# Soundscape Design of Motorway Parkland Environments – Transformation, Cancellation, and Ethnography

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**ABSTRACT:** This paper reports on a practice-led research project investigating the design of parkland soundscapes affected by motorway noise. The project, entitled Acoustic design innovations for managing traffic noise by cancellation and transformation, is funded by the Transurban Innovation Grant. Transurban is a transport infrastructure company operating in Australia and the USA that builds and manages tolled motorways. Car-dependent cities require extensive road networks, and traffic noise can impact those who live adjacent to motorways. We have based our project on three approaches – Cancellation, Transformation, and Ethnography. Since the writing of the paper, research was tested along the M2 motorway in Sydney and the Citylink in Melbourne. Future papers, and an industry report will compare the newly designed environments with community perceptions, to reveal new noise management approaches that infrastructure companies can incorporate in their planning and design phases. This papers draws on early fieldwork and laboratory tests, including descriptions of the three methodologies involved and some preliminary observations.

**KEYWORDS:** urban soundscape design.

# 1. Background

Road noise, like all sound, is the transference of energy through a medium. The notion that noise is annoying comes as a consequence of human perceptions, including its cultural and historical influences.[1] Our research seeks to reshape noisy roadside acoustic environments – the unused, often neglected grassy areas located on the non-roadside of motorway noise walls – to facilitate more desirable listening experiences that successfully meet community needs for improved urban livability. Our study aims to improve urban livability in these areas by creating information-rich, diverse listening experiences through the application of electroacoustic technologies. This is consistent with recent lab-based studies that have created models to "implement the soundscape approach in urban planning and design, with the objective to create (urban) environments of high acoustic quality" (Aletta 2016). This project investigates the possibility of implementing similar soundscape approaches as described in these lab-based studies, except through practice-based research and ethnographic community engagement.

Without total road enclosure, full noise attenuation is impossible. To date, the primary solutions for motorway noise issues are sound attenuating walls and acoustic insulation of adjacent buildings. Acoustic insulation is costly and ineffective in the outdoors, and installing noise barriers – the primary noise management approach – can only partially attenuate motorway noise. According to VicRoads, who plan, develop and manage the state of Victoria's arterial road network, noise barriers reduce traffic noise by 5–10 dB(A) in outdoor areas (VicRoads 2003). As such, acceptable levels of noise are determined quantitatively by SPL meters, which ensure noise levels do not exceed a pre-determined threshold. The extent of urban sound planning typically reduces urban soundscape design to mere noise mitigation (Cobussen 2016; Kamin 2015). This research will advance the effectiveness of existing noise management and urban planning approaches by exploring the possible integration of two electroacoustic approaches – cancellation and transformation – into existing noise wall infrastructures.

At the root of this project's innovation is a new understanding of noise as a design material (Hellstrom 2003; Lacey 2016). Effective noise design can positively impact sensory perceptions (Pink 2015; Kang 2011) for the recreation of urban listening experiences. By developing, testing and calibrating noise cancellation and transformation methods independently and in combination, the research aims to generate new soundscapes that might ameliorate noise issues by offering new listening experiences for residents exposed to ongoing traffic noise. To achieve these aims, an interdisciplinary research team has been

1. As with tuning in musical acoustics, sounds that constitute noise differ across cultures and through history. For a study of this concept, see Bailey, 1996.

formed involving RMIT University (Melbourne), UTS (Sydney) and Northwestern University (Chicago) that combines acoustic engineering, sound design, and ethnographic expertise. Specifically, Active Noise Cancellation (ANC) technology (Qiu 2014) will target the low frequency component of motorway noise, while an electroacoustic soundscape system (Harvey 2013) will transform motorway sounds with microphones providing a live feed to custom-built audio processing software written in the programming environment Max. From August to December 2016, we conducted a series of laboratory and field tests providing crucial information that will inform the on-site testing in February and March of 2017. While the findings of the laboratory tests are reported below, we first describe the key disciplinary approaches involved in this study. Future papers (Lacey 2017) and an industry report will describe in detail the final test-site installations along the M2 and Citylink.

## 2. Primary Disciplines and Approaches – Cancellation, Transformation, and Ethnography

### 2.1. Cancellation – Removing Noise

Cancellation refers to the application of an Active Noise Control system comprising of hardware – including microphones and speakers – and a processor housing an adaptive algorithm, which is able to cancel environmental sounds within a specific frequency range. Active noise control (ANC) is a method for reducing existing noise via the introduction of controllable secondary sources to affect generation, radiation, transmission and reception of the original primary noise source. ANC systems can provide better solutions to low frequency noise problems than current passive noise control methods – like sound barriers – when there are weight and volume constraints. ANC also provides an alternative noise control solution for applications where current passive noise control methods cannot be applied. The fundamental theories and methods of ANC have become well-established over the last 30 years. However, successful industry and civil applications of this technology are still limited to some specific cases, such as headsets, earplugs, propeller aircraft, and cars.

Active noise barriers (ANB) are a combination of ANC methods and passive noise barriers, where some loudspeakers are installed on the edges of the passive noise barriers to increase its performance, especially the insertion loss of the barriers in the low frequency range. After the first ANB research carried out by Omoto and Fujiwara in 1993, many researchers contributed to the field, and the first practical ANB system prototype along an expressway was established by Ohnishi et al. (2004) in Japan. Such experiments have demonstrated successfully that ANB can increase the low frequency performance or the equivalent height of passive noise barriers significantly and at low cost.

Virtual sound barriers (VSB) are a future method for controlling traffic noise along motorways. The VSB system is an array of acoustic sources and sensors forming an acoustic barrier that blocks direct propagation of sound without blocking air and light. The VSB system has been successfully applied on noise radiation from the opening of power transformers located inside enclosed rooms, which suffer from poor ventilation conditions and expensive built enclosure costs. The VSB system can be applied along motorways or the windows of residential housing to reduce traffic noise transmission (Qiu 2014).

The ANC system applied in this study could easily be expanded to have more impact on the sound environment, though at an increased cost. The cost depends on a number of factors, such as the size of the area to be controlled and the frequency to be controlled. It is most economical to combine the ANC system with existing passive noise control measures that have good middle to high frequency control effects but poor low frequency control performance. For a well-designed and constructed sound wall, the residual noise is usually dominated by low frequency components. ANC systems installed on the top edge of a barrier will have a significant perceptual effect *and* a measurable noise reduction. For example, the noise reduction (≤300 Hz) on the non-roadside of a 3m sound wall with an installed ANC system is similar to the noise reduction provided by a 6m sound wall in the same frequency range. Adding more channels to the existing ANC system would be required to increase the effective frequency range. So, while the perceived impact may be minimal in this study, our research is suggestive of future projects that apply an upscaled ANC system.

## 2.2. Transformation – Sculpting a Soundscape

To experiment with altering the soundscapes adjacent to roadways in urban areas, we designed a system of microphones and speakers with a computer at the centre. The computer runs sound analysis and processing software written in the Max environment, and is capable of interfacing with other common tools like Ableton Live and the GRM Tools suite of plugins. Collectively, we refer to this as the "Transformation System," which is distinct from the "Cancellation System" described above. The Transformation System's microphones capture environmental sound directly and pass it to the processor to be analysed for its amplitude envelope and spectral content. The sound is then either passed through a set of transformational processes, or new sounds are produced in response to the analysis results. We refer to a set of these processes as a "Transformation." Determining the makeup of these Transformations – a process that combines electroacoustic music composition, algorithmic design (coding) and audio engineering – has been the primary exploratory activity of this part of the project.

The sound resulting from a Transformation is then passed out to a multi-channel speaker system, which distributes it back into the soundscape according to the location of the system's microphones. Speakers must be positioned such that they are *behind* the system's microphones and pointing away from them. The microphones, in turn, should have a polar pattern – cardioid, for example – that rejects sound from behind. In our case, one speaker was used for every microphone, though other arrangements are possible. Transformation Systems are easily scalable when the ratio and relative placement of microphones to speakers can be fixed.

## 2.3. Design Considerations

The areas adjacent to roadways are noisy places, and the Transformation System, by definition, will introduce even more sonic energy into these soundscapes. Care must therefore be taken to ensure that the layer of added sound is applied as judiciously and sparingly as possible, so as not to create a nuisance greater than the one we intend to mitigate.[2] The realization of this constraint has guided us towards designing Transformations that are:

- closely tied to the actual environmental sounds: the contour of those sounds is reflected in the Transformation such that the two layers of sound merge in the listener's perception;
- dynamically constructed: capable of responding to variations in the average amplitude and spectral content of the soundscape as it passes from rush hour traffic levels to quieter times of day; and/or
- composed of middle-to-higher frequency sounds: so as not to compound the buildup of low frequency noise that is characteristic to motorway soundscapes, the transformation will impact specific frequencies (see 2.2.4 below).

During testing, we experimented with Transformations that have dynamically-activated layers of activity, and ones that sometimes fall silent or have periods of sparseness that occur in either direct or inverse relationship to the behaviour of the immediate soundscape. By way of example, we'll discuss two of the ten Transformations that were developed during laboratory tests – *Shimmer* and *Whistler* – in compliance with the above design principles. As with all the Transformations, they were not pre-determined but emerged from field and studio work during the Transformation design process.

The *Shimmer* transformation makes use of a kind of subtractive processing – instead of applying a resonant filter, it takes advantage of the FFT processing tool in Max. It periodically opens randomly selected single bins, allows sound to pass through them, and then gradually closes them again. There are two layers of activity – one with a fast-moving envelope that chooses bins pitched between 1000 and 3000 Hz, and another with a slower envelope that chooses bins with a centre frequency between 2000 and 6000 Hz. The resulting sound is a gentle, somewhat eerie collection of brittle tones that shimmer – the way stars

2. Consider a community living by an ocean where the soundscape is dominated by the sounds of waves and wind. The sounds of the ocean vary across the different time scales of a morning, a day, a week or a season. While the sound is always recognizable as an ocean, these variations ensure the variety, surprise or difference that provides new information about or from the environment. (See the *Handbook for Acoustic Ecology* online entries for "Keynote" and "Stationary Sound," acccessed February 14, 2017, available at https://www.sfu.ca/sonic-studio/handbook/Keynote.html and https://www.sfu.ca/sonic-studio/handbook/Stationary_Sound.html.)

shimmer in the night sky – whose presence relies on the sonic activity occurring within precise frequency ranges in the soundscape.

The *Whistler* transformation was created as an homage to Alvin Lucier's piece "Sferics," where antennae pick up radio-frequency signals in the ionosphere that result from lightning and other natural events. Some of these sounds, classified as "Whistlers," are high-frequency tones in the audible range that glissando at different speeds from one place to another. Using a tight bandpass filter at a variable (but always high) frequency, whistle tones are derived from the soundscape. Their pitch, sweep, and duration are all randomly determined, and as many as six may be active at once, though usually it is much fewer. This transformation introduces sonic activity into a part of the spectrum that is usually undistinguished in the roadside soundscape, with the result that this Transformation truly feels like it is operating alongside the soundscape it is active within, never masking its contents nor being occluded by it.

## 2.4. The Combination System – Connecting the Cancellation and Transformation Systems.

Part of the experimental process involved using Transformations in combination with the ANC system. A combination filter was built in Max that allowed us to combine the Transformation signals with the Cancellation signals. To be absolutely clear about the terminology:

1. The Combination filter is custom-built software designed in Max that combines the two incoming environmental signals.
2. The Combination system is the totality of the hardware, which is the physical system connecting the Transformation and Cancellation systems together (as shown in Fig. 1).

The Combination filter ensures that introduced sounds do not fall within the frequency range that the ANC system successfully removes. The strategy is to analyse the environmental sound both pre- and post-ANC processing and to compare these analyses to determine what effect the ANC system is having on the environment. This ongoing comparison forms the basis for a dynamic FFT-based filter, which we call the Combination filter. The Combination filter is then applied to all incoming ANC signals, to ensure that the Transformations augment the Cancellation system's influence by transforming *only* those sounds unaffected by the cancellation. In the case of the laboratory tests, these were frequencies above 300Hz. Whether or not the combination system is applied in the field depends on the capacity of the ANC system to create perceivable effects in the audible environment.

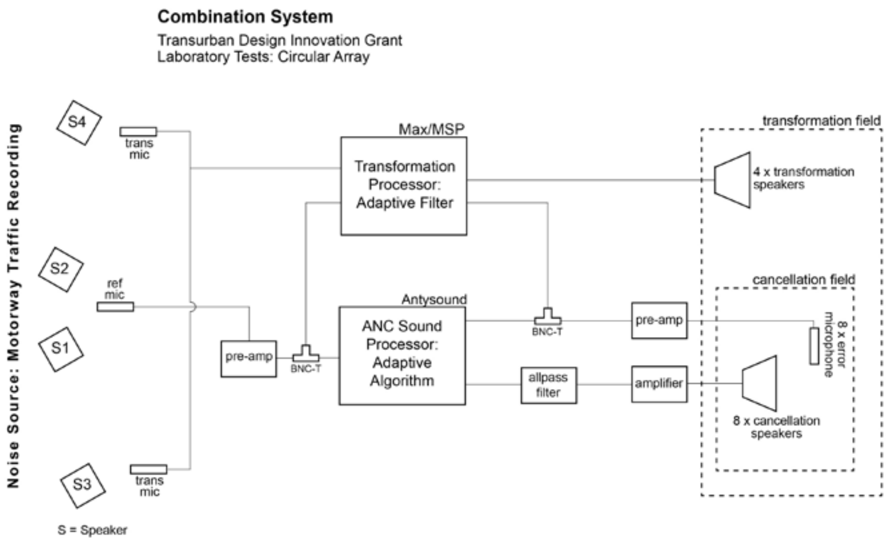


**Figure 1.** Diagram of the Combination System.

## 2.5. Ethnography – Community Perceptions of Cancellation-Transformation

For this project, we use a sensory ethnography (Pink 2015) approach to investigate how people experience existing and test-site sound experiences and how they imagine and anticipate possible auditory futures. Sensory ethnography goes beyond conventional interviewing and observational methods used in much qualitative research in order to attend to the unspoken and infrequently observed elements of mundane everyday life. They are important, because very often those seemingly mundane and non-glamorous everyday routines and habits that underpin the ways we live our lives determine the resources that we need and enable us to do other things. In the context of urban sound, we are interested in how people already live their lives in relation to sound, how they improvise in the context of traffic noise, and what this means for how they use their homes and the shared space around them spatially and temporally. We are interested in what people do to make the space they live in 'sound right,' the ways in which they value the comfort associated with such auditory experience, the relationship between this and other elements of sensory experience, and the things that sensory experience makes possible for them.

In the context of this project, we are specifically interested in how the use of sound transformation technologies enables people to experience their sensory environments differently, and what this means for possible future uses of their homes and everyday neighbourhoods. Through a series of video-based interviews and re-enactments with participants in their homes and neighbourhoods, we aim to understand how people improvise to create comfortable auditory environments. We intend to accompany participants and interview them as they experience the sound transformation technologies, and in doing so develop a series of insights into how the auditory affordances of these technologies are experienced and the ways that they enable people to imagine new possibilities for the ways they might use and experience everyday spaces.

## 3. Observations and Reflections to Date

The project is being conducted in close collaboration with our industry partner Transurban. As such we have produced industry reports and briefing workshops to present work to date and initial findings, some of which are summarised below. The project is suggestive of new opportunities for sound artists beyond the typical public art funded project. In this instance, our corporate partner is interested in ways sound parks adjacent to motorways might improve social well-being. Our research suggests that those passionate about soundscape design as an aesthetic enterprise might consider similar corporate and government partnerships as a means for working towards the type of environments desired by sound arts practitioners, which often manifest through funded artistic processes (see Lacey 2016a for examples). The final section of this paper presents a series of observations and reflections to date, with each emerging theme captured as a sub-heading.

### 3.1. Transforming Sensory Perceptions.

The Transformations aim to impact sensory perceptions, which necessitates slight increases in overall sound level. This component of the project could be criticized as simply adding more sound to the environment. However, this is based on the incorrect assumption that listeners experience a sound environment solely in dB. This is like saying the sound design of a feature-length film is just a series of fluctuating dB levels. Just as a cinema experience is not about measurable changes in acoustic energy, neither is a soundscape just about changes in sound pressure levels over time. The emotive responses and feelings of interconnectedness are equally important. The Transformations that we have created – both independently and in combination with the ANC system – are but a small subset of the possibilities afforded by the system. We envision articulating future design processes that could be undertaken by teams of sound artists, composers, audio engineers, ecologists, urban planners, and ethnographers to create soundscapes responsive to the needs and desires of visitors and residents of roadside environments. This project and its antecedents expand on the concept of “Sonic Rupture” (Lacey 2016), which employs sound art as a means of active engagement with ecological and human concerns around urban noise.

### 3.2. Scale and Pockets of Change.

While the ambition of the project is to deploy both the Cancellation and Transformation components in urban parks, at present only Transformations can be delivered at that scale.

However, it is worth noting that the majority of technological innovations start or are initially proved at a small scale. Radio transmissions were initially applied over metres – not over 1000's of kilometres as they are today. Wi-Fi was similarly tested over a short distance; the Internet did not emerge on server farms over continents but between two computers in a single building. The point being that while the affected area of the Cancellation and Transformation systems is small, there is great capacity for the future upscaling of both systems to diversify urban soundscapes dominated by single noise sources.

## 3.3. Combining Two Methodologies

Combining the different methodologies practiced by the engineering team and the design team presents two significant challenges. Firstly, during testing (see Fig. 2), the engineering team reported a successful reduction in noise level – measured with SPL equipment – that was not always perceivable to the human ear. However, for the design team, perceptible changes to the sound environment are critical if the Combination system (Fig. 1) is to function effectively as a soundscape design artefact. Secondly, the engineering team had to strip their equipment back to first stages as a means to resolve any underlying performance issues. This created challenges for the design team, who are engaged in a constant process of immediately responding to perceived aesthetic conditions of the sound environment. To resolve this issue, for the 2017 field research we plan to install the two systems adjacent to each other on the same site, but approximately ten metres apart so that listeners can walk between the two different Cancellation-Transformation systems. The Combination system will constitute a live feed from the designed environments into the engineer's final Cancellation environment, via a live speaker feed.

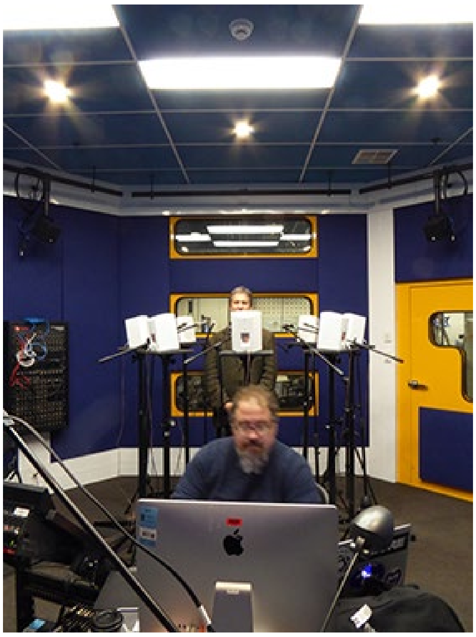

**Figure 2:** Left: Authors Stephan Moore and Jordan Lacey conducting sound transformation tests in The Pod, SIAL Sound Studios at RMIT University. Right: an experimental test of the cancellation system. A line of 4 dark-grey Genelec speakers play a multichannel soundscape recording of a Melbourne tollway. The line of 8 white loudspeakers are part of the cancellation system.

## 3.4. ANC Performance in Reflective Environments

The test was conducted in two spaces – the Pod, a small acoustically-treated sound environment with minimal reflections; and the Archive space, a large and highly reflective environment. The research team and visiting Transurban personnel could perceive the reduction in low frequency traffic sounds inside the Pod. However, although the same reduction of low frequency traffic sounds was achieved in the Archive space, the human ear could not perceive those changes. We suggest that the reason for this is that the highly reflective environment of the Archive space increased the volume of the mid and high frequencies, which masked the reduction in low frequencies achieved by the ANC system. We also suggest that the reason the reduction in low frequency sounds was perceivable in the Pod is because the highly absorbent walls of the Pod reduced the volume of the mid and high frequencies. This was useful, as it demonstrates that an inaudible outcome in the field may be a consequence of the mid-high frequency volume level rather that the ANC system's performance.

## 3.5. Refining the ANC

Also of note is that the successful Pod tests, in which the reduction in low frequency sounds could be perceived, was most efficient when the ANC system's reference microphone was pointed at a directive noise source (see S1&2, Fig. 1). However, when extra speakers were turned on to feed the Transformation speakers (see S3&4, Fig. 1) the perceivable cancellation effect was reduced. This suggests a reduced likelihood of a successful field result with the current available ANC system, given that the traffic sounds will come from multiple directions. If multiple reference sensors are used with better ANC systems, better noise reduction performance can be obtained. The ANC system is typically tested with still point sources such as generators and idling engines. The present research offers an excellent opportunity to test the equipment with moving point sources. Given that the system we are testing is limited to one reference microphone, it is predicted that upscaling will be required to provide audible outcomes for future infrastructure projects.

## 3.6. The Combination System as a Design Platform

The Combination system (see Fig. 1), as a soundscape design artefact, requires any change in the sound environment to be perceivable by the human ear. Because the ANC system effects are imperceptible to the human ear when higher frequencies are louder, the combination system may be redundant in the field. There is little purpose for a Combination system in environments where the impact of the ANC system cannot be perceived. Nevertheless, the Combination system will be tested in the field in preparation for future improved performance of the ANC technology. In fact, the research team sees the benefits of the ANC system not only as an engineering tool but also as a soundscape design tool. If the ANC system can cancel low frequency sounds, which are associated with anxiety (Berglund 1996; Leventhall 2004) and fatigue (Foraster 2016), then the residual mid-high frequencies can be used as design material for the development of more diverse and sensorial-enriching listening experiences. This combination system represents first stages in bringing together two separate methodologies in an effective way.

### 3.7. Benefits for Human Health

The research team recognizes that even if the human ear cannot perceive a change in low frequency sound, it doesn't mean that change isn't beneficial to human health. There is much research showing that low frequency sounds have adverse mental, physical, and psychological health effects (Berglund 1996; Bluhm 2004; Passchier-Vermeer & Passchier, 2000). While outside the scope of this study, this insight suggests that the attenuation of low frequency sounds could warrant further studies regarding possible health impacts of an installed ANC system. In an earlier study, Qiu (2014) tested "a prototype natural ventilation ANC window installed in a glass room [consisting] of two layers of glass with a space of 0.1m." It was found that the performance of the open window was equivalent to that of a closed window and that people approved of the changed acoustic environment. This demonstrates that ANC can produce desirable audible environments – even if the effects can't be perceived, as tested in an outdoor environment, it is still possible that beneficial health outcomes are being achieved.

## 4. Conclusion

Future combination systems might be exclusively focused on park environments as a soundscape tool to augment existing motorway noise management. Rather than relying exclusively on mitigation via noise wall technology and acoustic insulation of buildings, soundscape design might discover effective ways to transform listening perception. By combining Cancellation systems with Transformation systems this research allows an expansion of thinking in relation to existing technologies, which can both reduce noise levels and change perceptions of residual noise. This is an effective means to locate design within existing noise policy strategies. For instance, a soundscape design approach might target improvements in the liveability and walkability of spaces adjacent to urban motorways, which should be of significant interest to local councils and health agencies. This is a direct response to research that suggests motorway noise creates fatigue and lethargy leading to negative health impacts. These preliminary findings warrant existing and future research on the possibility of soundscape design to reverse such impacts. Environments with diverse and engaging listening environments may be attractive to residents who otherwise have little incentive to visit parklands and grasslands dominated by repetitive and information-poor soundscapes from motorways. The present research will provide some evidence for these possibilities via ethnographic engagement with local communities. It is the ambition of this study to imagine future urban environments in which soundscape design is a feature of the landscape. Rather than sounds being the incidental consequence of infrastructure projects, effective soundscape design might create a future in which listening is central to the enrichment of everyday life and the establishment of healthier communities. Importantly, the notion of noise in this research is not reduced to an unhealthy by-product of the city but considered to be a design material that can be reshaped into new soundscapes.

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