Discrete layered sound

PHILIP NEWELL outlines the essentials of a recent paper, co-written with Shelley Katz, that describes an interesting new approach to surround sound*.

MORE THAN 30 years have now passed since the introduction of commercially available recordings with four or more channels. Much of the relative failure of Quadrophonics during the 1970s was attributed to the limitations of domestic vinyl disc and analogue magnetic tape reproduction systems, but even in the 1990s, with the launch of multichannel digital discs, many of the old failings still seemed to be evident. Clearly, with the perfect reproduction ability of the digital discs, the medium could no longer be blamed for the lack of realistic reproduction. Something therefore seemed to be missing from the concept of the recording and reproduction systems, and not just from the distribution systems.

After some months of discussions with Shelley Katz, who had been developing his Layered Sound concept, a recording session was arranged to take place over two days in the wood-panelled, Elizabethan Room, at Herstmonceux Castle in southern England. The first day's recordings were of a trio of grand piano, flute and soprano voice, and the second day's recordings were of grand piano, double bass and a drum kit. The microphone arrangement for the first recordings is shown in Figure 1.

What gave rise to the concept of these recordings was a pair of papers presented at the Institute of Acoustics Reproduced Sound 20 conference in November 2004. The first paper was highly critical of the current state of affairs with surround sound (1) while the second suggested a new means of creating much less correlated ambience in the reproduction room (2). One of the main criticisms in the first paper was about the way in which so many surround systems and designs of surround room acoustics were limiting the full potential of the frontal stereo sound stage, and one of the main benefits claimed in the second paper was that distributed mode loudspeakers (DMLs) could reproduce ambience better than conventional pistonic loudspeakers.

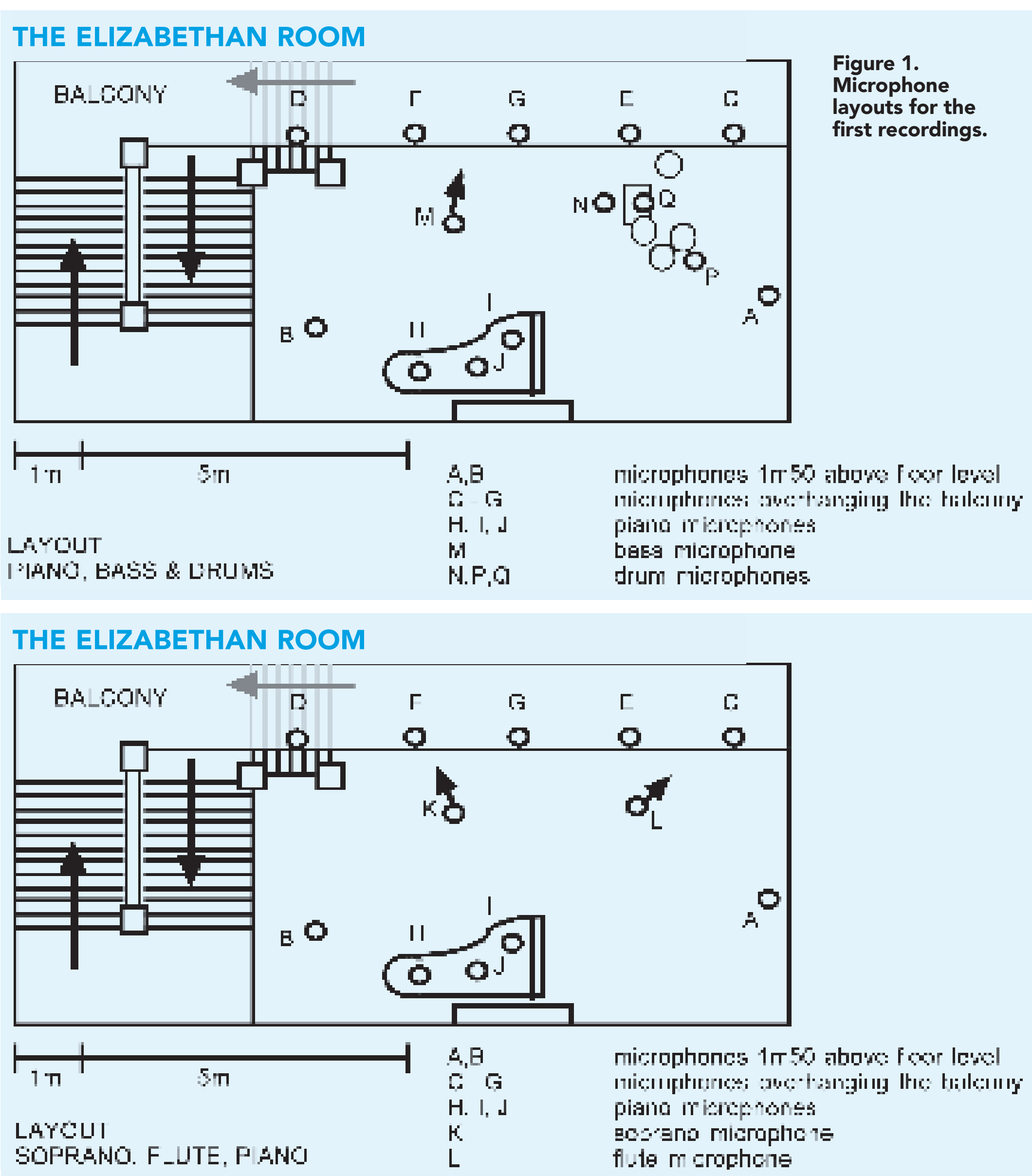

Figure 1. Microphone layouts for the first recordings.

The authors decided that recordings should be made in such a way that the microphones close to the instruments would be subsequently mixed as a conventional frontal sound stage and reproduced by conventional high-fidelity loudspeakers. The ambience microphones would be placed close to the room boundaries and would be reproduced only via DMLs, which would be initially positioned in the listening room in directions corresponding to the ambience microphone directions relative to a defined listening position in the recording room.

Transverse bending wave loudspeakers, of which DMLs are currently the best known commercially available examples, radiate in a manner that is spread out physically and temporally. At least at the higher frequencies, the radiation emanates from multiple points on the panel, and the transient response is somewhat smeared in the time domain. Another characteristic difference between pistonic sources and DMLs is that the DMLs radiate in a generally omnidirectional manner that is relatively equal with frequency. These characteristics of DMLs have led to difficulties in their application in high fidelity music reproduction, where the radiation from DMLs has not been conducive to the traditional goal of reproducing the waveform of the electrical input signal. Smearing transients is, by definition, not 'high fidelity' where the accurate reproduction of the impulse response is the Holy Grail.

Taking as an example of a high fidelity pistonic radiator a loudspeaker such as a Quad ESL 63 electrostatic loudspeaker, its transient response is exemplary. The loudspeaker is also designed such that as the frequency rises, the source area both diminishes in size and recedes in apparent distance from the front surface of the loudspeaker, to emulate the radiation from the hypothetical point source, or small pulsating sphere. As conventional two-channel stereo loudspeakers, the reproduction from such devices can be extremely lifelike, especially when reproducing close miked instruments. In a well-designed room, the reproduction of a frontal sound-stage via such loudspeakers can almost define the current state of the art. If distributed mode loudspeakers were to be substituted for the electrostatics in listening tests, the 'failings' of the DMLs, in terms of conventional reproduction, would be plainly evident. The very concept of the DML is not conducive to the reproduction of such a clearly defined frontal sound stage.

Reflections from architectural surfaces do not behave like the visual images in a mirrored room. Even a narrowly beamed source of high frequency sound aimed at a flat wall will not reflect in a manner much akin to what its continued trajectory would have been had the wall not changed its direction of propagation. Even at frequencies as high as 10kHz, a narrowly beamed incident source will reflect from the surface with a broadened conical directivity pattern, with a minimum of around 30 degrees. The concept can be visualised better by a look at Figure 2 (3). Lower frequencies will exhibit wider reflected directivity patterns. If the reflective surface is relatively free to vibrate, such as with wood panelled

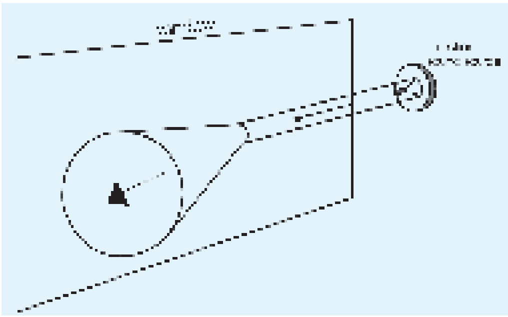

Figure 2. Conical reflection patterns.

walls, the reradiation from the surface will be even more distributed spacially and temporally. In fact, the musical reflections from many architectural surfaces behave rather similarly to the radiation of musical signals from DMLs.

We therefore appear to have a situation whereby the frontal sound stage of a conventional recording with ambient surround is best reproduced by pistonic loudspeakers, with fast transient responses and small source areas (commensurate with wavelength). Conversely, the surface reflections that form the ambient rear channels of a recording would appear to be potentially better reproduced by loudspeakers radiating with the characteristics of DMLs. The recordings at Herstmonceux Castle were intended to test this hypothesis.

Barron's 'Cosine Law' (4) states that the sense of spaciousness created by lateral reflections roughly corresponds to the cosine of the angle of arrival at the listening position. The cosine of 90 degrees is zero, and the cosine of 0 degrees is one. The spaciousness effect created by the lateral reflections is optimal when coming from 90 degrees to the listening axis, and negligible when coming from 0 degrees — centre front. The cosine of 60 degrees is 0.5, which would suggest that we would lose half of the optimal effect if the reflections came from only 30 degrees from centre front, which would be a typical location for stereo loudspeakers of a pair subtending 60 degrees at the listening position. (The 'Cosine Law' relates to the angle from the axis through the ears.)

In a recent paper, Toole (5) reported that 'In both concert halls and listening rooms reflected sounds arriving from the front or rear do not contribute to a positive impression [of envelopment]. [There is] a diminished preference for reflected sounds arriving within about 20-30 degrees of the median plane'. In general, the recorded reflections in a stereo presentation with a 60 degree total subtended angle cannot deliver a sense of full spaciousness.

That sense of spaciousness is largely a result of low inter-aural cross-correlation (IACC). In other words, the delivery of significantly different signals to the two ears. Obviously, an acoustic signal arriving from centre front will arrive symmetrically at each ear of a listener on the central plane, so the IACC will be high. In the test recordings, therefore, the reproduction of the reflections was initially set with loudspeakers either side of the listening room at 45 degrees and 135 degrees from centre front. The inherently low IACC of the DML reproduction (as compared to pistonic sources) was also expected to aid the perception of spaciousness.

The recordings were carried out in September 2005. The instruments in each trio were miked in a conventional way, using AKG C414 microphones. Similar microphones were also placed in seven positions in the recording room, two at floor level (one at each side), and five along the balcony which ran along the back of the room. Photographs of the room are shown in Figure 3. The intention was that each microphone should receive a unique perspective of the trios. Each microphone would receive the direct wavefronts from the instruments in a unique manner, with the instruments at the left hand side of the room arriving at left-located microphones

Figure 3. The Elizabethan Room.

before the instruments placed in the centre and the right of the room. The opposite would apply to the microphones at the right of the room, while the one, central microphone on the balcony would receive the acoustic signals from the left and right instruments in more or less equal timing. This was intended to be used if overall room reverberation were to be added. The signals from each microphone were recorded on individual tracks of a hard disk recorded, all via good quality A-D convertors, and no equalisation, compression or other processing was used.

On the day after the recordings had been completed, the hard disk recorder and a small mixing console were transferred to a relatively large room, sometimes used to accommodate guests at the castle, which had a carpeted floor, a double bed, general furnishings including a sofa, and also several large windows.

A stereo mix was made of the close microphones on the instruments. This was reproduced via Yamaha NS10 loudspeakers, which were used because of their familiarity to all the recording personnel involved. Four of the ambience microphones were then selected for reproduction via four Amina ACPT DMLs, positioned at roughly the aforementioned 45 and 135 degrees either side of centre front. The microphones which were selected were fed to the panels which most closely related to their angular distribution in the listening room. It was hoped that the reproduction via the panels would closely mimic the nature of architecturally reflected sound. All microphones, were set to a cardioid response, because it was intended that only the direct sound to the boundary should be recorded, it being unknown at that time whether the rapid reflection from the wall, if picked up by an omnidirectional microphone, would confuse the ear on playback.

Obviously, the four microphones which were used for the playback of the ambient spaciousness represented only a fraction of the total reflections within the room, but many acoustic studies have shown that only a few reflections are normally required by the ear to detect a sense of space.

The big question awaiting answer at the replay stage related to whether the reflections from the walls of the listening room, about two metres from the rear of the omnidirectional DMLs, would create confusing time response anomalies, or whether they would reinforce the effect of the spaciousness.

When the four ambience microphone channels were faded up, the four people in the listening room were immediately aware of the sense of being in the recording room. This was a surprise to everybody, but especially to the two very experienced recording engineers, who had deliberately not been told about the true purpose of the recordings they had been making.

At the time of the first playback, nobody in the room had ever heard such realistic reproduction of a space, and attempts were soon made to upset the system. The panel loudspeakers were moved such that heights and relative distances from the listening area were varied, and their relative angles to centre front were also changed. Quite contrary to the situation with conventional surround loudspeaker systems, which should be sited on the circumference of a circle centred on the listening position, all set at the same height, and all adjusted to within a decibel of each other, the Herstmonceux system was highly tolerant to heights, angles, distances from the listeners and level differences. This bodes well for domestic reproduction systems, where loudspeakers are often placed where they are convenient for domestic life rather than being positionally optimised from an electro-acoustic viewpoint.

In practice, the reflections from the hard walls of the reproduction room also seemed to have little effect, thus relieving one of the aforementioned worries. However, this lack of effect was recently highlighted by Toole (6, in 5) who stated that 'The basic audible effects of early reflections in recordings seem to be remarkably well preserved in the reflective sound fields of ordinary rooms.' In the case of the recordings being discussed here, the temporal relationships between the time of flight from the different instruments to the different ambient microphones, and the attendant level differences in the left and right hand sides, appear to have coded the acoustic sound stage in a very robust way.

The whole system showed a very high degree of positional abuse tolerance and even level changes at the mixing console of up to 5dB in various loudspeakers still yielded reasonable results. In fact, it was even abused so far as to put one of the surround loudspeakers on the floor, behind the sofa, another on the floor in a corner, and the remaining two at different heights, angles and distances, and still the reproduction sounded recognisably like the recording room.

In order to test whether the robustness was a sole attribute of the recording concept, the DMLs were replaced the next day by conventional domestic loudspeakers with approximately the same frequency range and cost. The result was abject failure. With panel loudspeakers on the front channels the results were even worse. The non-flat power response of the piston loudspeakers could not send the same frequency response to the listening position as was captured by the microphones whose signals they were reproducing. The 'point source' of the high frequencies — a dome tweeter of less than 20cm diameter — could not even begin to emulate the spacially and temporally distributed reradiation that would be characteristic of an architectural reflection.

The entire system performed very realistically. With two long days previously spent in the recording room, the sensation of being there was still fresh in everybody's minds. The realism of the reproduction was uncanny. The frontal stereo sound stage was very clear and well defined, and nothing in the surround channels detracted from its clean and tight response. It all happened in its own time and space, and no reflections were heard before their time of flight from the instruments to the microphones, and from the DMLs to the listeners. The natural reverberation of the Elizabethan Room was, of course, captured to some degree by all of the microphones.

A further, unusual experience was perceived by all present, in that everybody was aware of a sensation of clean, deep bass, way below what any of the loudspeakers were capable of achieving. The reason behind this has still to be investigated, but it was postulated that some reconstruction of fundamentals was occurring in the brain after receiving the unusually accurate stream of harmonic, spacial and temporal information. Mutual coupling between the six loudspeakers seems to be an unlikely cause because of the lack of simultaneous reproduction, due to the time of flight to the surround microphones.

Despite the known colouration of the DML reproduction, very little 'DML sound' was perceived in the playbacks, probably because neither the colouration of the panels nor the wall reflections in the listening room were colouring the perception of the front, direct sound stage. Indeed, nothing else was emanating from the same direction. The primary sound stage was clean at all times, exactly as in the case when that stage consists of real instruments.

Many modern day recordings are built up track by track, and are recorded in rooms that do not have the ambience required for the finished mix. Obviously, the recording technique described here would not relate directly to such recordings, which make up the majority of current recordings. Nevertheless, surround reflection generation could emulate a large degree of the acoustic effects. By defining the room size, the stage location, the position of each instrument on the stage, the listening position, the wall surfaces, and other such parameters, a group of instruments, recorded separately, and even in different rooms, could be electronically inserted into the desired 'room'. The virtual microphone locations for the reflection pick-up would then be defined, and would receive the signals from the different instruments with different delays depending on the distance from each virtual microphone to each virtual instrument. Reverberation would then be applied also to the instrument microphones after an appropriate delay.

What has been described here is a surround sound system that requires six transmission channels. The frontal stage pair are traditional in every way, except that they do not carry all the ambience information as usually applied in conventional stereo. The principal ambient information is transmitted via DMLs, whose inherently diffuse time and spacial responses are well suited to the reproduction of room reflections and reverberation. Additionally the reflections and reverberation reproduced via these panels are more robust in terms of their use in domestic listening rooms.

The permutations of which and how many ambient microphones would be fed through which and how many panels are virtually endless, but the system described using four ambient loudspeakers with only one cardioid microphone feeding each panel has been shown to be both realistic and robust.

Hopefully, what has been described in this article is only the tip of an iceberg. If this is so, then the prospects for further work are very promising indeed. ■

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