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| **Institution:**<br>Loughborough University | | |
| **Unit of Assessment:**<br>UOA9 - Physics | | |
| **Title of case study:**<br>Noise-cancelling structures for urban and industrial environments | | |
| **Period when the underpinning research was undertaken:**<br>2007-2012 | | |
| **Details of staff conducting the underpinning research from the submitting unit:** | | |
| **Name(s):** | **Role(s) (e.g. job title):** | **Period(s) employed by submitting HEI:** |
| Prof Feodor Kusmartsev | Professor of Condensed Matter Theory | 1990 – present |
| Dr Gerry Swallowe | Senior Lecturer<br>Visiting Fellow | 10/1984 – 08/2015<br>08/2015 – present |
| Dr Daniel Elford | Research Associate<br>Visiting Fellow | 02/2011 - 03/2013<br>09/2013 – present |
| Dr Luke Chalmers | Research Associate | 02/2011 - 03/2013 |
| **Period when the claimed impact occurred:**<br>2014 onwards | | |
| **Is this case study continued from a case study submitted in 2014?** Y | | |

## 1. Summary of the impact

Noise pollution caused by road, rail, air and industry has wide-ranging negative impacts from simple annoyance to serious health effects, but installing noise barriers in dense urban areas is difficult to achieve. Research at Loughborough University underpinned the development of acoustic metamaterials that can be used in installations where traffic and industrial contributors such as electricity substations are in close proximity with inhabitants. This game-changing technology reduces low-frequency noise levels below the 30 dB benchmark set by the World Health Organisation and led to two impacts: 1) Generated over [text removed for publication] via commercialization through a university spin-out company, Sonobex, and 2) Reduced noise pollution from electricity substations at installations [text removed for publication].

## 2. Underpinning research

Noise barriers are commonly used to reduce noise disturbance from road, rail, air and industry. Traditionally, outdoor noise barriers are constructed from solid structures (concrete walls or steel plates filled with mineral wool) which act both to absorb the sound and also, by reflection, to deflect it away from the areas that require protection. Whilst these traditional methods can be very effective, they generally suffer from the major disadvantage of preventing the free flow of air and light through the barrier.

Recent years have seen a growing interest in the potential for use of acoustic metamaterials such as sonic crystals - arrays of cylindrical rods - as noise barriers. An advantage of sonic crystals (SCs) is that by varying the distance between the rods it is possible to attain peaks of attenuation in a selected range of frequencies. A further advantage of a SC barrier in comparison to more traditional sound barriers is its ability to allow light to pass and, uniquely, that it does not present an obstruction to the free flow of air. However, barriers using ‘conventional’ SCs can suffer from the major disadvantage of providing attenuation only over a rather narrow frequency band (and harmonics thereof) and are therefore unsuitable as barriers to broadband sound.

The research outlined here was the result of a collaboration between Prof Feodor Kusmartsev (FK) and Dr Gerry Swallowe (GS) from 2007 onwards. The key research

question was whether an acoustic metamaterial could be designed to attenuate specific frequency ranges of sound waves. FK provided expertise and knowledge with regards to theory and simulation, whilst GS oversaw validation of the models with experiment. The concept developed by FK and GS was to use Locally Resonant Sonic Crystals (LRSC) in which the cylinders in the array act individually as resonators whose frequency differs from that of the array. Experimental and modelling work was carried out in the Loughborough University Physics Department by the team of Prof Kusmartsev and Dr Swallowe, and PhD students Dr Dan Elford and Dr Luke Chalmers (2007-2010); Dr Dan Elford later went on to win an RAE Enterprise Fellowship (2012) to establish the spin-out Sonobex. It was shown that carefully designed LRSCs can provide attenuation well in excess of that provided by normal 'mass law' attenuators (current noise reduction technology) and in broader frequency ranges than conventional SCs [R1,R2].

The key aspects of the initial research outcomes that underpin the impact described in this case are:

1) Barriers can attenuate at low acoustic frequencies without the need to satisfy the mass law [R1, R2].

2) In all situations a flow of air and light is possible – thus systems such as industrial compressors can be acoustically shielded without being enclosed. This is a major advantage since air flow is required to provide cooling and suggests that they can also be built into the design of new buildings [R1].

These properties of LRSCs make them a disruptive technology in the noise reduction industry leading to economic, environmental and health and wellbeing impacts as described in this impact case. Initial results of this work were published in [R1] and [R2] before developing further as protected UK and internationally patented NoiseTrap® technology.

## 3. References to the research

**R1:** D.P. Elford, L. Chalmers, F.V. Kusmartsev and G.M. Swallowe, "Matryoshka locally resonant sonic crystal" *The Journal of the Acoustical Society of America* **130**, 2746 (2011) doi: 10.1121/1.3643818

**R2:** D.P. Elford, L. Chalmers, F. Kusmartsev and G.M. Swallowe, "Acoustic band gap formation in metamaterials" *International Journal of Modern Physics B* **24**, 4935-4945 (2010) doi: 10.1142/S0217979210057110

This body of research was supported by competitively-awarded funding: an EMDA Innovation Fellowship "Sound Blocking Technology" (PI Dr G. Swallowe, CI Prof F. Kusmartsev, 2010); the EPSRC project "Practical Sound Attenuation using Broad Band Sound Attenuating Devices", (EP/I029001/1 PI Prof F. Kusmartsev, CI Dr G. Swallowe, 2011); a Knowledge Transfer Award (D. Elford, 2012); a Royal Academy of Engineering Enterprise Fellowship (Dr D. Elford, 2012) to turn research into a viable operating spin out company - Sonobex; and a 2014 Innovate UK project to support lab testing.

## 4. Details of the impact (indicative maximum 750 words)

The underpinning research collaboration between Prof. Kusmartsev and Dr Swallowe was augmented by research associates, Dr Luke Chalmers and Dr Dan Elford, the latter during a Knowledge Transfer Award and RAE Enterprise Fellowship, to form the basis of the spin out Sonobex - the **pathway to impact**. In 2014 Sonobex obtained Innovate UK funding to support lab testing and demonstrate the viability of their technology. By 2015 two distinct patents had been filed [S1] and the groundwork of the NoiseTrap® technology had been laid. Sonobex has been the recipient of several innovation awards (e.g., IET Emerging Technology Design Award 2018, RAEng silver medal 2019, IoP Business Innovation Award

2018) [S2]. It was later purchased by Merford in 2017, an international company specialising in noise control. Merford purchased Sonobex to integrate the NoiseTrap® technology into their products, with projected economic impact [text removed for publication] [S3].

The **impacts** of the research are as follows:

**Impact 1: Economic benefit for UK noise cancelling technology companies Sonobex and Merford**

The research produced by the team [R1, R2], commercialised by Sonobex,

> *"offered exactly what Merford - with more than sixty years' experience in noise control - was looking for."* Joost Vertooren, Director of Corporate Development, Merford [S3]

Sonobex and their parent company Merford have reaped benefits of Sonobex's innovative technology via a) design and installation projects, and b) new product development.

a) Design and installation projects: Between 2017 and 2020 **[text removed for publication] were completed by Sonobex** primarily on substations [S4, S5]. The outcome of these installations has been an increase in Sonobex's profile as demonstrated [text removed for publication] [S4].

b) New product development: Merford Group acquired Sonobex in order to enhance their R&D function and future innovation. Having fully validated the technology they are now integrating it into their existing products, [text removed for publication] [S3]. Merford, which manages the international arm of this technology's deployment, achieved sales revenues solely based on the [text removed for publication] [S3].

   The patented NoiseTrap(R) technology developed by Sonobex has resulted in five new product families:

   - NoiseTrap® Acoustic Panels (LF150, LF250, LF350 and LF450)
   - NoiseTrap® Airflow Panels: LF250(A) Acoustic Panel
   - NoiseTrap® Road Acoustic Panel
   - NoiseTrap® Rail Acoustic Panel
   - NoiseTrap® Blox – Modular Acoustic "Block" system designed for machine enclosures and chiller units

   These have been customised to target the main stakeholders of this technology: transport and electricity substations (which require noise control and passive cooling).

[text removed for publication]. Merford have adopted our "disruptive technology" since they believe it improves their ability to *"provide solutions to the challenges of the future"* [S3].

**Impact 2: Noise pollution and cost reductions**

The primary impact of the technology developed by Sonobex ***after installation*** is improvement to the local environment by a reduction in noise pollution [S4, S5, S6-9]. As detailed in [S5], Sonobex [text removed for publication] at the following sites:

1. [text removed for publication]).
2. [text removed for publication].
3. [text removed for publication].
4. [text removed for publication].
5. [text removed for publication].

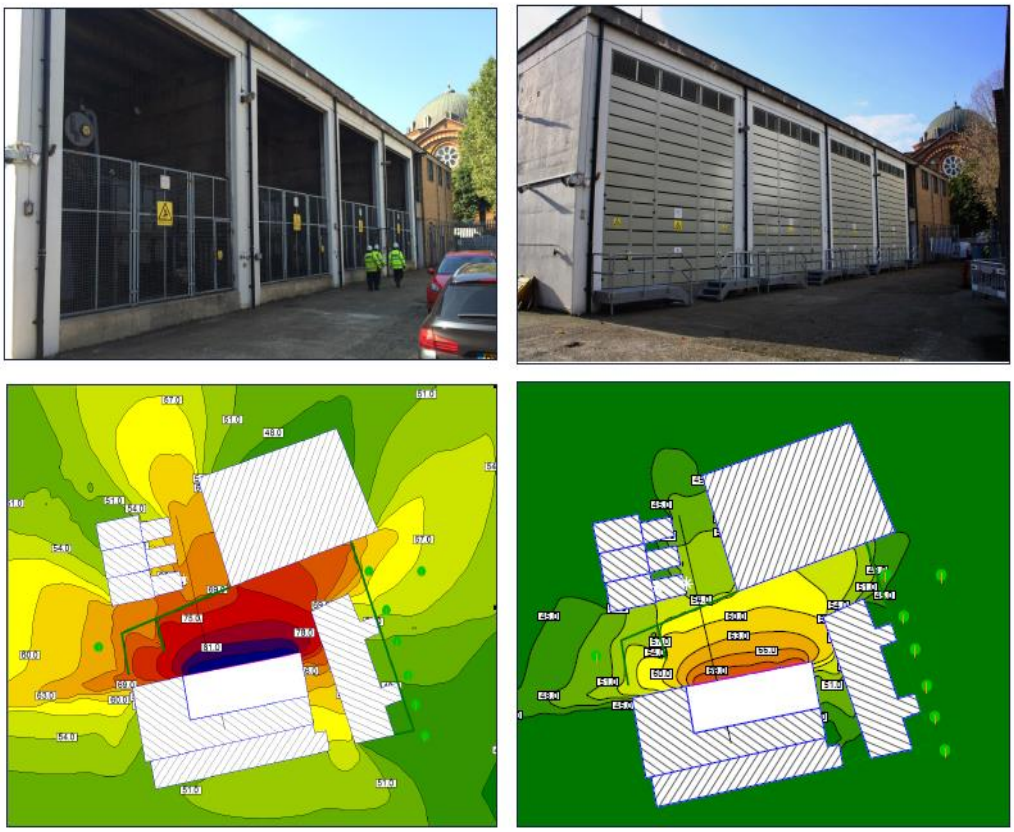

Fig 1: Photos and noise maps of (left) before and (right) after installation at Moscow road, Bayswater. Fig. taken from [S9].

The UK Accreditation Service (UKAS) accredited results for the NoiseTrap® technology developed by Sonobex cite performance at 100 Hz with a 34 dB transmission loss and an absorption coefficient of 1.13. For comparison, the next best materials for sound insulation have an absorption coefficient ranging from 0.1 - 0.35 at 100 Hz, i.e., Sonobex's technology shows a 3-10x improvement. It is therefore the superior technology for low frequency performance and has the advantage that it can be designed to specific frequency ranges [S4, S9]. For example, the relevant frequency range for fire alarms could be designed in to pass through undisturbed, whilst blocking other noise sources.

Sonobex has also highlighted that another advantage of this technology compared to existing noise barriers is its longer lifetime [S4]. This is due to the porous structure of the materials (a result of the metamaterial design) that removes the need for an acoustic infill whilst enabling passive ventilation. Competing technologies rely on materials such as mineral wool (as an acoustic infill) [S8] which degrades and sinks due to gravity over time, reducing their effective lifespan. This results in significantly lower maintenance and replacement costs (for example, the technology will remain as effective 40 years after installation, where fencing may require wood treatments or replacement) [S4].

Due to the superior performance of this technology for low frequency ranges it has been used at several electricity substations where transformers step up/down voltage from supply networks for end-use [S5]. **Secondary environmental impacts** that have been realised in application of these metamaterials to substations stems from the passive ventilation that is built in [S4]. The passive cooling enabled by this has the additional benefit of (a) reducing power consumption in a complete installation as air conditioning is not required, and (b) extending the life cycles of transformer substations where it is installed due lower overall operating temperatures.

As an example of local installation impact, the NoiseTrap® technology developed by Sonobex was installed in a UK Power Networks substation on Moscow road, Bayswater, London in August 2017 [S5, S6], as summarised in Figure 1. This was in response to a complaint about noise from locals due to the necessity of including an opening on a set of four transformers housed in concrete compartments, in order to allow natural ventilation. The challenge with reduction of noise produced by transformers was the low frequency (< 100 Hz), which could be heard by residents and which could not be simply reduced due to cladding techniques (conventional noise reduction) as it would block the natural ventilation that was required. The NoiseTrap® acoustic panels were chosen as a solution and installed where this natural ventilation was, with the advantage of reduced external noise (from 60 dB (A) to below 30 dB (A), in line with WHO guidelines) and continued passive cooling.

The new noise-reducing installation therefore resulted in an **improvement to the environment** (for residents, including those in a nearby hotel) and avoided an increase in energy demand (did not require accompanying air conditioning) [S7]. [text removed for publication] [S4] [text removed for publication] than the cost of using conventional acoustic barriers and the effectiveness of this project was reported in the UK Power Networks' Environment Report 2017/2018 [S7].

**5. Sources to corroborate the impact**

**S1: Sonobex patents granted 2014 - 2020**
Description: List of patents and their URLs for innovation related to this impact case.
**S2: Sonobex awards won 2016, 2018 and 2019**
Description: List of URLs reporting innovation awards to Sonobex.
**S3: Support letter from Merford Group's Director of Corporate Development 26/11/2019**
Description: Letter outlining significance of Sonobex acquisition to Merford Group.
**S4: Testimonial letter from Sonobex's Chief Technology Officer & Director, 9/10/2020**
Description: Letter outlining impact generated by Sonobex
**S5: NoiseTrap Installations 2017 - 2020**
Description: Case studies of NoiseTrap installations
**S6: Reports of Sonobex impact on the web 2017 - 2020**
Description: List of URLs where Sonobex projects are discussed or reported
**S7: UK Power Networks' Environment Report 2017/2018**
Description: Mention of Bayswater case study and Sonobex referenced as an innovative solution to noise pollution (pages 30-31).
Source: https://www.ukpowernetworks.co.uk/
**S8: The Present and Future Role of Acoustic Metamaterials for Architectural and Urban Noise Mitigations, Aug 2019**
Description: Review article on acoustic metamaterials. See section 3 for reference of Sonobex as launching the "first commercially available acoustic metamaterial-based noise barrier."
**S9: "Acoustic Metamaterials for Low Frequency Industrial Applications" Poster**
Description: Copy of poster which won award at 2018 COMSOL conference in Lausanne.