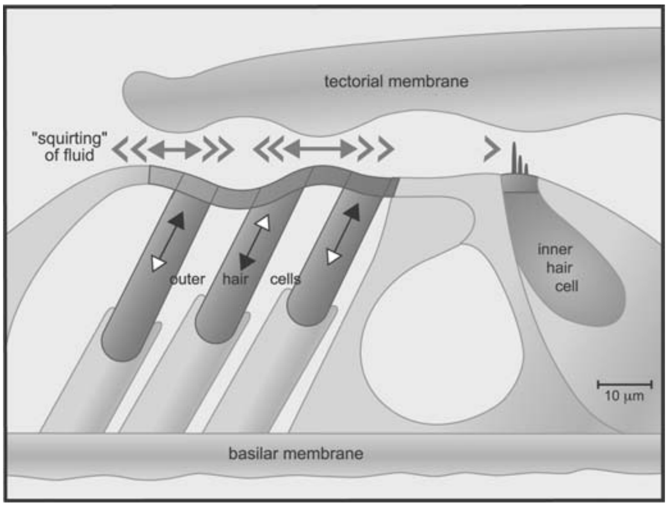

Figure 1. Strings of an underwater piano? The cochlea's resonant elements could be tiny parcels of liquid oscillating in a positive feedback loop between rows of outer hair cells. Outer hair cells moving up and down (in response to intracochlear pressure) could create 'squirting waves' in the fluid gap above. The waves could in turn bend stereocilia (for clarity, not shown), creating positive feedback and a standing wave. Wave energy escapes to the inner hair cell's stereocilia, and we hear.

of formulating a satisfactory time-domain model and suggested that "non-causal" factors must be at work [19]. In addition, people with blocked round windows can still hear, as can those who have lost middle ears to disease – observations difficult to square with a travelling wave model.

If a pressure wave is the exciting stimulus in these cases, it raises the possibility of parallel excitation of a resonant system. But what, then, are the resonating elements? As set out below, candidates for the piano strings can be identified and they appear to have the necessary pressure sensitivity [20], allowing construction of a fully resonant model of the active cochlea.

8. A NEW RESONANCE MODEL OF THE COCHLEA

My conceptual resonance model takes as its starting point the special nature of spontaneous otoacoustic emissions. It sees these stable and narrow-band signals as the cochlea's intrinsic resonant elements – its piano strings – and not as by-products of over-active forward and reverse travelling waves in a recirculating loop. That implies we have an array of highly tuned generators, exquisitely sensitive to sound, disposed from base (high frequency) to apex (low). Each string has its distinct place on the membrane, as required by Helmholtz's place principle.

We know that outer hair cells are active elements responsible for the so-called "cochlear amplifier" [21], so each string must somehow involve these cells. The inspiration for this work is that a string can form in the *space* between cells. Outer hair cells are precisely arranged in three distinct rows, and because the cells are, as mentioned earlier, both sensors and effectors, it is possible for positive feedback to occur between the motor element of one cell (its cell body) and the sensing element of a neighbour (its stereocilia). The result is stable oscillation, and this, I suggest, is the cochlea's elusive tuning element.

Oscillation occurs in a direction across the partition, not up and down as the travelling wave theory supposes. This bypasses the requirement for the mechanics of the partition to be governed by differential pressures and travelling waves. However, it introduces its own tuning problem: how can the space between the rows be tuned over 3 decades of frequency? If we require a single wavelength between the rows – a distance of about 30 micrometres – this calls for a very slow wave. For example, a 1 kHz wave shuttling between the rows will need to travel 30 µm in 1 ms, or just 30 mm/s.

Happily, such waves do exist. They are known in ultrasonics as symmetric Lloyd–Redwood waves, or "squirting waves", and propagate in the thin gap between two compliant plates immersed in water – just the arrangement we find in the space occupied by the hair cell stereocilia (Fig. 1). A recent paper [22] shows how the slow speed and high dispersion of these waves allows the "strings" to be tuned over the full range of human hearing. The standing wave produced by the squirting wave provides a natural explanation for the cochlear amplifier: it is a positive feedback system that amplifies the input signal before passing it to the inner hair cells (which finally transduce the signal into nerve pulses and send it to the brain). In other words we have a regenerative receiver performing amplification before detection, just as Gold required. The system is like his "underwater piano": it uses a system of sensors and actuators in a positive feedback loop to overcome the effects of viscosity and produce high Q.

We have the piano strings, but for a true resonant system we need the bank of resonators to be excited in parallel (that is, simultaneously). As foreshadowed, that could happen if outer hair cells are sensitive to the fast pressure wave. Outer hair cells are constructed like pressure sensors and are in continuous hydraulic connection with the cochlea's entire fluid contents – anatomically, they are, unlike inner hair cells, surrounded by fluid spaces, not other cells. Intracochlear fluid pressure could therefore be an important stimulus.

This new resonant scheme, unlike a bank of pendulums, is not limited to phase variations of ±90º. This is because the wavelengths involved are small compared to the width of the basilar membrane, and so phase delays can accumulate in the supporting structure before they are communicated to the basilar membrane where observations are finally made.

Like all pianos, the cochlear version has that essential component, dampers. The dampers are the efferent system, which is able to electrically adjust the gain of each of the outer hair cell triplets. The mechanical gain from positive feedback depends on having a differential response between the three rows, so by adjusting the resting membrane potentials between rows, the efferent nerves could quickly raise or lower the gain.

The evidence that outer hair cells react to pressure stimuli [23] is scattered and indirect, but prevalent. Naturally, if the cells are pressure detectors, they will have some compressibility. Imagine what would happen if the stapes pushed in on the nearly incompressible fluids of a cochlea surrounded by solid bone: the energy would be funnelled directly to the most compressible parts – in particular, I suggest, the outer hair cells. These cells are well designed to be pressure sensors: they are constructed like rigid test tubes with a small compliant spot (the cuticular pore) at the top. Significantly, this pore is a vestige of where, during development, a sensory apparatus (the kinocilium) used to be. Thus, the biochemical signalling could still be in place to register movement of the cuticular pore created by pressure differences between the cell interior and the cochlear fluid.

For efficient operation, outer hair cells would need to contain a very compressible material. Air would be a good choice, and these cells do contain a peculiar spherically layered structure – Hensens body – whose function could be to generate an air bubble, much like the swim bladder cells of fish do and, even more so, like the hearing cells of sharks and their 'vacuities'. The compressibility is possibly part of a positive feedback loop of its own in that when a cell changes length in response to stimulation it is difficult for it not to change volume too. If so, outer hair cells could appear much more compressible than air itself – rarefied air, if you will.

If this begins to sound like "implanted air", one can only respect the insight of those ancient Greek philosophers and wonder again whether they, and Helmholtz and Gold, might have been right.

9. CONCLUDING REMARKS

"The resonance theory of Helmholtz is probably the most elegant of all theories of hearing", said Békésy [24], and I agree. The travelling wave theory strikes me as failing to meet the cochlea's requirement for utmost finesse. It is based on the assumption that up and down motion of the basilar membrane always drives the outer hair cells, when it could be that, at low sound levels, it's the other way round. In a living system, common-mode pressure could resonantly stimulate outer hair cell motion in a direction across the partition; in this way we could escape the long-assumed need for differential pressure to be the sole driving force in the cochlea.

The cochlea could make the best of both worlds, using resonance at low sound levels and a travelling wave at higher ones. This division of labour might underlie the cochlea's astounding dynamic range. Whatever the case, I think there must be a major role for resonance. Sympathetic resonance is a principle behind everything from quarks to quasars, and must surely have a place in the raison d'etre of acoustics – the ear.

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ENGINEERING METHODS OF NOISE CONTROL FOR MODULAR BRIDGE EXPANSION JOINTS

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ABSTRACT Modular bridge expansion joints are widely used throughout the world for the provision of controlled pavement continuity during seismic, thermal expansion, contraction and long-term creep and shrinkage movements of bridge superstructures. It was known that an environmental noise nuisance occurred as motor vehicle wheels passed over the joint but the mechanism for the generation of the noise nuisance was not previously known. Noise abatement options were investigated before settling on a Helmholtz Absorber installation. The benefit is most obvious in the frequency range of 50 to 200 Hz. The noise reduction provided by the Helmholtz Absorber installation is of the order of 10 dBA.

1. INTRODUCTION

Whilst the use of expansion joints is common practice in bridge construction, modular bridge expansion joints are designed to accommodate large longitudinal expansion and contraction movements of bridge superstructures. In addition to supporting wheel loads, a properly designed modular joint will prevent rainwater and road debris from entering into the underlying superstructure and substructure. Modular bridge expansion joints are subjected to more load cycles than other superstructure elements, but the load types, magnitudes and fatigue-stress ranges that are applied to these joints are not well defined [1].

The basic modular joint design appears to have been patented around 1960 but the original patent has now expired and approximately a dozen manufacturers now exist throughout the world.

Modular bridge expansion joints are generally described as single or multiple support bar designs. In the single support bar design, the support bar (beam parallel to the direction of traffic) supports all the centre beams (beams transverse to the direction of traffic). In the multiple support bar design, multiple support bars individually support each centre beam. Figures 1 & 2 show typical single support bar and welded multiple support bar design MBEJ's respectively. In Figure 1, the term "blockout" refers to the recess provided in the bridge superstructure to accommodate the casting-in of an expansion joint.

The MBEJ installed into the Western abutment of Anzac Bridge is, in fact, a hybrid design having pairs of support bars in series across the full width of the joint. Each pair of support bars is attached to alternate groups of four centre beams (i.e. Centre beams 1, 3, 5 & 7 are attached to the odd numbered support bars and centre beams 2, 4, 6 & 8 attached to the even numbered support bars). The support bar pairs are spaced at 2.25m centres across the full width of the bridge resulting in a total of 24 support bars.

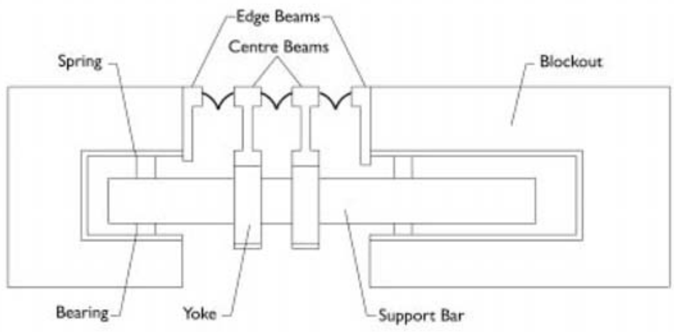

Figure 1 Typical Single Support Bar Design MBEJ

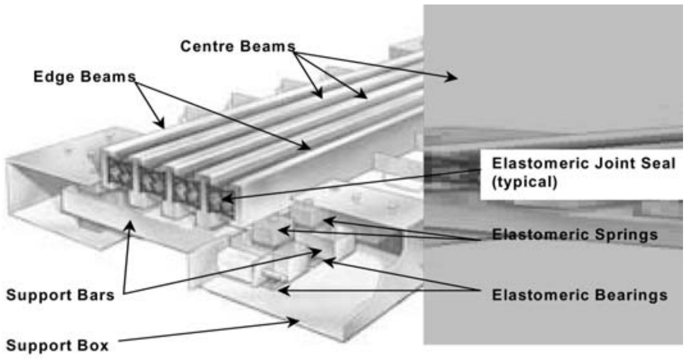

Figure 2 Typical Multiple Support Bar Design MBEJ

The MBEJ installed into the southbound carriageway of the bridge over the Georges River at Tom Ugly's Point is a typical welded multiple support bar design as shown in Figure 2.

It is known that an environmental noise nuisance occurs as motor vehicle wheels pass over the joint but the mechanism for the generation of the noise nuisance is not widely understood although Barnard & Cuninghame [2] do confirm the role of acoustic resonances.

A study was undertaken and the modular bridge expansion joints built into the Georges River (Tom Ugly's) Bridge and Anzac Bridge were selected for the study due to their proximity and ease of access. Engineering measurements were made under operational conditions to determine how the noise nuisance originated and was subsequently propagated into the surrounding environment [3].

2. NOISE GENERATION HYPOTHESIS

There was anecdotal evidence from environmental noise nuisance complaints received by the Roads & Traffic Authority of NSW (RTA) that the sound produced by the impact of a motor vehicle tyre with modular bridge expansion joints was audible at least 500 metres from the bridge in a semi-rural environment. Site inspection suggested that the noise generation mechanism involved possibly both parts of the bridge structure and the joint itself as there was distinct difference between the subjective character of the noise above and below the bridge deck.

The hypothesis was developed by Ancich [3] that motor vehicle tyre impacts vibrationally excite modular bridge expansion joints thereby producing noise that is amplified within the bridge superstructure (due to acoustic resonances) and then propagated into the surrounding environment.

As Figures 1 & 2 show, each transverse centre beam is connected (at the tyre contact level) to the adjoining centre beam or edge beam by a thick rubber strip seal. It is this combination of the rubber strip seals with the steel beams that acts as a continuous membrane and affords MBJS their unique water proofing properties. However, when the MBEJ vibrates, this membrane behaves in much the same way as the skin of a drum or the diaphragm of a loudspeaker. Experimental modal analysis studies [4] [5] indicated that typical MBEJ's have both flexural and translational modes. The most significant translational mode was a vertical bounce/bending mode where all parts of the MBEJ were vibrating essentially in phase at the same frequency and in combination with some vertical bending of centre beams and support bars.

Ancich *et al* [6] confirmed with finite element modelling the measured natural modes and indicated that MBEJ's were very sensitive to damping and operational conditions where motor vehicle tyre impacts to successive centre beams were in-phase or notionally in-phase. In the worst combination of low damping (<5% of critical) and in-phase excitation, the modelled dynamic amplification factor was as high as 11.

3. MEASUREMENT PROCEDURE

To test the hypothesis, simultaneous noise and vibration measurements, at the Georges River (Tom Ugly's) and Anzac Bridges, were recorded and analysed. Vibration data were obtained from an accelerometer attached to a transverse beam (centre beam) of the MBEJ. Noise data were obtained from a precision Sound Level Meter located inside the void space within the bridge abutment directly beneath the MBEJ and at external locations.

The simultaneous noise and vibration data were recorded onto a Sony Model PC 208A DAT recorder using a Bruel & Kjaer Type 2260 (Investigator) Sound Level Meter, Type 4370 Accelerometer and Type 2635 Charge Amplifier and subsequently analysed using a OROS Type OR25 FFT analyser.

4. RESULTS & DISCUSSION

Measurements were initially made at the Georges River (Tom Ugly's) Bridge and the narrow band frequency analysis of the vibration data indicated the presence of a small number of discrete frequencies generally in the range 50-150 Hz.

It was believed that these frequencies were likely to be the vertical and/or horizontal bending frequencies for the transverse beams (tyre contacting) of the modular expansion joint. Figure 3 shows the vibration spectrum of a typical

Table 1 Calculated and Measured Natural Frequencies - Georges River (Tom Ugly's) Bridge

Measured Frequency, Hz	Calculated Frequency, Hz[2]	Calculated Vibration Mode[1]
70	67.11	Vertical (1)
82	80.1, 80.8, 81.7, 82.9, 83.4, 83.5, 87.8, 89	Horizontal (4), Horizontal (2), Horizontal (3), Horizontal (5), Vertical (2 & 6), Vertical (1 & 4), Horizontal (4), Vertical (2 & 5)
90	89, 91.2, 97.4	Vertical (2 & 5), Horizontal (3), Vertical (3, 5 & 7)

Notes: (1) As the precise boundary conditions for the Georges River (Tom Ugly's) Bridge joint are not known, some assumptions were made. The Mode numbers associated with the various frequencies reflect the range of assumptions. Numbers in brackets refer to the calculated mode number.
(2) Calculated frequencies are considered correct ± 10% due to assumption uncertainties.
(3) Bracketed numbers following mode type refer to the calculated mode number.

Table 2 Calculated Room Acoustic Modal Frequencies compared with Measured Vibration Frequencies - Georges River (Tom Ugly's) Bridge

Measured Frequency, Hz		Calculated Frequency, Hz[1]	Calculated Acoustic Mode
Noise	Vibration		
N.A	N.A	11.1	Transverse (1)
76	70	74.1	Vertical (1)
82	82	81.9	Vertical (1)
N.A	90	148.3; 163.8	Vertical (2)

Notes: (1) Calculation of multiple frequencies for some acoustic modes arises from varying dimensions within the void space.
(2) Bracketed numbers following mode type refer to the calculated mode number.
(3) N.A indicates that the calculated frequency was not identified in the measurements.

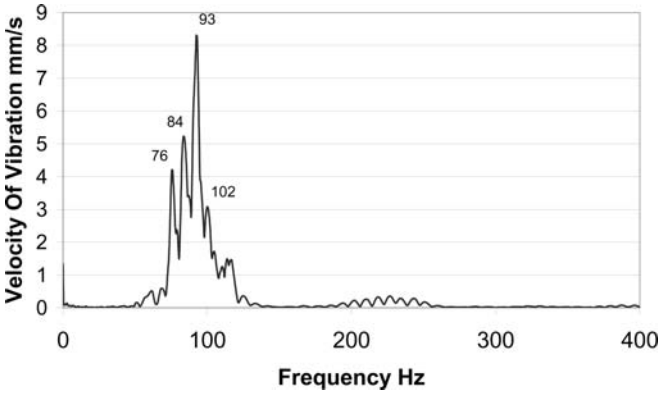

Figure 3 Centre Beam Vibration Spectrum – Tom Ugly's Bridge

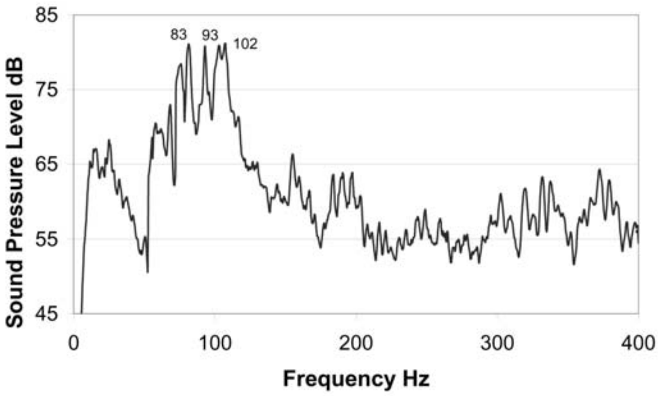

Figure 4 Acoustic Excitation Spectrum – Tom Ugly's Bridge

Georges River (Tom Ugly's) Bridge centre beam. Examination of Figure 3 reveals the presence of three dominant peaks in the frequency spectrum (70 Hz, 82 Hz & 90 Hz). Consequently, a grillage analysis of the joint was undertaken using Microstran® [7]. This analysis was used to calculate natural modal frequencies and **Table 1** shows the measured and calculated vibration frequencies.

Table 1 indicates a high degree of correlation between the calculated natural frequencies and the three dominant

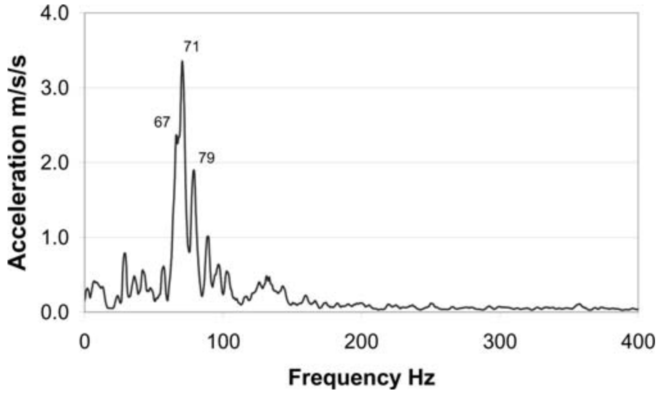

Figure 5 Centre Beam Vibration Spectrum – Anzac Bridge

frequencies (70 Hz, 82 Hz & 90 Hz) measured at the Georges River (Tom Ugly's) Bridge.

A possible explanation for the high environmental noise nuisance is acoustic coupling between vibration of the modular joint and room acoustic modes inside the void space within the bridge abutment beneath the modular joint. This possible explanation was tested by calculating the frequencies of the various room acoustic modes encompassed by the vibration frequencies of interest [8]. This comparison is shown as Table 2.

Additional calculations were undertaken to determine the acoustic modal frequencies within the bridge box girders as these structures are acoustically connected to the void space within the bridge abutment beneath the modular joint. The calculated frequencies appear as Table 3.

Figure 4 shows the acoustic excitation spectrum from measurements undertaken inside the void space within the bridge abutment beneath the modular bridge expansion joint. Examination of Figure 4 reveals the presence of two dominant peaks in the noise frequency spectrum (76 Hz & 82 Hz) and similar or matching frequencies also appear in Figure 3 and Table 2.

Similar measurements to those undertaken at Georges River (Tom Ugly's) Bridge were repeated at the Anzac Bridge. Figure 5 shows the corresponding vibration spectrum of a

Table 3 Calculated Box Girder Acoustic Modal Frequencies compared with Measured Vibration Frequencies - Georges River (Tom Ugly's) Bridge

Measured Frequency, Hz	Calculated Frequency, Hz[1]	Calculated Acoustic Mode
70	59, 73	Transverse (1), Vertical (1)
82	73, 86	Vertical (1), Transverse (1)
90	86	Transverse (1)

Notes: (1) Calculation of multiple frequencies for some acoustic modes arises from varying dimensions within the box girder.
(2) Bracketed numbers following mode type refer to the calculated mode number.

Table 4 Calculated and Measured Natural Frequencies (Anzac Bridge)

Measured Frequency, Hz	Calculated Frequency, Hz[2]	Calculated Vibration Mode[1]
57	34.5	Horizontal (1)[3]
65	N.A[4]	N.A
70.5	N.A	N.A
84	91.3, 94.9, 99.4	Vertical (2 & 3), Horizontal (4)
122	103.4, 108.4, 111.2, 118.8, 119, 124.3	Horizontal (5), Vertical (6), Horizontal (7), Vertical (8), Horizontal (9), Vertical (10)
189	N.A	N.A

Notes: (1) As the precise boundary conditions for the Anzac Bridge joint are not known, some assumptions were made. The Mode numbers associated with the various frequencies reflect the range of assumptions.
(2) Calculated frequencies are considered correct ± 10% due to assumption uncertainties.
(3) Bracketed numbers following mode type refer to the calculated mode number.
(4) "N.A" indicates that no calculated frequency was found to correspond with the measured frequency.

typical Anzac Bridge centre beam. Examination of Figure 5 reveals the presence of six dominant peaks in the frequency spectrum (57 Hz, 65 Hz, 70.5 Hz, 84 Hz, 122 Hz & 189 Hz).

Consequently, a grillage analysis of the joint was undertaken using Microstran®. This analysis was used to calculate natural modal frequencies and Table 4 shows the measured and calculated vibration frequencies. The possibility of acoustic coupling to room modes in the Anzac Bridge abutment void space was also tested by calculating the frequencies of the various room acoustic modes encompassed by the vibration frequencies of interest. This comparison is shown as Table 5.

5.0 NOISE ABATEMENT OPTIONS

The analysis of measurements supported the hypothesis that an environmental noise nuisance resulted from the interaction of vibration of the modular bridge expansion joint with acoustic resonances produced inside the abutment void space below the joint.

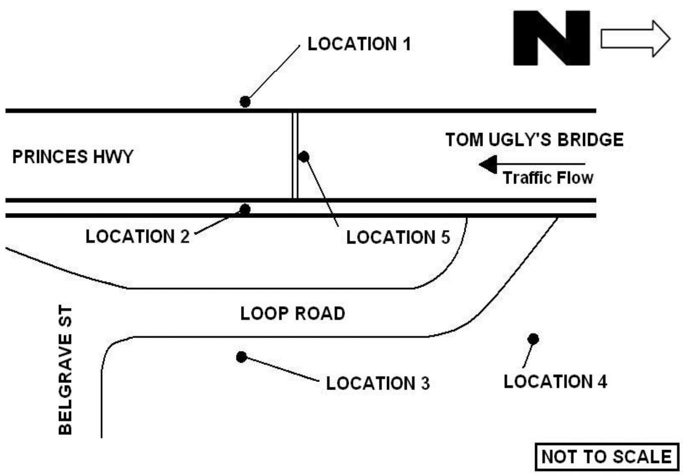

Figure 6 Site Plan Showing Noise Measurement Locations

Table 5 Calculated Room Acoustic Modal Frequencies compared with Measured Vibration Frequencies (Anzac Bridge)

Measured Frequency, Hz	Calculated Frequency, Hz[1]	Calculated Acoustic Mode
N.A	19.0	Transverse (3)
57	45.3, 47.8, 53.8	Axial (1), Vertical (1), Axial (1)
65	63.7	Vertical (1)
70.5	71.7	Vertical (1)
84	86.0	Vertical (1)
122	127.4, 135.8, 143.3	Vertical (2), Axial (3), Vertical (3)
189	172.0, 191.1	Vertical (2), Axial (2) & Vertical (3)

Notes: (1) Calculation of multiple frequencies for some acoustic modes arises from varying dimensions within the void space.
(2) Bracketed numbers following mode type refer to the calculated mode number.
(3) N.A indicates that the calculated frequency was not identified in the measurements.

Table 6 Helmholtz Absorber Modules Target Frequencies

Segment	Design Centre Frequency of Helmholtz Absorber, Hz					
	1	2	3	4	5	6
Frequency (Hz)	64	80	90	105	110	120

The reverberant nature of the void space was considered to be the reason for the apparent amplification of the low frequency sound pressure within the void space. As true standing waves do not propagate, this highly reactive (long reverberation time characteristic) of the void is not apparent in the far field. Due to the small amount of acoustic absorption in the void, some of this sound energy is absorbed within the void and some is radiated to the environment through openings. The build-up of acoustic energy is then radiated into the environment.

Martner [9] reports the results of noise measurements of a number of different types of bridge expansion joints, including modular bridge expansion joints. Whilst he indicates that the installation of an acoustic enclosure beneath the expansion joint was very effective, it is not clear whether the enclosure was used with the modular design. Rhombic plates welded onto the top surface of the edge and centre beams are reported to offer noise reductions of up to 9 dBA below the bridge deck [10]. However, these engineering methods of noise control were considered to be either too expensive or, in the case of the rhombic plates, largely developed for a particular proprietary design MBEJ. In addition, whilst these noise control measures are undoubtedly effective, their use may have an adverse impact on the ability of the asset owner to routinely inspect and maintain the joint.

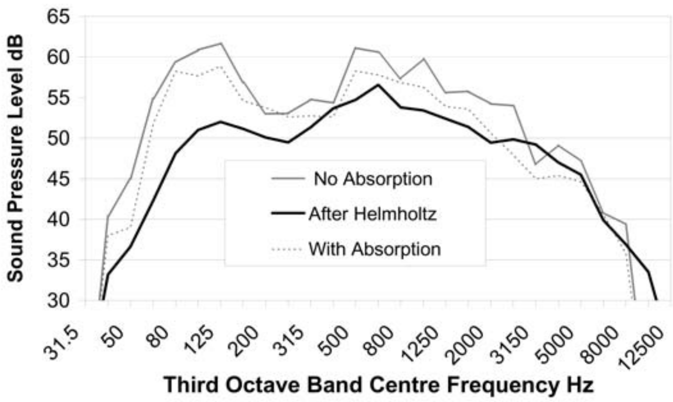

Figure 7 RMS Average Third Octave Band Noise Spectra at Location 4

It was considered that cost-effective noise abatement could be undertaken by:

1. Modifying the dynamic behaviour of the joint to shift the natural frequencies so that they no longer co-incide with acoustic resonances.

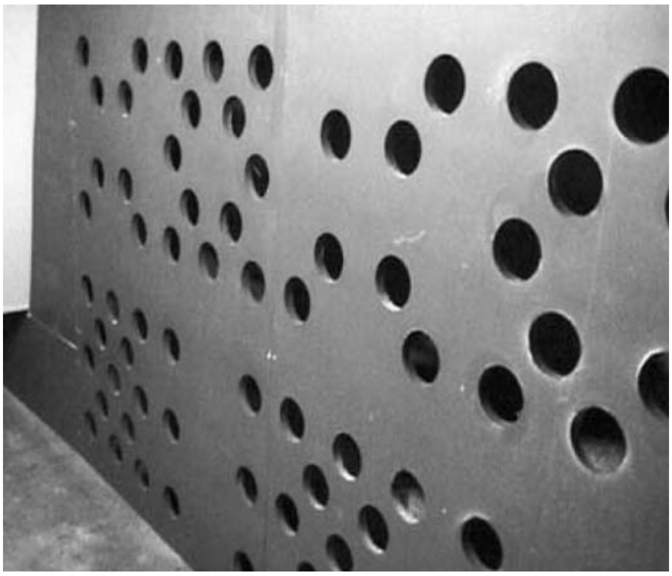

Figure 8 Helmholtz Absorber

2. Reducing the overall dynamic response by additional modal damping. This option included the trial use of tuned mass dampers.
3. Providing acoustic absorption and limited screening, adjacent to the joint, to reduce noise propagation.
4. Modifying the acoustic absorption properties of the void space to eliminate or reduce the incidence of acoustic resonances.

The above strategies represent both “new construction” and “retro-fit” options. However, their efficacy and cost-effectiveness was still to be established by engineering measurement

There were initial plans to design and test Option 2. However, this option was ultimately not pursued. Although tuned mass dampers (TMD) would likely provide an effective noise reduction, these devices were not strongly advocated due to the high number of natural modes present and hence a high number of TMD’s needing to be fitted and tuned [11]. An alternative to the TMD concept would be the use of broadband damping coupled mass absorbers.

The perceived disadvantage of this approach being the requirement for a significant mass attachment to each centre beam. An array of damping coupled mass absorbers was subsequently trialled at Anzac Bridge to reduce the risk of fatigue failure but elaboration of that work is beyond the present discussion.

Due to resonances within the void space, the use of acoustic absorption and limited screening, adjacent to the joint was not considered practical. Consequently, only Option 4 was investigated. This investigation was undertaken using two different approaches. Firstly, the simple addition of acoustic absorption into the void space was tested.

Noise measurements were conducted on 4 May 2001 at which time trial acoustical absorption material had been installed over the floor of the void below the expansion joint. The absorption was arranged in a 100 mm thick layer over the floor area of the void and raised 75 mm (nominally) above the floor surface (to optimise low frequency sound absorption). Noise measurement locations are shown as Figure 6.

Whilst the above deck (Locations 1 and 2) and the side (Location 3) measurements show no significant change in the noise spectra, the below deck Locations 4 and 5 show a significant increase in the low frequency bands when the trial absorption was removed.

As the measurements at Location 5 (from within the void space) are the result of sound pressure due to both propagating sound energy as well as non-propagating standing waves, the results at Location 4 provide a better indication of the effect on the emitted (propagating) noise.

The second approach involved the construction of a Helmholtz Absorber within the void space. The internal dimensions of the Helmholtz chambers were calculated to co-incide with the dominant acoustic frequencies. The Helmholtz Absorber panels were designed to target the critical frequencies shown in Table 6.

Figure 7 shows a comparison of RMS average one-third octave band noise spectra at Location 4 before and after the Helmholtz absorber installation. Also shown are the one-third octave band noise spectra with floor absorption only, for comparison.

These results clearly demonstrate the effectiveness of the Helmholtz absorber modules in the target range of 60 Hz to 160 Hz.

Figure 8 shows the installed absorber modules.

6.0 CONCLUSION

Noise and vibration measurements have been undertaken at Anzac and Georges River (Tom Ugly’s) Bridges. The analysis of these measurements supported the hypothesis that an environmental noise nuisance results from the interaction of vibration of the modular bridge expansion joint with acoustic resonances produced inside the void space below the joint.

The trial addition of acoustic absorption batts into the void space of Tom Ugly’s Bridge was considered to be only marginally effective for noise control and was not pursued. However, the installed Helmholtz Absorber at Tom Ugly’s Bridge has reduced the modular expansion joint induced low frequency “booming” noise emissions by up to 10 dB. The character of the noise emission from the underside of the bridge deck would no longer be classified as tonal and hence the likelihood of modular expansion joint related noise complaints has been significantly reduced.

The use of Helmholtz Absorbers at other bridges with modular expansion joints is considered to be viable as an engineering method of noise control.

ACKNOWLEDGEMENT

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NOISE ANNOYANCE FROM SEASONAL INDUSTRY IN NSW

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INTRODUCTION

Industry noise from scheduled premises in New South Wales (NSW), Australia is generally assessed with reference to the Industrial Noise Policy (2000) [1]. The Industrial Noise Policy (INP) is used by relevant Government Bodies for setting statutory limits to license noise sources from premises scheduled under the Protection of the Environment Operations Act (1997) [2]. The policy is designed for large and complex industrial noise sources but includes commercial premises, warehouses and maintenance repair facilities. Intrusive noise is one of the factors considered in the INP to quantify noise impacts and is defined as noise which is 5 dB above the background. No modifying factors are given to allow for industry which is seasonal. Seasonal industries are found, for example, in farming and food processing industries such as wineries, nut farms, sugar farms and fruit farms. These industries rely on harvesting and processing product over relatively short durations each year, typically two months to five months, but the duration can be as short as a few days or as long as six months. It is expected that people would prefer the noise to occur on for example 90 to 110 days rather than every day of the year if the level of noise and annoyance were the same. Hence it is hypothesised that the noise impact is less if the noise occurs on significantly fewer days in any one year. Industry would always be expected to reduce noise levels to the lowest level reasonably practicable regardless of criteria. Nevertheless there is a trade-off between acceptable levels above the background and annual duration, even if the degree of that trade-off is difficult to identify. Codes of Practice have been developed by some NSW Local Authorities in an attempt to address this issue [3,4].

SEASONAL NOISE SOCIAL SURVEYS

Limited research has been carried out to assess the difference between seasonal noise and continuous noise. However in one social survey [5] from the Netherlands, there was a difference between the day-evening-night level (DENL) for noise that occurred and every day of the year compared to noise that occurred only 90 days per year for the same noise impact. This difference was found to be 12 dB as shown in the examples in Table 1 below. As this is based on the same DENL averaged over a full year, the actual noise level would be 6 dB greater for the 90 day period to give the same noise exposure (i.e. $12 – 10 \log_{10} (356/90)$ dB) assuming the rest of the year was comparatively quiet.

This research indicates that a modifying factor based on $10 \log_{10} (365/n)$ dB(A), where n is the number of days per year that the seasonal noise occurs, could be applied to produce the same noise impact as for continuous noise. It may then be appropriate to apply this to the intrusive noise given in the INP. For example for noise which only occurs for 90 days per year the intrusive noise would be background plus 11 dB (i.e. $5 + 10 \log_{10} (365/90)$ dB(A)), 110 days would be background plus 10 dB and six months would be background plus 8 dB (i.e. $5 + 10 \log_{10} (365/182)$ dB(A)). Where cumulative noise from different seasonal industrial sources affects individual residences, this modifying factor may not be valid.

Noise Level (DENL)		Noise Impact	
Continuous Noise Every Day of the Year	**Seasonal Noise 90 Days per Year**		
45 dB(A)	57 dB(A)	18%	A Little Annoyed
		8%	Annoyed
		3%	Highly Annoyed
53 dB(A)	65 dB(A)	31%	A Little Annoyed
		16%	Annoyed
		7%	Highly Annoyed

(Source: Miedema and Vos [5]). Note : The DENL applies a 5 dB penalty to evening and a 10 dB penalty to night time levels.

FURTHER RESEARCH AND CONCLUSIONS

The social survey [5] supports the intuitive hypothesis that noise from seasonal industry, which may occur on significantly less days than one full year, will result in a lower noise impact for neighbouring residents than noise which is continuous for the whole year. However, the survey is only based on a single case study. This case study is indicative, but similar social surveys for Australian seasonal industry are required before firm conclusions can be reached.

Whilst all industry should minimise noise to the lowest level reasonably practicable, a modifying factor based on $10 \log_{10} (365/n)$ dB(A) could be added to the intrusive noise criterion. This is one additional factor when considering realistic noise impact assessments for seasonal industry within NSW.

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RECENT CHANGES TO THE SOUND INSULATION PROVISIONS OF THE BUILDING CODE OF AUSTRALIA*

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ABSTRACT: This paper discusses the recent changes to the Building Code of Australia (BCA) sound insulation requirements. It outlines the main drivers for the changes and looks at the process used by the Australian Building Codes Board to develop the measures. It also outlines the extent of the changes and the different options for demonstrating compliance with the BCA.

Nomenclature

R_w	Weighted sound reduction index
C_I	Spectrum adaptation term
C_{tr}	Spectrum adaptation term
$L_{n,w}$	Weighted normalised impact sound pressure level
$D_{nT,w}$	Weighted standardised level difference
$L'_{nT,w}$	Weighted standardised impact sound pressure level

1. INTRODUCTION

The Building Code of Australia 2004 (BCA) [1] came into effect on 1 May 2004 and introduced new sound insulation requirements. The changes were a response to increasing evidence that the previous BCA sound insulation requirements were not meeting community expectations. The purpose of the requirements is to reduce sound transmission between attached dwellings and units and also between dwellings or units and other areas within the building. The requirements do not address external noise.

As part of developing the new measures, a number of documents were released for public consultation. The ABCB used comments received on those documents to assist with finalising the changes.

The scope of the changes included:

- increase in the level of airborne sound insulation for walls/floors separating dwellings/sole-occupancy units.
- introduction of impact sound insulation requirements for floors separating dwellings/sole-occupancy units.
- introduction of field testing as an option for verifying compliance of walls/floors.
- sound insulation requirements for services extended to cover water supply pipes, duct work and storm water pipes.

Queensland, Western Australia and the Northern Territory have not adopted the new requirements. The previous requirements continue to be applicable in these States/Territories.

2. BACKGROUND

The Building Code of Australia

The BCA is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Australian Government and each State and Territory Government. It is a performance based code, which sets out the level of performance that the building is to achieve. In most cases, it also gives a prescriptive solution (i.e. Deemed-to-Satisfy).

The BCA is prepared and written on the basis that it is the uniform set of technical provisions for the design and construction of buildings and other structures throughout Australia.

The BCA contains 2 volumes. Volume One covers Class 2 – 9 buildings, and Volume Two covers Class 1 and 10 buildings.

Each State and Territory has its own building control legislation that references the BCA as the technical standard that specifies the requirements for the design and construction of buildings. The State or Territory legislation is generally administrative and does not contain technical requirements.

The building control authority within each State and Territory determines the application of the BCA within its jurisdiction. The manner of application and administrative arrangements differ between the States and Territories due to recognition of local influences.

The States and Territories may also vary the technical provisions of the BCA. These variations are included in the BCA as State and Territory Appendices and are given legal effect by the relevant State or Territory building control legislation.

Because of these differences between the States and Territories, there are different criteria or 'triggers' for how the

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BCA applies to buildings. Essentially the BCA applies to -

- All new buildings.
- New building work in existing buildings, such as additions and alterations.
- Existing buildings that are to be used for a purpose different from that for which they were originally designed (often referred to as a "change of use").

BCA Sound Insulation Provisions

The BCA sound insulation provisions apply to Class 2, 3 and 9c buildings. The requirements also apply to attached Class 1 buildings. Generally a Class 1 building is a single dwelling, such as a detached house or an attached house (i.e. townhouse, terrace house, etc.). Class 1 buildings also include smaller type buildings where unrelated persons live, such as boarding houses, hostels and guest houses. A Class 2 building is a building such as an apartment building or block of flats. Class 3 building covers buildings, such as hotels, motels larger type boarding houses and aged care buildings where low levels of care are provided. A Class 9c building is an aged care building where levels of care ranging from low to high are provided.

There have recently been concerns with the BCA sound insulation requirements, particularly with Class 1a and 2 buildings where people may have made a major investment to purchase or may have entered a long term lease. Once they are in residence, they may find the sound insulation to be below expectation.

It could be argued that with commercial short-term accommodation such as hotels, motels and tourist hostels, there is some degree of self-regulation by the market. Further, food preparation and clothes washing areas are less likely within a Class 3 building unit.

There has also been a dramatic increase in recent years in the number of people living in both low and high rise apartments and in attached Class 1a houses such as townhouses. This is particularly the case in major cities and other large population centres throughout Australia. In addition, many commercial buildings in major cities have been converted into residential accommodation.

Associated with this increase in higher density residential living has been a corresponding increase in the number of complaints being received from the building occupants about the high sound levels being transmitted through adjoining floors and walls. There have also been some complaints about sound coming from service pipes and duct work.

According to information provided by the Home Unit Owners Association, investigations by members of the Australian Association of Acoustical Consultants and recent media attention, complaints and litigation are on the increase. Where fault has been found, it has generally resulted in high rectification costs. In other instances, it has not been possible to resolve the dispute because the provisions of the BCA had been achieved even though the owner is of the view that the sound penetration is unacceptably high.

Some of the sound passing through adjoining walls and floors can be attributed to inferior practices and poor quality workmanship. However, there is strong evidence that the principal reasons for the complaints were that the insulation levels specified in the BCA were no longer relevant to current lifestyles and modern appliances.

It should be noted that the BCA sets minimum acceptable standards and that the building industry may provide higher levels by using better performing systems. However, the latter is only likely to occur in more prestigious developments where greater attention may be paid to sound insulation design or where there may be high quality control during construction.

The BCA provisions have received considerable criticism in the press over recent years and many Councils, particularly in NSW, have imposed higher standards. A number of Councils in Sydney have adopted criteria considerably more demanding than that of the BCA.

In other developed countries, building control authorities had already adopted higher minimum levels than those that were required by the BCA.

ABCB Sound Insulation Project

Due to the concerns raised about the BCA sound insulation provisions, the ABCB undertook a review of the requirements applicable to Class 1, 2 and 3 buildings. The requirements for Class 9c aged care buildings were not considered. The conclusion of the review was that the BCA sound insulation requirements were not meeting community expectations and that the provisions needed to be amended.

The review and development of the changes were conducted in consultation with peak professional and industry organisations. The ABCB's Building Codes Committee (BCC) also had significant input into the development of the provisions. The BCC is the ABCB's peak technical advisory body and has responsibility for providing technical advice on reforming, maintaining and upgrading the technical content of Australia's building codes and standards. The BCC's membership includes representatives of the Australian Government, State and Territory Government agencies responsible for building regulatory matters along with members of industry.

As part of the development of the sound insulation requirements, proposals to amend the provisions were released for public comment on three separate occasions. A Regulation Document (RD) was released in January 2001, a combined RD and Regulatory Impact Statement (RIS) was released in May 2001 and an amended RD/RIS in February 2002. A final RD/RIS was released in April 2004. All of these documents are available from the ABCB web-site (www.abcb.gov.au).

The Office of Regulation Review has written to the Board stating its satisfaction with the April 2004 RIS methodology.

Over 80 submissions were received on the February 2002 RD/RIS. In April 2002, the ABCB held a forum with key stakeholders to identify and resolve the key issues. The forum was attended by 49 people representing the range of views expressed in the submissions.

Significant outcomes from the forum included:

- Agreement that a change to the BCA provisions were warranted.
- General support for the levels of sound insulation

proposed in the February 2002 RD/RIS.

- Identification of technical matters to be resolved before amending the BCA.
- An identified need for an industry-developed (ABCB coordinated) guideline to assist in achieving compliance with the BCA.

The ABCB also undertook to consult with industry when developing the BCA Deemed-to-Satisfy methods. The Deemed-to-Satisfy methods are contained in Specification F5.2 of Volume One and Table 3.8.6.2 of Volume Two, and are wall/floor systems that have been tested in the laboratory in accordance with the relevant standards, and meet the BCA sound insulation requirements.

3. SCOPE OF CHANGES

The changes affected the BCA sound insulation requirements applicable to Class 1, 2 and 3 buildings. The following explains the changes in general terms.

Addition of Spectrum Adaptation Factor

Spectrum adaptation factors are commonly used to compensate for the fact that certain kinds of sounds are more readily transmitted through insulating materials than others. ISO 717-1 [2], which is reproduced as AS/NZS 1276.1 [3], sets out testing methodologies for the sound insulation properties of building elements and incorporates these factors and explains their use.

Under the previous BCA requirements for airborne sound insulation, the weighted sound reduction index (R_w) of a building element was the only consideration. On advice from industry, the adaptation factor C_{tr} has now been introduced for most building elements which require an airborne sound insulation rating. The only exception is a wall which separates a dwelling from a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification.

Therefore, both the C_{tr} factor and the R_w of the building element need to be considered in most cases.

The C_{tr} factor takes into account lower frequency level sounds, and was chosen in large part in recognition of the problem of the high bass frequency outputs of modern home theatre systems and music reproduction equipment.

Adopting C_{tr} is also likely to minimise inconsistencies between laboratory test results and on-site test results.

C_{tr} is a negative number which means that the $R_w + C_{tr}$ of a building element will be less than the R_w of the building element. For example a wall system may have an R_w of 55 but would have an $R_w + C_{tr}$ of 50 if the C_{tr} value was -5.

The C_{tr} for a building element varies according to the insulating material employed. For example a 90 mm brick cavity wall has a C_{tr} value of around -6, as does a wall constructed of 150 mm core-filled concrete blocks. By contrast, a double cavity masonry/plasterboard wall has a C_{tr} of around -12.

Increase in Levels of Airborne Sound Insulation

The previous BCA Deemed-to-Satisfy Provisions for airborne sound insulation were:

- R_w not less than 45 for walls between dwellings and between dwellings and other parts of the building; and
- R_w not less than 50 for walls between a bathroom, sanitary compartment, laundry or kitchen in one dwelling and a habitable room (other than a kitchen) in an adjoining dwelling; and
- R_w not less than 45 for floors between dwellings.

There has been some confusion about whether the above requirements were for what should be achieved in the laboratory or what should be achieved on-site. The new BCA Deemed-to-Satisfy Provisions increase the levels of airborne sound insulation and now make it clear that the Deemed-to-Satisfy Provisions apply to wall/floor systems that are tested in the laboratory. For airborne sound insulation the new requirements are:

- $R_w + C_{tr}$ not less than 50 for walls between dwellings; and
- R_w not less than 50 for walls separating a dwelling from a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification; and
- $R_w + C_{tr}$ not less than 50 for floors between dwellings and between dwellings and a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification (i.e. retail, office area, etc.).

The scope of the provisions for airborne sound insulation have been extended slightly as the requirements now apply to floors which separate a dwelling from a plant room, lift shaft, stairway, public corridor, public lobby or the like. Also, the requirements now apply to a wall or floor which separates a dwelling from parts of a different classification.

Quantification of Floor Impact Sound Insulation Ratings

The previous BCA sound insulation Performance Requirements for floors made reference to floors providing insulation against impact generated sound. However, unlike the requirements for walls, there was no corresponding Deemed-to-Satisfy Provision to establish compliance.

The ABCB received advice from various sources that the Deemed-to-Satisfy Provisions in this area were inadequate as they did not provide guidance as to what was required to meet the Performance Requirement. Anecdotal evidence suggested that complaints were being received, particularly in relation to wet areas or uncarpeted living areas that are above sleeping areas.

Consequently, the Deemed-to-Satisfy Provisions have introduced impact sound insulation requirements for floors. The terms to describe the impact sound insulation of the floor is the weighted normalised impact sound pressure level ($L_{n,w}$) plus the spectrum adaptation term (C_I). The lower the $L_{n,w} + C_I$ of the floor, the better the performance of the floor in terms of impact sound insulation.

The new BCA Deemed-to-Satisfy Provisions require the $L_{n,w} + C_I$ of a floor to be determined by testing in the laboratory. The impact sound insulation requirements for floors are:

$L_{n,w} + C_I$ not more than 62 for floors separating dwellings and for floors separating dwellings from a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification.

Increase in Impact Requirements for Walls

The previous BCA Deemed-to-Satisfy Provisions required walls separating a bathroom, sanitary compartment, laundry or kitchen in one dwelling from a habitable room (other than a kitchen) in an adjoining dwelling, to provide a satisfactory level of insulation against impact sound. The options for compliance were for the wall to:

- be in accordance with Table F5.5. Table F5.5 listed 3 wall systems which were deemed to have satisfactory level of resistance to impact sound; or
- for other than masonry, be 2 or more separate leaves without rigid mechanical connection except at the periphery; or
- be no less resistant to the transmission of impact sound when tested in accordance with Specification F5.5 than a wall listed in Table F5.5.

The impact sound insulation requirements for walls have changed slightly. The application of the requirements has not changed, however walls which require impact sound insulation must now be of discontinuous construction. For the purpose of the BCA, discontinuous construction means a wall having a minimum 20 mm cavity between two separate leaves, with no mechanical linkage between the leaves except at the periphery. For masonry wall systems, resilient wall ties are not considered to be mechanical linkage.

Wall systems using staggered studs on common plates are not considered to be discontinuous construction.

Provision of On-site Testing

The previous BCA Deemed-to-Satisfy Provisions did not include requirements for on-site testing of building elements. The changes now provide a means of verifying compliance on-site. This is one way of verifying a performance approach (Alternative Solution). An Alternative Solution must be assessed according to one or more of the Assessment Methods as defined in the BCA. These Assessment Methods are:

- Documentary Evidence as described in Clause A2.2 of the BCA.
- Verification Methods
- Expert Judgement
- Comparison to Deemed-to-Satisfy Provisions

The on-site testing requirements appear as Verification Methods FV5.1 and FV5.2 in Volume One and Verification Method V2.4.6 in Volume Two. For Class 2 and 3 buildings, FV5.1 relates to floors and has requirements for both airborne and impact sound insulation while FV5.2 covers requirements for walls and only considers airborne sound insulation. For Class 1 buildings, Verification Method V2.4.6, like FV5.2, covers requirements for walls and only considers airborne sound insulation.

There is no Verification Method for verifying the impact sound insulation performance of walls on-site as there is not currently an accepted test method available. Therefore, where a wall requires impact sound insulation, the wall can be discontinuous construction. Alternatively, if appropriate an Alternative Solution could be developed using one of the Assessment Methods outlined above i.e. expert judgement, comparison to the Deemed-to-Satisfy Provisions, etc.

The terms to describe the airborne sound insulation rating of a building element when tested on-site, is the weighted standardised level difference ($D_{nT,w}$) plus the spectrum adaptation term (C_{tr}). $D_{nT,w}$ is similar to R_w, whilst the purpose of C_{tr} is explained previously in this paper. The higher the $D_{nT,w} + C_{tr}$ of a building element, the better the performance of the building element in terms of airborne sound insulation.

For building elements tested on-site, the airborne sound insulation requirements are as follows:

$D_{nT,w} + C_{tr}$ not less than 45 for walls between dwellings; and

$D_{nT,w}$ not less than 45 for walls separating a dwelling from a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification; and

$D_{nT,w} + C_{tr}$ not less than 45 for floors between dwellings and between dwellings and a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification.

It should be noted that the level of airborne sound insulation that the wall needs to achieve on-site, is less than that required for a building element tested in the laboratory. The lower requirement for elements tested on-site reflects the fact that on-site airborne sound insulation performance is generally less than laboratory tested samples due to the penetration of pipes, doors, and possibly less than exact standards of workmanship. There are also "flanking sound" considerations. Flanking sounds are where noise is able to pass through an element via wall/floor junctions, cross walls or service penetrations. Thus, the on-site testing requirement has been set with the objective of ensuring that the stringency of this requirement is, as near as possible, equal to that of the laboratory testing requirement. The differential proposed between laboratory and on-site testing standards, accords with advice from the acoustics industry. In this context it can be noted that the USA International Building Code also has a 5-unit concession for on-site testing.

The terms to describe the impact sound insulation rating of a floor when tested on-site, is the weighted standardised impact sound pressure level ($L'_{nT,w}$) plus the spectrum adaptation term (C_I). $L'_{nT,w} + C_I$ is similar to the laboratory term $L_{n,w} + C_I$ (see Quantification of Floor Impact Sound Insulation Ratings). For floors tested on-site, the impact sound insulation requirements are as follows:

- $L'_{nT,w} + C_I$ not more than 62 for floors separating dwellings and for floors separating dwellings from a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification.

Doors

The new provisions have introduced requirements for dwelling entry doors where the entry door adjoins an enclosed common area within the building, e. g. hallway, and stairway. If a door assembly is located in a wall that separates a sole-occupancy unit from a stairway, public corridor or the like, the door assembly must achieve a certain level of airborne sound insulation. For a door assembly tested in the laboratory, this level of sound insulation is R_w not less than 30, and for a door assembly tested on-site the level of airborne sound insulation is $D_{nT,w}$ not less than 25. For a door assembly located in a wall that separates 2 dwellings, the door assembly must meet the requirements prescribed for the wall, i.e. $R_w + C_{tr}$ not less than 50 or $D_{nT,w} + C_{tr}$ not less than 45.

Services

The BCA Performance Requirements for sound insulation previously specified that the required sound insulation of walls and floors must not be compromised by the incorporation or penetration of a pipe or other service element. The BCA Deemed-to-Satisfy Provisions had some requirements to deal with piping, but these requirements only dealt with soil and waste pipes.

The changes have extended the Deemed-to-Satisfy Provisions so that they also cover water supply pipes, duct work and storm water pipes. The level of acoustic performance that water supply pipes, duct work and storm water pipes must meet are as per the requirements for soil and waste pipes. The requirements for soil, waste, water supply pipes and duct work apply only where these elements pass through more than one dwelling. The requirements for storm water pipes apply to any pipe that passes through a dwelling in a Class 2 or 3 building.

Deemed-to-Satisfy Methods

The Deemed-to-Satisfy Provisions in Volume One of the BCA and the acceptable construction practice in Volume Two had tables listing the R_w for some common forms of construction. The tables were included in the BCA to give practitioners details of some forms of construction that meet the sound insulation requirements. Therefore practitioners using the prescriptive (Deemed-to-Satisfy) BCA requirements had the option of using a system listed in these tables, or using a system that had been tested in the laboratory in accordance with the appropriate test.

In light of the changes, these tables have been updated to list wall and floor systems which comply with the new requirements.

4. CASE STUDY

Due to the proposed changes there are a number of methods to determine compliance with the proposed BCA sound insulation Performance Requirements. For example, any one of the following ways could achieve compliance for a new apartment building:

Option 1 – Prescriptive Approach – Deemed-to-Satisfy Provisions

The developer could use a prescriptive approach and comply with the BCA Deemed-to-Satisfy Provisions. As an apartment building is typically a Class 2 building, the building would need to comply with the sound insulation provisions of Volume One. The developer would need to install wall/floor systems that achieve the levels set out below:

- Walls between apartments would require an $R_w + C_{tr}$ not less than 50 when tested in the laboratory.
- Walls between an apartment and a plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification would, require an R_w not less than 50 when tested in the laboratory.
- Door assemblies located in a wall between an apartment and a stairway, public corridor, public lobby or the like, would require an R_w not less than 30 when tested in the laboratory.
- Walls between a bathroom, sanitary compartment, laundry or kitchen in one apartment, and a habitable room (other than a kitchen) in an adjoining apartment would need to be discontinuous construction.
- Floors between apartments and between an apartment and another part of the building would require a $R_w + C_{tr}$ not less than 50 and a $L_{n,w} + C_I$ not more than 62, when tested in the laboratory.

The developer could use-

- wall/floor systems that have been verified by laboratory testing as achieving the above levels; or
- wall/floor systems described in the BCA that meet the above levels.

Option 2 – Performance Approach – Verification Methods

The developer could use a performance approach, where compliance is to be checked using the Verification Methods. The Verification Methods relevant to a Class 2 building are FV5.1 and FV5.2. The Verification Methods require the following:

- Walls between apartments would require a $D_{nT,w} + C_{tr}$ not less than 45 when tested on-site.
- Walls between an apartment and plant room, lift shaft, stairway, public corridor, public lobby or the like, or parts of a different classification, would require a $D_{nT,w}$ not less than 45 when tested on-site.
- Door assemblies located in a wall between an apartment and a stairway, public corridor, public lobby or the like, would require a $D_{nT,w}$ not less than 25 when tested on-site.
- Floors between apartments and between an apartment and another part of the building, would require a $D_{nT,w} + C_{tr}$ not less than 45 and an $L'_{nT,w} + C_I$ not more than 62 when tested on-site.

There is no Verification Method for satisfying the Performance Requirement FP5.2(b). This requirement requires a wall separating a bathroom, sanitary compartment, laundry or kitchen in one apartment from a habitable room (other than a kitchen) in an adjoining apartment to have resistance to impact generated sound.

The options for compliance for walls in this situation would be to comply with the Deemed-to-Satisfy Provisions (i.e. discontinuous construction) or develop an Alternative Solution using one of the Assessment Methods outlined in the BCA, i.e. expert judgement, comparison to Deemed-to-Satisfy, etc.

Option 3 – Performance Approach – Checking of Compliance

The developer could use a performance approach where compliance is checked using:

- Documentary Evidence as described in A2.2 of the BCA; or
- Expert Judgement; or
- Comparison to Deemed-to-Satisfy Provisions.

An example of Documentary Evidence would be the use of a wall or floor system which has a Certificate of Accreditation or Certificate of Conformity. A Certificate of Accreditation is a certificate issued by a State or Territory accreditation authority stating that the properties and performance of a building material, or method of construction or design, fulfill specific requirements of the BCA. A Certificate of Conformity is similar to a Certificate of Accreditation however, it can only be issued by the ABCB.

An example of Expert Judgement would be the use of a wall or floor system that meets the sound insulation Performance Requirements as determined by an appropriately qualified and experienced person.

An example of comparison with the Deemed-to-Satisfy Provisions could be the use of a test method that is not referenced by the BCA. If it is demonstrated that the test method is suitable for the particular application, a Deemed-to-Satisfy wall or floor system could be tested, followed by testing of a system that the developer wishes to use. If testing the wall or floor system shows that the system is no less resistant to sound than the Deemed-to-Satisfy system, it could be deemed that the system is comparable and therefore meets the Performance Requirement.

5. CONCLUSIONS

The changes to the BCA sound insulation provisions are significant and will contribute to the BCA sound insulation requirements better meeting community expectations. The new measures have generally increased the levels of sound insulation, introduced impact requirements for floors, extended the scope of the requirements for services and introduced the option of on-site testing to verify compliance.

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Interlude

ACOUSTICS IN THE INTERNATIONAL YEAR OF PHYSICS

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As readers may or may not know, the year 2005 has been designated by the United Nations as the International Year of Physics. Although the present issue of *Acoustics Australia* is nominally that for December 2004, most of you will not be reading these words until January 2005, so it is appropriate to reflect briefly upon the role of acoustics in the history of physics.

First, however, let me remind you of why there is something special about the year 2005 in relation to physics. It all relates to someone who is today regarded as probably the most famous physicist of all time, Albert Einstein. In 1905 he was working as a patent examiner in the Patents Office in Zurich, Switzerland, a position that he apparently enjoyed, although he was ultimately to become a University Professor. In the spare time allowed from his work he carried out experiments and devised theories in physics, and in 1905 he published three papers that revolutionised the subject.

The first, and least quoted of these, was an explanation of Brownian motion, the jittering behaviour of tiny particles suspended in liquid when they are observed with a microscope. This he interpreted in terms of the random impact of molecules in the surrounding liquid, and from this he devised a theory to explain diffusion at a molecular level.

The second was his explanation of the photoelectric effect, in which electrons are emitted from a solid under the influence of light, for which he was awarded the Nobel Prize in 1921. Why was this so important? Well, it showed that light, which was well known at the time to be an electromagnetic wave, behaved also as a stream of particles, much as Newton had thought two hundred years before. Einstein thus shed new light on Planck's equation $E=h\nu$ for the energy E of one of these particles, later called a photon, where h is Planck's constant and ν is the frequency of the light involved. This work paved the way for the later development of modern quantum mechanics by Schrödinger, Heisenberg and Bohr.

The third paper put forward Einstein's most celebrated work, the theory of Special Relativity, and introduced the equation $E=mc^2$, which is certainly the most famous equation in modern physics. This equation relates the energy E contained in a particle to its mass m and the speed of light c. It shows ultimately that, by sacrificing a very small amount of mass, an immense amount of energy can be released. This led in due course to an understanding of the Sun's energy and to the development of nuclear reactors and the atomic bomb.

So what does acoustics have to do with all of this, apart from the fact that Einstein played the violin? At first sight one might be inclined to say "Nothing!" But perhaps we have to look back much further in the history of physics to find the connection, and this is what I will try to do here. I know of three excellent books on the history of acoustics, by R. Bruce Lindsay [1], Frederick V. Hunt [2], and Robert T. Beyer [3] respectively. I have consulted these frequently in writing this short piece and I leave you to check these for further details on what I have written. They will well repay your attention.

IN THE BEGINNING …

Physics as we know it today can probably be regarded as beginning with the Greek philosopher Pythagoras in about 600 BC. Certainly there were many well-developed technological activities such as metallurgy and architecture before that time, but Pythagoras was one of the first to attempt to quantify behaviour in numerical terms. He was particularly fascinated with small prime numbers such as 2 and 3, and felt that much of the universe could be explained in numerical terms. According to legend, one reason for this fascination was his observation that musical intervals such as the octave and the fifth corresponded to dividing the length of a string in simple ratios such as 2:1 (for the octave) and 3:2 (for the fifth). These two primes remained the basis of musical tunings for nearly a thousand years, and it was not until the time of the Muslim philosopher Al Farabi or Alpharabius (ca. 870–950AD) that the third prime 5 was introduced and made the musical major and minor thirds (5:4 and 6:5) concordant. These intervals were regarded as discords in Pythagorean tunings, since their ratios were 81:64 and 32:27 respectively and thus far from simple. Modern ears, of course, have become tolerant of discords because of the use of equal temperament, in which no intervals except the octave have a simple frequency ratio and everything is based upon $2^{1/12}$. Musical acoustics was not just concerned with tunings, however, and as early as the 13th Century Safi al-Din produced a good qualitative description of resonance in the tubes of wind instruments in terms of the reflection of pulses of air.

Music, in ancient times, was also taken to be the basis of astronomy, or at least of the arrangement of the planets in the solar system. The "Music of the Spheres" tended to dominate ancient astronomical thinking and, while it proved to be a false analogy, it did at least serve to bring some sort of order into what was otherwise a completely inexplicable system.

Music, the underlying theme of acoustics, was also close to the basis of medieval education, which was traditionally divided into two parts. The more basic disciplines Grammar, Rhetoric and Logic constituted the *trivium* (from which is derived our word "trivial"), for without knowledge of these no-one could express themselves effectively and be considered educated. Above the trivium came the *quadrivium*, consisting of Arithmetic, Geometry, Music and Astronomy, for these four subjects were those upon which something intellectually useful might be said.

One of the most widely known early observations in the science of acoustics and vibration was that of Galileo (1564–1642), who introduced the modern concept of frequency and observed, during a long and boring religious ceremony, that the period of a pendulum is independent of its amplitude. Galileo is, of course, best known for his astronomical theories, but in the present context it is relevant to note that he also "had a modest skill on the lute". I return to this observation later. Another important contributor to acoustical knowledge at about this time was Marin Mersenne (1588–1648), who wrote several books on the subject and was also a well-known composer whose works are still heard today. Among many other things, he made semi-quantitative measurements of the speed of sound, arriving at the value of 448 m/s, which is pretty good considering the measurement apparatus available at the time. Isaac Newton returned to this problem from a theoretical perspective about a hundred years later.

Architectural acoustics, of course, also has a very long history, albeit of a rather qualitative but practical kind. Seneca (4BC–65AD) posed questions about the effect of absorbent straw placed on the floor where an orchestra is playing, while Vitruvius (ca. 25BC) at about the same time raised questions about reverberation. Without a doubt, however, the amphitheatres built in Roman times and the cathedrals built nearly a thousand years later do have very impressive acoustical properties. By the 17th century, architects had a good understanding of sound propagation and reflection, as indicated by the architectural drawings of Athanasius Kircher in about 1650.

MODERN TIMES

Acoustical knowledge developed steadily from the time of Newton (1642–1727) in a prelude to modern times. Among the famous mathematicians and physicists who published books and papers on acoustics can be numbered Euler, Lagrange, Poisson, Laplace, Wheatstone, Faraday and Ohm. Details of some of their contributions can be found in the compilation by R.B. Lindsay [1]. All of them, of course, also contributed immensely to other branches of mathematics and physics.

Modern times in acoustics, however, begin with Hermann von Helmholtz (1821–1894) and John William Strutt (1842–1919), later to be Lord Rayleigh. The immensely influential books that they published on the subject [4,5] are still consulted today. Both were notable scientists – Rayleigh as Professor of Physics at Cambridge and Helmholtz as Professor of Physiology in a succession of German universities, and then the first Director of what is now the PTB (the Physikalisch Technische Bundesanstalt), the premier government physics laboratory of Germany. Rayleigh, in particular, set down mathematical versions of the theory of acoustics which, in that they described waves of many types and included dispersion phenomena and variational principles, later provided much of the mathematical basis of quantum mechanics (though he did not, of course, foresee the Schrödinger equation!).

A further notable advance in acoustics took place in the late 19th century with the development of mechanical and then electronic methods for recording, analysing, and distributing sound. It is interesting to note in this connection that Edison had a strong interest in acoustics and was made the first Honorary Fellow of the Acoustical Society of America in 1928, less than a year after its foundation. No other Honorary Fellow was appointed for another ten years.

As in most branches of science, the twentieth century saw huge advances in physics generally, and these tend to overshadow the advances made in acoustics. But think where we would be without those advances. No stereophonic sound, or even high quality sound reproduction at all. No music CDs or even LPs. No broadcast concerts on radio or TV. No electronic musical instruments. No ultrasound medical scanning. Certainly life would still go on, but it would be much less rich in sensory experience.

MUSIC AND LIFE

Finally, let me comment briefly upon the relationship between music and the intellectual lives of some of the great physicists, and even of the ordinary physicists of today. I have already mentioned that Mersenne played the lute and Einstein played the violin. How many other famous scientists were also competent performing musicians I do not know, but an observation of the connection between physics and music in contemporary society is illuminating. I have myself played in perhaps half a dozen amateur orchestras in America and Australia, and I have recently made a practice of discovering the educational and occupational backgrounds of the more competent players in these groups. Omitting those few who are retired professional musicians, I find that, somewhat surprisingly, the overwhelming majority of these players have a background in mathematics, physics or engineering and a smaller number in other branches of science; very few have a background in the humanities or social sciences. It seems that competence in the actual performance of music is closely related to ability in the physical sciences, while those whose interest is in the humanities are generally content to write about and discuss the subject without having much practical ability themselves. I put this hypothesis forward as a fruitful theme for a possible PhD thesis in psychology!

Let me return then to restate my original theme. I believe that there has always been a close link between acoustics, particularly in its most refined form as music, and deep and original thinking in mathematics and the physical sciences. The Australian Institute of Physics is holding a special Congress in Canberra from January 31 to February 4, 2005, and our Society is organising two special sessions on Acoustics and Music. Let us join in celebrating this International Year of Physics in the knowledge that this also makes it the International Year of Acoustics.

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2. F.V. Hunt *Origins in Acoustics* (Acoustical Society of America, 1978, 1992)
3. R.T. Beyer *Sounds of Our Times: Two Hundred years of Acoustics* (Springer-Verlag, New York, 1999)
4. H.L.F. Helmholtz *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (1877) (reprinted, Dove, New York,1954)
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Book Reviews

Computer Speech - Recognition, Compression, Synthesis

2nd Edition

Manfred R Schroeder

Springer-Verlag, Berlin, 2004, 375 pp (hard cover), ISBN 3 540 21276 1. DA Information Services, www.dadirect.com Price A$152.52 approx.

Computer Speech consists of eleven chapters, two appendices; together with a list of references, genral reading, selected journals, and a sample of significant societies and conferences. Topics covered by the book include an introduction and history of speech (a chapter each), speech recognition and speaker identification (a single chapter!), speech dialogue systems, speech compression, speech synthesis, speech production, the speech signal, hearing, binaural hearing (a separate chapter to hearing), and basic signal concepts. The appendices include a discussion of vocal tract modelling and the relationship between linear predictive coefficients and the cepstrum. It is worth noting that this is the 2nd edition of “Computer Speech” - having first been published in 1999. It differs from the 1st edition by the inclusion of the 40-page chapter on speech dialogue systems and natural language processing.

Schroeder has a unique style that manifests in a number of ways. Firstly, the chapter structure is quite unusual. In most books, chapters such as The Speech Signal and Basic Signal Concepts would be found early; perhaps straight after an introduction - providing both a building-block and background for their discussion as part of recognition, identification, or synthesis systems. Here they are found as chapters eight and eleven of an eleven chapter book. Similarly, topics are given emphasis in disproportion to their prominence in the literature. Speech Recognition and Speaker Identification are grouped together as a single 26-page chapter - if you attended a typical speech conference you would find over half of all papers presented would be in these two areas. Conversely, hearing is given two chapters - the second being on binaural hearing. Secondly, Schroeder’s prose is quite distinctive; including a number of anecdotes and personal references. This is in marked contrast though to the strong mathematical streak found in a few of the chapters and the appendice; where formulae are the norm.

In all the book stands as a unique reflection of the work and perspective of an important speech researcher active during the last half century and particularly in the early seminal years of computer speech processing. Those readers seeking a “textbook” introduction to speech processing by computer in order to come up to speed with the cutting edge, will be disappointed. What you will find is a link to the earlier days of computer speech research and an eclectic mix with wide ranging scope that can be quite thought provoking.

Spike Barlow

Dr. Michael (Spike) Barlow is a senior lecturer and director of the Virtual Environments & Simulation Laboratory within the school of ITEE, UNSW@ADFA (University of NSW, Australian Defence Force Academy). Spike has worked in computer speech since 1985 including speech synthesis, speaker recognition, and large vocabulary continuous speech understanding systems - both in Australia and Japan.

Ecological Psychoacoustics

John G Neuhoff (editor)

Elsevier Academic Press, California, 2004, 350 pp (hard cover), ISBN 0-12-515851-3. Distributor Elsevier Australia, Tel 1800 263951, service@elsevier.com.au Price A$117 approx.

This is a well-intentioned, and certainly timely, foray into some relatively uncharted territory, namely, sound and hearing understood as integral to the structures and ongoing currents of the environment and activities within it. There are valuable chapters on dynamic and intersensory events, and, with some exceptions, the mix of theoretical and empirical presentation is well-balanced.

An ecological approach to sound and hearing is largely inspired by the radical theorising of James Gibson, whose work included a lively treatment of the auditory world and animals’ orientations within it (Gibson, 1966). One or two contributors to the present volume note that the great bulk of Gibson’s effort was oriented to giving accounts of the perception of the visible world. Part of an explanation for that may lie in the fact that Gibson was profoundly hearing impaired (Gibson, 1967), hence the visible world probably took up more of his time. Nonetheless, he captured many significant issues needing to be addressed in an ecological approach to sound and hearing, and a great deal of the literature reviewed in the present book shows that a large range of subsequent researchers have taken up the challenge. Given my own predilections, I would have welcomed a section on the auditory ecology considered in relation to impaired hearing (something Gibson shunned).

The majority of the contributions to this book serve well the cause of taking a real-world approach to the study of sound and hearing. I found particularly effective the chapters on dynamic localization, developmental psychoacoustics, perceiving articulatory events, perceptual interactions, and ecological treatments of pitch and loudness. Less satisfactory, and unfortunately, were the first two chapters. The writing quality was not good, and as sections designed to invite the reader into a relatively novel conceptual and empirical world, might actually serve to put people off.

Part of the problem in chapters that are less compelling is that authors are trying on ecological clothing whilst hoping to remain in a different camp. This risks conceptual confusion, and while I am not a dogmatic follower of the Gibsonian line, one of its great virtues is the degree of conceptual clarity Gibson was able to achieve.

This book, despite its unevenness, is a welcome addition to the literature on sound and hearing from an ecological perspective. It is indisputable that such an approach is a necessary addition to the study of auditory perception. Without a strong understanding of how sound behaves in everyday terms, and how listeners behave in relation to it, a more complete appreciation of this foundational system and its links to other perceptual systems is unreachable. This book will serve for no little time into the future as a valuable source of reference and ideas for an enlarging field of inquiry.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton-Mifflin.

Gibson, J. J. (1967). James J. Gibson. In E. G. Boring & G. Lindzey (Eds.), *A history of psychology in autobiography* (Vol. 5, pp. 125-143). New York: Appleton.

William Noble

The reviewer is Professor of Psychology at the University of New England. His research is in the areas of spatial hearing and hearing disabilities with particular emphasis on binaural hearing.

Excellence in Acoustics Award 2004

Winner - Dr Chris Field for 'Silenceair'

This award aims at fostering and rewarding excellence in acoustics and entries are judged on demonstrated innovation from within any field of acoustics.

Dr Chris Field is the 2004 winner of the Excellence in Acoustics Awards for his 'Silenceair – Natural Ventilation and Noise Reduction for Buildings' project. The project involved the development of Silenceair, which is a fresh air ventilator that also reduces noise intrusion into buildings. Silenceair uses patented passive technology to significantly reduce the transmission of sound through building ventilation openings. Each unit has an aerodynamically shaped ventilation opening and incorporates rows of tubes of different lengths, known as resonators, which are specifically tuned to capture certain sound frequencies that are then diffused and scattered in a direction away from the inside of the building, whilst allowing air to flow in. The unique combination of so many resonators in a singular unit represents the inventive step of the design to reduce noise over a wide range of frequencies. Silenceair can be easily integrated into both existing walls as well as new constructions. Its modular design means that it can be used in multiple units or singularly and can be customised to suit both small and large buildings. Air is drawn into the ventilation opening via an aerodynamically designed path with only minimal resistance.

Finalist - Department of Transport and Regional Services Australian Government for 'Introducing Transparency into Aircraft Noise Assessment and Reporting'

The team from Department of Transport and Regional Services included David Southgate, Jonathan Firth, Nick Fisher and Donna Perera. The opening of the new runway at Sydney Airport in 1994 led to the Australian Noise Exposure Forecast (ANEF) system coming under sustained attack. In response the Department has worked with airports and their communities to develop new ways of describing aircraft noise that allow the layperson to gain an intuitive picture of aircraft noise exposure patterns. A software package TNIP (Transparent Noise Information Package) has been developed and has broken new ground by its user interface and its ability to rapidly produce comprehensible aircraft noise information. TNIP enables generation of 'instant' what-if noise contours – these are innovations that have been picked up internationally.

Dr. Chris Field

David Southgate

Submissions for Excellence in Acoustics Award 2005 – see www.acoustics.asn.au

AAS Council

The Council of the Society met three times during 2004; in June via a telephone hookup and twice during the conference at the Gold Coast. At the last meeting Neil Gross was appointed President and Ken Mikl Vice-President. Byron Martin, Terrance McMinn and David Watkins are continuing in the positions of Treasurer, Registrar and General Secretary. The other Councillors are Charles Don, Norm Broner, Ian Hillock, Colin Speakman, Peter Teague and Alex Duncan. Following is a summary of some of the key outcomes.

Finances - The Council has no income of its own and relies on funding from the Divisions. This takes the form of a levy on membership subscriptions, conference registrations and the amount held in bank accounts of the Divisions. From this income Council pays the cost of running the Society website, subscriptions for organization such as I-INCE, ICA and FASTS, secretarial expenses, Education Grant, audit fees, meetings, etc. This year Council has set a levy on membership subscriptions of 75%, a levy of 5% on Divisions cash assets held at the end of the financial year and a levy on the annual conference of 15% of registration fees. A copy of the Society Financial Report and Accounts can be viewed on www.acoustics.asn.au

Membership - Membership of the Society has increased during the year but there are still many acousticians who do not belong to the Society. Members are asked to encourage their colleagues to join the Society. There has been a fall in the number of Sustaining members over the last few years.

Fellow - Professor Graeme Clark has been awarded the grade of Fellow. Professor Clark, Laureate Professor Emeritus in the University of Melbourne. Professor Graeme Clark, is known around the work for his pioneering research over the past thirty years in development of the multi-channel cochlear implant, now known as the Bionic Ear. This implant allows profoundly deaf children and adults to converse confidently, not only in person but even on the telephone, and leads the world in technology and sales. Some tens of thousands of implants have now been made and have brought immense prestige to Australian acoustic and medical sciences and to Australian industry through the company Cochlear P/L. Professor Clark has received many prestigious Fellowships and Awards, and it is an honour for the Society to be able to name him among our Fellows.

Education Grant - The grant was initiated in 2002 to assist in the teaching and promotion of acoustics. The Education Grant will be continued and is open to anyone seeking funds to assist in the teaching and promotion of acoustics. The grant can be used for scholarships, funding for research projects, equipment for educational purposes and any other worthwhile use.

One award in 2004 was to Joe Wolfe from UNSW who reports that the grant of $3,000 to the Acoustics group at UNSW was used to help set up the testing rig for PhD student John McLennan. A graduate in engineering, John is also a violin maker. He is a distance education student and the grant allowed the purchase of components for a rig to measure components used in the construction of a violin, the mechanoacoustic properties of the instrument at various stages during construction, and the effect on these properties of some of the changes made by makers to finished instruments. Some of John's work is on the group's website at www.phys.unsw.edu.au

The other 2004 awardee was Nicole Kessissoglou from UNSW. As there were 11 PhD students in the School of Mechanical and Manufacturing Engineering in the field of dynamics and acoustics the Head of School (Hartmut Kaebernick) donated $200 so that $2,200 was available. Each student received $200 in cash and free AAS student membership for one year. The awards were presented at the School's annual prize giving ceremony by Ken Mikl, President of AAS. The recipients and their project titles were:

Geoffrey Lucas -The Relationship of Transmission Error in Rear Axle Differentials to Vehicle Noise

Hiroaki Endo - Differential Diagnosis of Spall vs. Cracks in the Gear Tooth Fillet Region

Anne Shen - Adaptive Design and Adjustment of Low Noise Gearboxes

Darren Good - Bladed Disk Diagnostics and Prognostics

Xianhua Liu - Mechanical Application of Blind Source Separation Techniques

Paul G. Dylejko - Optimisation of a resonance changer

Wee-Lee Chia - Blind System Identification in a Multiple Input Multiple Output (MIMO) system using the Mean Differential Cepstrum

Nader Sawalhi - Rolling Element Bearings Diagnostics and Prognostics using Artificial Intelligence Techniques

Jason Middelberg - Prediction of acoustic and mean flow performance of large diesel engine silencers using computational fluid dynamics

James Neale - Development of a Compact Air Distribution System for Ocean Going Fast Ferries

David Hanson - Blind Parameter Identification of a MIMO System with Cyclostationary Inputs and Finite Element Updating

The winning entries for 2005 were announced at the Annual Conference. Rick Morgan from Adelaide University was awarded $2500 for a project titled "Learning Acoustics through Boundary Element Method" to develop interface/documentation for existing BEM codes. Marion Burgess, from UNSW@ADFA, was awarded $2500 to compile a comprehensive information document on careers in acoustics to be placed on the Society website for easy access.

Excellence in Acoustics Award – The winner for 2004 is Chris Field for the Silenceair Acoustic ventilator. Chris has advised he will use the prize to cover some of the legal costs associated with the commercialization of his invention. The runner up team from Department of Transport and Communications Council is pleased that CSR Bradford Insulation will continue to support this award for 2005 and that it has increased the value of the runner up prise.

Award for Outstanding Contribution to Acoustics - Council has decided to initiate a new award to be known as the "Outstanding Contribution to Acoustics awarded by the Council of the Australian Acoustical Society". It is an award made to a member of the Society to recognize extensive contribution to the advancement of acoustics and significant service to the Society. The award consists of a plaque, the cost of travel and accommodation to a function of the Society where the award will be conferred and free life membership of the Society.

Conferences - The conference in November 2005 will be held in Busselton, Western Australia. This will be followed in November 2006 by a combined New Zealand Acoustical Society and Australian Acoustical Society conference.

Retiree registration fee - At future conferences there will be a retired members rate equivalent to the student rate. The criteria for retired status have been changed so that a person applying for the retired rate must have been an AAS member for a least 10 years and must not have been engaged in more that an average of 20 hours of paid work per month.

Position Vacant Advertising – It has been decided to create a Positions Vacant page on the Society website. A small charge will be made for the advertisement and it will be administered by the Business Manager of Acoustics Australia.

Science Meets Parliament - Each year the Federation of Australian Scientific and Technological Societies (FASTS) holds a "Science Meets Parliament" day in Canberra. The event gives those involved in science and technology an opportunity to meet federal politicians and their staff, raise issues of concern, and emphasise the importance of science to the future of Australia. In 2003 Marion Burgess and Joe Wolfe attended the event and raised a number of issues concerning education, research and the future of publicly funded acoustics facilities. This year the Science Meets Parliament day was not held due to the Federal election. The next Science Meets Parliament day is planned for March 2005 and the Society is planning to be represented at the event. If you wish to have issues raised at the event please forward a one page summary to GeneralSecretary@acoustics.asn.au.

Standards Australia - An important part of the activities of the Society is its involvement with the development and revision of standards. For a number of years the Society has been represented on Standard Australia acoustics committees. In addition, the President represents the Society on the Council of Standards Australia. The following is a brief summary of the committee activities during the year.

- *AV-001 Acoustics – Terms, Units and Symbols***.** Graeme Harding and Jim Fowler. The committee has not met during the year.
- *AV-002 Acoustics – Instrumentation and Measurement Techniques.* Peter Always and one position vacant.
- *AV-003 Acoustics – Human Effects.* Les Huson and Ken Scannell. The committee has revised and updated the 5 parts to the Australian/New Zealand Standard AS/NZS 1269 (0-4):1998 "Occupational Noise Management. The final committee ballot has closed and the new standard is expected to be available in 2005. A working group has been formed for the revision of AS 1948.
- *AV-003-03 Audiology.* Tim Klar. The committee has not met during the year.
- *AV-004 Acoustics – Architectural.* Norm Broner and Norbert Gabriels. The committee held a two day meeting in April 2004. Some of the issues discussed include:

    AS 2822-1985 Acoustics – Method of assessing and predicting speech privacy and speech intelligibility. An important standard due for review. Proposed to revise the standard in two parts, one for amplified speech and one for un-amplified speech.

    AS 1045-1988 Acoustics – Measurement of sound absorption in a reverberation room and AS 2253-1979 Acoustics – Methods for field measurement of the reduction of airborne sound transmission in buildings. It was decided to revise these two standards.

    Draft ISO 140-7 Acoustics – Measurement of sound insulation in buildings and of building elements, Part 7: Field measurements of impact sound insulation in buildings. Comments were discussed at the meeting – amendments to be made and published. This document is important as it supports tests required in the Building Code of Australia.

- *EV-010 Acoustics – Community Noise.* Russ Brown and Peter Teague. The committee has not met during the year.
- *AV-007 Acoustics – Noise from Office and Household Equipment.* Valerie Bray. The committee has not met during the year.
- *AV-009 Vibration and Shock Applications.* Byron Martin. The committee did not meet during the year but a number of ISO and Australian Standards, drafts and new work items were reviewed.
- *EV-011 Aircraft and Helicopter Noise.* Norm Broner and Rob Bullen. The committee has not met during the year. It is expected that it will meeting during 2005 to discuss the revision of the standard.
- *EV-016 Acoustics – Wind Turbine Noise.* Peter Teague and Ken Williams. The draft was released and over 200 comments were received which are being examined by the committee. A revised draft is being finalized which will be released for public comments, probably in December 2004.

Standards Australia Committee Vacancy -

AV-002 Committee - *Acoustics - Instrumentation and Measurement Techniques*.

Any member who would like to nominate for this committee is invited to provide a brief description of their experience in this field by 31 January 2005 to the General Secretary, Australian Acoustical Society, PO Box 903, Castlemaine, Victoria 3450 or GeneralSecretary@acoustics.asn.au

Letter

Spectra Wanted

The National Acoustic Laboratories are trying to build a catalogue of typical workplace noise spectra. The current spectra that are used for looking at the noises individuals experience in their work places – the 'NIOSH 100' and the 'SA 300' - were collected from information gathered in the 1950s, '60s and early '70s. Many modern workplaces have changed considerably with new technologies being developed and old work methods being replaced. Hence the current spectra used as workplace examples could be considered old and possibly not really representing the sorts of noises to which people are currently exposed.

NAL would like to collect acoustic spectra from current workplace activities - the sort of information that is gathered during a typical noise survey for occupational noise management purposes. This would include all noisy activities not simply those that may be considered extra noisy. We are after typical noises. The information could be either in hard copy or from electronic records, preferably in the form of octave (or 1/3 octave) band data accompanied by a description of the activity and perhaps a note of how long that activity is undertaken during a typical work day. Activities can include anything that is noisy and is done by people working: heavy plant and equipment; power tools; metal work; wood work; welding; cutting; aircraft; car; trucks; busses; music; … anything that produces a potentially hazardous noise.

This is an on-going project so there is no immediacy to this request. Just be aware that if you have any bits of existing reports you could send in, if you collect any future information or have access to such information we are interested. This project is just too difficult to carry our without your assistance so please think what information you have even one or two spectra will be useful.

Warwick Williams, NAL, 126 Greville Street, Chatswood, NSW, 2070; tel 02 9412 6926, warwick.williams@nal.gov.au

News

Noise and Vibration Course

The University of New South Wales offers postgraduate programs in Noise and Vibration leading to a Graduate Diploma or Master of Engineering Science. The program material provides a combination of theoretical and practically oriented topics, starting from fundamentals of noise and vibration and leading to advanced studies in design, application and noise and vibration control. Specialised courses deal with control of environmental noise and building acoustics, as well as machine condition monitoring based on vibration analysis. Loose leaf insert in this issue gives more details

Information: Mrs Sharon Turnbull, External Studies Coordinator, School of Mechanical & Manufacturing Engineering, The University of New South Wales, NSW 2052 Australia Tel: (02) 9385 4085 Fax: (02) 9663 1222, s.turnbull@unsw.edu.au

Acoustic Invention

As well as winning the AAS Bradford Insulation Excellence in Acoustics Award, Chris Field is the outright winner for the Invention of the Year from the 2004 ABC series New Inventors for his Silenceair. You can read about it on http://www.abc.net.au/newinventors/.

Conference Listing

A comprehensive listing of Science, technology and engineering conference is available on http://www.sciencealert.com.au/events.htm There is no charge for adding your own conferences, workshops, public lectures and events to this listing.

New NATA Image

For the first time since its inception in 1947, NATA (the National Association of Testing Authorities, Australia), has changed its emblem and added descriptors appropriate to both NATA and its accredited facilities. For NATA accredited facilities and the users of testing, inspection and calibration services, the new emblem provides a more contemporary and progressive image for identifying and promoting accredited services. The new emblem will continue to be widely used throughout industry and government to identify competent testing and inspection services.

The new emblem may be accompanied by one of two taglines that clearly describe the unique attributes of NATA-accredited facilities and delineate them from ISO 9000 certified organisations. "World Recognised Accreditation" will be used by NATA and can be used by NATA-accredited facilities covered by the current mutual recognition arrangements. The alternative tagline, "Accredited for Technical Competence", can be used by NATA-accredited facilities in most programs and fields.

Supporting the new emblem is a major upgrade of the NATA website (www.nata.asn.au) based upon recent surveys and feedback from users of the site. The main improvements include more powerful and flexible search options and more secure on-line ordering.

New Facts on Insulation Products

CSR Bradford Insulation now has available new literature from The Insulation Council of Australia and New Zealand (ICANZ) reinforcing the OH&S and environmental facts and dispelling some misconceptions about glasswool and rockwool insulation. Used extensively throughout the world for over 70 years, evidence from monitoring and research indicates that no serious health effects have ever occurred in those manufacturing, using or otherwise exposed to glasswool and rockwool insulation. In October 2001, the International Agency for Research into Cancer (IARC) removed glasswool from its list of possible carcinogens, and reclassified all glasswool and rockwool insulation as 'Category 3 - not classifiable as carcinogenic to humans'. This finding was based on over 30 years of exhaustive research, including long term health assessments on more than 60,000 workers. This followed the introduction of biosoluble glasswool and rockwool (FBS-1) leading to the joint development with key Australian building unions of an Industry Code of Practice for the Safe Use of Glasswool and Rockwool Insulation Products. The Code was then upgraded in 2003 to reflect the new IARC classification of glasswool and rockwool insulation.

Copies of the ICANZ information are available from Bradford on 1300 850 305.

Brüel & Kjær Design Prize

Brüel & Kjær has received the Danish Design Prize 2004 for their new Hand-held Analyzer, developed in cooperation with users in four countries. Sound and vibration is often measured under difficult conditions Brüel & Kjær, therefore, decided to involve 70 professional users from four countries in the development of their latest Hand-held Analyzer Type 2250. The result is a completely new design with well thought-out functions, making it easy and reliable to use, even under extreme conditions. The professional users involved in its development set many requirements for the new generation of sound analyzers. Besides providing a series of intelligent solutions to users' practical problems, the new analyzer can be securely held and easily operated using only one hand. The jury statement was that this Sound Level Meter combines outstanding design and 'state of the art' technology. It is a coherent design expression and ergonomics at its best without aesthetic compromise. The design is clearly influenced by the users who have, laudably, been at the centre of the design process.

Sound Insulation Guideline

The Building Code of Australia (BCA) Sound Insulation Guideline has been released by the Australian Building Codes Board (cost A$47). It has been written to provide additional information to supplement the BCA Acoustic Provisions. The guideline is not intended to replace or supersede the BCA but rather it is an interpretation of the acoustic provisions of the BCA. The objectives of the guideline are to:

- provide guidance on the acoustical design process;
- provide guidance on methods of compliance with the BCA;
- provide guidance on the installation of acoustical elements;
- help achieve acceptable acoustical outcomes within buildings;

The guideline has been written to act as a link between the BCA and users such as architects, builders, engineers, certifiers, project managers, acoustical consultants, subcontractors and other trades people. It is intended to provide guidance to all users of the BCA, be they involved in design, construction, development, certification or approval, as they work to develop, implement or review solutions that provide acceptable levels of acoustic insulation. The guideline summarises the BCA acoustic compliance process, as well as all the options that can be used to satisfy the BCA. It provides tips and examples on good design and construction practices as well as ways of avoiding bad design and construction practices.

Informatio:n Australian Building Codes Board, www.abcb.gov.au

OAEricle

After 15 years at NAL, Eric Le Page is now the director of OAEricle, based in Sydney. Eric is well known for his pioneering work on otoacoustic emission and cochlear physiology. Narelle Murray, formally from NAL, is also working for OAEricle. The web page, www.oaericle.com.au provides a resource for articles and consultation on topics related to the ear and hearing and an on line Tinnitus Survey. Le Page is seeking many respondants for this survey as he states "there is much which we could still learn about the phenomenon, particularly the mechanisms which give rise to it."

New Products

Quest

Sound Level Meter & Real Time Analyser

The SoundPro DLX is a hand held Sound Level Meter and Real Time Frequency Analyser that measures the entire spectrum of full or 1/3 octave bands simultaneously. At the push of a button, measurements are captured at identical phases in the noise cycle on a continuous and automatic basis, ensuring that data is both accurate and credible. Easy to operate, the SoundPro DLX features a large colour graphics PDA-Style Touch-Screen and back-lighted key pad. It is ideal for applications that require monitoring and reporting in accordance with more than one regulation, or where there are two different thresholds for determining compliance with an action level and a permissible exposure level. The SoundPro DLX is suitable for compliance assessment, administrative or engineering controls assessment.

Information from Air Met Scientific, 1800 000 744.

Warsash

Vibration Free Platform

The new 2200 Series BenchMate vibration-free platforms from Kinetic Systems are designed to enhance the performance of atomic force microscopes, microhardness testers, profilometers, balances, audio components, and other precision tabletop equipment. The platforms are available in three different models, each providing application-specific vibration control with low natural frequency. Model 2210 features excellent vertical vibration control and uses a passive-air design that can be operated with an optional hand pump if an air source is not available. Model 2212 BenchMate also features excellent vertical vibration control but uses a self-leveling, active-air unit and is recommended for more regular use. Model 2214 BenchMate offers excellent vertical vibration control and an enhanced, multistage horizontal isolation feature. It is recommended for applications where both vertical and horizontal vibrations are a problem. The 2214 is also a self-leveling, active-air unit that must be connected to a compressor.

Information from WARSASH Scientific Pty ltd on (02) 9319 0122 or sales@warsash.com.au

Matrix

Double Stud Acoustic Wall Tie

Matrix Industries has released a resilient wall tie, the MB-06, for double stud walls. They are ideally suited for both multi residential timber framed construction and steel stud systems. The ties are used to acoustically isolate but structurally connect the two wall leaves together at ceiling height and are spaced at 1.2 m centres along the wall. Builders had been trying to adapt the MB-01 masonry acoustic tie and although it worked it is too rigid for the lighter mass and greater allowable deflection of plasterboard.

Information Matrix Industries P/L, tel (02) 6553 2577 info@matrixindustries.com.au

Bradford Insulation

Comfort Sleeve

The Bradford ComfortSleeve™, makes onsite glasswool installation and handling even easier. An arm's length in size, the unique sleeve design means workers no longer need to wear long sleeve shirts in order to install and handle Glasswool Insulation. A recent survey conducted by CSR Bradford Insulation of over 200 commercial contractors and specifiers suggested that while 74 per cent were aware that glasswool and rockwool fibres were no longer considered hazardous, many were still concerned about possible minor irritation during installation. CSR Bradford FBS-1 Biosoluble Glasswool and Rockwool insulation is considered to be low irritant and low allergen. Any irritation that may exist during installation is mild and easily managed with basic personal protective equipment and measures as detailed in the MSDS and union handbook.

Information tel1300 850 305 or www.bradfordinsulation.com.au.

New Members

Member
John Cristaudo (Qld),
Jeffrey Parnell (NSW)

Associate
Robert Mason (NSW)

Subscriber
Paul Johnson (Qld)

Student
Jacqueline Giles (WA),
Magaesh Naidu (NSW),
Cornelius Petersen (SA),
Robin Wood (SA)

Meeting Reports

Acoustics 2004

Acoustics 2004, the annual conference of the AAS, with the theme 'Transportation Noise and Vibration' was held at the Gold Coast 3-5 November. On all fronts this conference was an outstanding success. There was an impressive range of presentations including invited and keynote lectures and contributed papers. To cater for the high number of submissions the program included up to five parallel sessions including special focused workshops. The lunches and tea breaks allowed time for the all important discussions with colleagues. The conference dinner, held at the conference venue, provided another social opportunity to be enjoyed by all. Ian Hillock and his team are congratulated on organizing such an outstanding conference and hopefully are taking a well earned rest after their sterling efforts. The proceedings of the conference are available on CD from www.acoustics.asn.au

Victoria AGM and TV Studio Visit

On Sep 9 the 2004 Victoria Division AGM was held in conjunction with a site visit to the new Channel 7 Docklands studios as a combined AAS/ANCE meeting. A total of 34 were present. Norm Broner (AAS Vic Div chairman) welcomed all present and opened the AAS AGM. Three of the four retiring committee members were re-elected, with Peter Pirozek elected to replace Elizabeth Lindqvist, who was thanked for her secretarial and other contributions to the committee's work. The Vic Div treasurer, Louis Fouvy, tabled and distributed copies of the audited accounts for 2003/04 and outlined the Division's financial situation.

Following the AGM, Norm Broner introduced John Albiston, Channel 7's Technical Services Manager, who then outlined the various broadcasting activities carried out at these studios. The new Docklands studios were built during 200 to 2002 and opened in April. All master and presentation control functions are located in these Melbourne studios, with interstate distribution. Programs are recorded on to the equivalent of a hard drive (the servers) so that one file only needs to be accessed, instead of several tape records as formerly.

Of particular acoustical interest during the inspection were the studios and control rooms for talk sessions which were designed for low reverberation, and the news reading studio, which was on a floating slab floor supported on low frequency springing to minimize vibration transfer into the studio. At the end of the visit, Norm Broner, on behalf of all present, thanked Channel 7 for an interesting and informative visit.

City Sounds

On Oct 26 around 20 members of the Vic Division attended an audible demonstration of 'City Sounds' in the SIAL Sound Studios of the main RMIT Campus, Melbourne. Norm Broner introduced Lawrence Harvey (of RMIT Architecture & Design) who began by describing the work done on recording 'City Sounds"

CitySounds was developed for the City of Melbourne, to investigate individual persons' awareness of, and attitudes towards sounds occurring within the CBD. The Melbourne City Council (MCC), in seeking to promote a diverse and lively inner city culture, deals with a wide variety of sounds and related issues which affect its commercial operators, residents, visitors and workers. The Council required a means of collecting a wider variety of individual persons' responses to the CBD's acoustic environment and aural experiences than was currently available from noise complaints or acoustical measurements.

To achieve this, the SIAL Sound Studio staff, using the Auran Jet games engine, developed a combined 3D visual model of typical CBD precincts with their corresponding soundscape, together with a series of survey questions to be answered by those taking part in the survey. All sounds were recorded in stereo CD quality audio.

A special feature of the audio-visual recordings was that they are not static, but designed to simulate the sights and sounds experienced by a person moving through each particular location in order to test people's awareness of, and attitudes towards the various corresponding sounds. These included those such as loudspeaker noise in city streets, the sounds in laneways and arcades partially protected from street noise, construction site noise, and the various apartment sounds in rooms with different degrees of soundproofing. These were all demonstrated in a specially designed sound-proofed low reverberation listening room within the Sound Studios, and afforded a good impression of the high degree of realism obtainable.

At the end of the demonstration, Norm Broner thanked Lawrence Harvey and his assistants for a most interesting and informative evening.

Louis Fouvy

Building Acoustics Workshop

The following issues were discussed in the workshop focused on the changes to the acoustic provisions in the Building Code of Australia which was held during Acoustics 2004 Conference at the Gold Coast. *(Refer to article by Patterson in this issue)*

Ci – Correction term for impact rating It was generally agreed that $L_{n,w} + C_i$ <62 is not an appropriate form of impact rating of floors. Approximately 115 floor systems have been tested by Renzo Tonin and Assoc. These floors were of all standards, including some which were bare and untreated, and all floors passed the BCA impact requirement. Suggestions were to upgrade the BCA impact noise criterion with either: $L_{n,w}$<57, or $L_{n,w}$<45. The suggestion of the use of $L_{n,w} – C_i$ <62 is an inappropriate one because it is not consistent with ISO 717-2

Waste Pipe Separation Comments were that $R_w + C_{tr} > 40$ may not be met by the current practice of wrapping waste pipes in a loaded-vinyl barrier material over foam backing, and with a single plaster ceiling barrier. The C_{tr} term is reliant on the performance of the system especially at low frequencies such as 200 Hz. At this frequency the ceiling/wrapping combination has poor performance. No-one has yet conducted formal testing of waste pipe treatments which demonstrates compliance or otherwise with the BCA requirements.

Field $D_{nT,w}$ rating of floors and walls Comments were made that R'_w is not an appropriate replacement for $D_{nT,w}$ and that $D_{nT,w}+Ct_r$=45 is easier to meet than R_w+C_{tr} =50. Field data provided by Renzo Tonin & Associates show that $D_{nT,w}+C_{tr} = R_w+C_{tr} – 2.5$ and for R_w+C_{tr} = 50, a limit of $D_{nT,w}+C_{tr}$ 45 is probably too low. The relative difference between R_w+C_{tr} and $D_{nT,w}+C_{tr}$ is also dependant on the depth of the receiving room, so that the deeper the room, the better the value.

Field $D_{nT,w}$ rating of access doors Because of the more lax standard in the $D_{nT,w}$ noted above, tests reveal that a $D_{nT,w}$ 25 rating can probably be met for access doors with no acoustic seals despite such doors probably not meeting the R_w 30 laboratory criterion. Comments were made that field tests using the apartment corridor as the source room and the public hallway behind the access door as the receiving room are not considered appropriate. Comments were also made that limits should be set on the depth and shape of rooms in which valid tests can be conducted.

BCA Verification Methods Five methods of verification can be used to meet the BCA acoustic provisions. Discussions regarding inconsistent results between the different methods of verification on the same building especially where, for example, field test results showed poor performance or non-compliant performance whereas other methods of compliance were used to meet the

BCA requirements. An opinion was ventured that the BCA verification methods can only be used to demonstrate compliance, not non-compliance. For example where an occupant of an apartment commissions field testing which demonstrates poor performance after another form of verification (e.g. DTS or Equivalence) was used for the design. It was discussed that this scenario may prove rare as the degree of proof required to verify compliance would be high in practice if field testing was not used. It may be that only a court case could confirm the validity of the different methods of verification.

Deemed to Satisfy Systems Deemed-to-satisfy systems are not well defined in the BCA. Currently some described systems have test results which show a pass and other results which show failure to comply with the BCA provisions. It was discussed that there is variability in the testing regimes. National Acoustics Laboratory would expect a variability of 3 dB in R_w performance. It was ventured that the ABCB should administer and research this information more closely and that an updated method of description of DTS systems should be used to define acceptable systems. An approach similar to the UK "Robust Standard Details" could be used

Changes in the Building Industry A comment was made that there has been a change evident in the general attitude of members of the building industry since the launch of BCA 2004. Previously some members of the building industry were happy to meet the BCA R_w 45 & R_w 50 limits with little or no margin of safety. Now there appears to be a larger section of the industry developing the attitude of exceeding the BCA requirements to provide a larger margin of safety.

Martti Warpenius

Future Meetings

AIP Congress - Acoustics and Music

For the first time there will be a special session on Acoustics and Music at the Australian Institute of Physics Congress in Canberra , 31 Jan to 4 Feb 2005. Joe Wolfe has organized this session and it will include 14 presentations – some as posters. Further information on this congress from www.aip.org.au

Acoustics 2005

ACOUSTICS 2005, the annual conference for the AAS will be held in Bussleton, WA from 9 to 11 November 2005. It will be a time to consider how well the acoustics profession is serving the community in applying the best available science and technology in our ever changing environment. The emphasis of the Conference will be on practical applications of acoustical science and technology and practical solutions to acoustic problems. Topics will include: Underwater, bioacoustics, propagation, sonar, environmental impact, architectural acoustics, environmental noise, transport, industrial, occupational health, engineering noise control. Papers on all these topics are welcomed and deadline for abstracts is 29 April with papers due 1 July 2005

Abbey Beach Resort, the venue for ACOUSTICS 2005, is 2.5 hours south of Perth in the beautiful South West and nestles on the beachfront of Geographe Bay amidst landscaped gardens and lakes. It provides convenient access to nearby scenic attractions, wineries, galleries, restaurants and secluded beaches. The Resort comprises a Hotel and 1, 2 and 3 bedroom fully serviced, self contained apartments and studio units all of which have a private balcony and private double spa.

Information from www.acoustics.asn.au

Inter-noise 2005

Inter-Noise 2005 Congress will be held from 7 to 10 August, 2005 at the SOFITEL Hotel on the beautiful Copacabana beach in Rio de Janeiro, Brazil. The main theme of the Congress is ENVIRONMENTAL NOISE CONTROL, but technical papers in all areas of noise and vibration control are very welcome. Congress participants and accompanying persons will have the opportunity to take part in a wide range of social, cultural and sightseeing activities organised during and after the congress.

Inter-Noise 2005 will have a very rich exhibition of worldwide noise and vibration equipment, software, and materials for noise and vibration control. Pre-congress courses and distinguished speakers will provide information on up-to-date technologies in the field. A number of structured sessions and distinguished lectures are in preparation. The congress will be the most prestigious noise control event of the year 2005. Deadline for the receipt of the abstracts is January 30, 2005 with final manuscripts by April 30, 2005.

At this Inter-Noise 2005 Congress, you will not only exchange information with all your international colleagues, but you will also be able to explore the rich market for noise and vibration control engineering in South America. Brazil has many industrial products such as passenger jet airplanes manufactured by EMBRAER and the largest automotive assembly plants in the world representing all the major brands worldwide. And these are two of the many categories of South American products for which noise and vibration technology plays a very important role regarding comfort and quality. Other categories include hydroelectric power stations (numerous), food industries, domestic appliance manufacturers, construction companies, and many others.

Information http://www.internoise2005.org.br

Musical Acoustics Course

The International Advanced Course on Musical Acoustics (IACMA) will be held in Bologna (Italy), July 18-22, 2005. The course is especially intended for people with a basic knowledge of mathematics, physics and acoustics, but with more experience in music, including all aspects, like restoration and conservation of musical instruments, construction of new instruments, or performing music in a widely sense. It will cover all aspects on musical acoustics, ranging from the basic fundamental of linear acoustics to experimental aspects of the restoration and conservation of musical instruments. The topics are so important also for musicians and composers, as sound synthesis and room acoustics. The lecturers will come from a range of countries to give a real international overview of this fascinating discipline. All lectures will be in English.

Information http://www.iacma.it/

ICSV 12

The 12th International Congress On Sound And Vibration (ICSV12) will be held on July 11-14, 2005 in Lisbon, Portugal. This conference will have both an important and comprehensive scientific programme as well as an exciting social programme so that you can experience first hand the considerable cultural attractions of Lisbon and the many sites of historical and general interest in and around the city. The city has many splendid architectural treasures, including the most beautiful buildings of the late 18th century in Baixa Pombalina and historic neighbourhoods such as Alfama. Lisbon is now a modern and a very safe city.

ICSV is sponsored by the IIAV (the International Institute of Acoustics and Vibration) and by Instituto Superior TÊcnico (IST), in cooperation with the Portuguese Acoustical Society (SPA), the Portuguese National Civil Engineering Laboratory (LNEC), the Spanish Acoustical Society (SEA), the American Society of Mechanical Engineers (ASME International) and the International Union of Theoretical and applied Mechanics (IUTAM).

Information: *www.icsv12.ist.utl.pt.*

Diary

2005

31 Jan-4 Feb, Canberra
AIP Conf, Physics for the nation
www.aip.org.au

19 - 23 March, Philadelphia
International Conference on Acoustics, Speech, and Signal Processing.
www.icassp2005.org

18 - 21 April, Saint Raphaël
Intl Conf Emerging Technologies of Noise & Vibration Analysis & Control.
goran.pavic@insa-lyon.fr

01 - 03 June, Hiroshima
1st Int Symp on Advanced Technology of Vibration and Sound.
dezima.ike.tottori-u.ac.jp/vstech2005

20 - 23 June, Brest
IEEE Oceans05 Europe.
http://www.oceans05europe.org

27-29 June, Le Mans
Managing Uncertainties in Noise Measurement and Prediction
www.uncertainty-noise.org

28 June - 1 July, Heraklion
Int Conf Underwater Acoustic Measurements: Technologies and Results
http://UAmeasurements2005.iacm.forth.gr

11-14 July Lisbon
ICSV12
www.icsv12.ist.utl.pt, icsv12@ist.utl.pt.

19-23 March, Philadelphia
Int Conf Acoustics, Speech, and Signal Processing.
http://www.icassp2005.com

18-21 July, PenState
Int Symp Non Linear Acoustics.
atchley@eng.psu.edu

7-10 August, Rio de Janeiro
Inter-Noise 2005.
www.internoise2005.ufsc.br,
support@internoise2005.org.br

05 - 09 September, Bath
Boundary Influences in High Frequency, Shallow Water Acoustics.
http://acoustics2005.bath.ac.uk

11 - 15 September, Beijing
6th World Cong Ultrasonics (WCU 2005).
www.ioa.ac.cn/wcu2005

17 - 21 September, Pittsburgh
Interspeech 2006 - ICSLP
www.interspeech2006.org

9-11 November, Bussleton
Acoustics 2005
Acoustics in a Changing Environment
www.acoustics.asn.au

2006

15 - 19 May, Toulouse
IEEE International Conference on Acoustics, Speech, and Signal Processing
(IEEE ICASSP 2006).
http://icassp2006.org

26-28 June, Seoul
WESPAC9
www.wespac9.org

03 - 07 July, Vienna
13th International Congress on Sound and Vibration (ICSV13)
http://info.tuwien.ac.at/icsv13

28 November - 02 December, Honolulu
Acoustical Soc of America & Acoustical Soc of Japan Fourth Joint Meeting.
http://asa.aip.org

3-6 December, Honolulu
Inter-Noise 2006.
www.i-ince.org

2007

9-12 July, Cairns
ICSV14
n.kessissoglou@unsw.edu.au

2-7 September, Madrid
ICA2007
www.ica2007madrid.org

9 - 12 September, Barcelona.
Symposium on Musical Acoustics (ISMA2007)
www.ica2007madrid.org

2010

August, Sydney
ICA2010
www.acoustics.asn.au

Meeting dates can change so please ensure you check the www pages.
Meeting Calendars are available on www.icacommission.org/calendar.html and www.i-ince.org.

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Vol 32 2004

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* Payment of annual subscription
* Proceedings of annual conferences

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