UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

INSTITUTO UNIVERSITARIO EN SISTEMAS INTELIGENTES Y APLICACIONES NUMÉRICAS EN INGENIERÍA

International Conference on Evolutionary and Deterministics Methods for Design, Optimization and Control with Applications to Industrial and Societal Problems
EUROGEN 2013

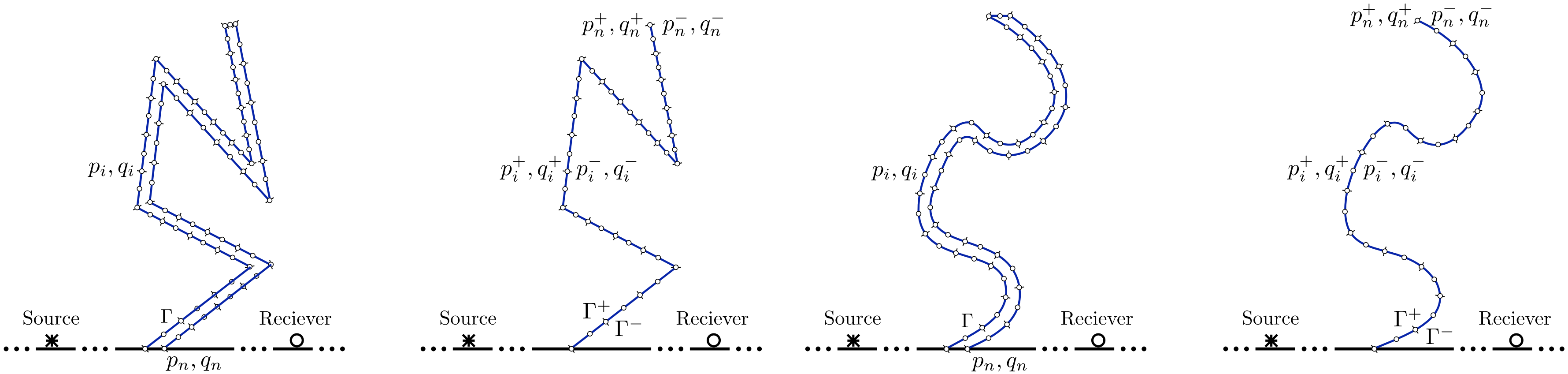
Las Palmas de Gran Canaria, 8th October 2013

A comparative study in design optimization of polygonal and Bézier curve shaped-thin noise barriers using dual BEM formulation

R. Toledo, J. J. Aznárez, O. Maeso, D. Greiner

POLYGONAL-SHAPED BARRIER | BÉZIER CURVE-SHAPED BARRIER

REAL VOLUMETRIC BARRIER | IDEALIZED NULL-THICKNESS BARRIER | REAL VOLUMETRIC BARRIER | IDEALIZED NULL-THICKNESS BARRIER



Introduction

NOISE IN THE ROAD ENVIRONMENT

ENVIRONMENTAL NOISE POLLUTION

NOISE REDUCTION STRATEGIES

To abate the noise at source

Impossible all too often

To abate the acoustic impact

Noise barrier inclusions between the source and the intended to be protected

BOUNDARY ELEMENTS METHOD (BEM)

BARRIER PERFORMANCE ASSESSMENT

Introduction

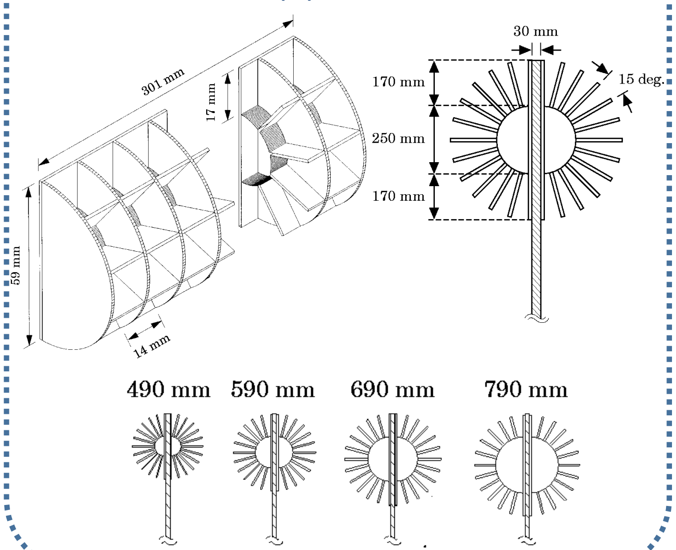
EXAMPLES OF SOME NOISE BARRIERS

State of the Art

BEM IN PERFOMANCE OF NOISE BARRIERS

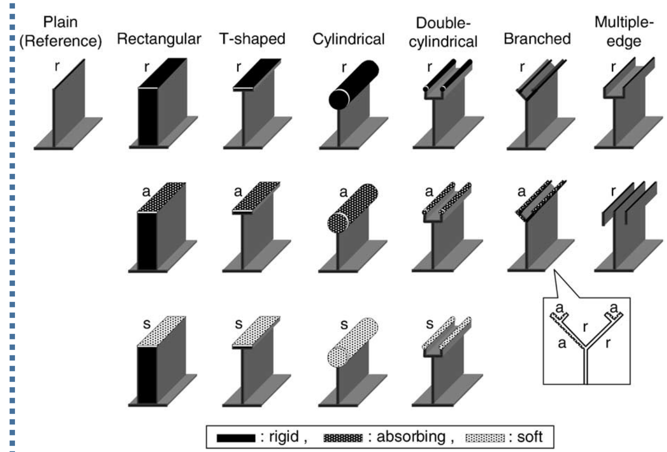
OKUBO & FUJIWARA (1998)

- Efficiency of a noise barrier on the ground with an acoustically soft cylindrical edge. *Journal of Sound and Vibrations* **216**(5), 771-790.



ISHIZUKA & FUJIWARA (2004)

- Performance of noise barriers with various edge shapes and acoustical conditions. *Applied Acoustics* **65**, 125-141.

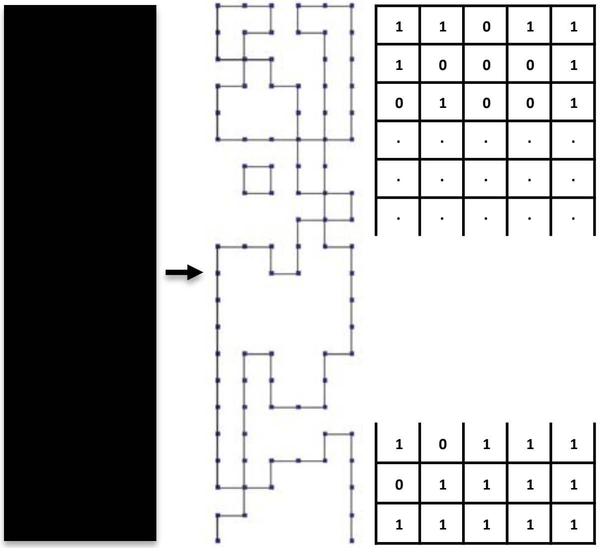


State of the Art

GA AND BEM IN SHAPE OPTIMIZATION

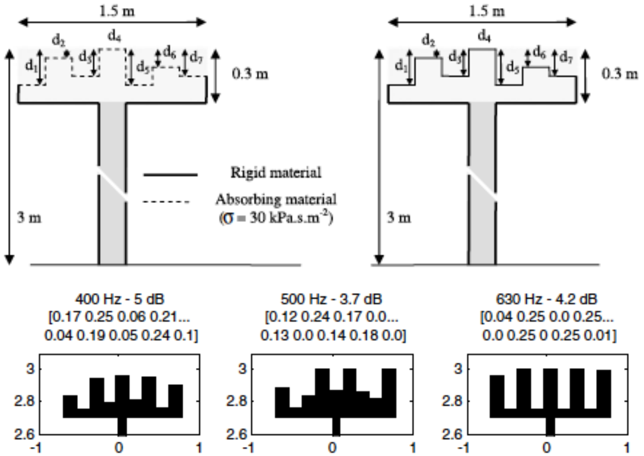
DUHAMEL (2006)

- Shape optimization of noise barriers using genetic algorithms. *Journal of Sound and Vibrations* **297**, 432-443.



BAULAC ET AL. (2008)

- Optimisation with genetic algorithm of the acoustic performance of T-shaped noise barriers with a reactive top surface. *Applied Acoustics* **69**, 332-342.



State of the Art

Introduction
State of the Art
Optimization Protocol
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Problem Presentation
Results
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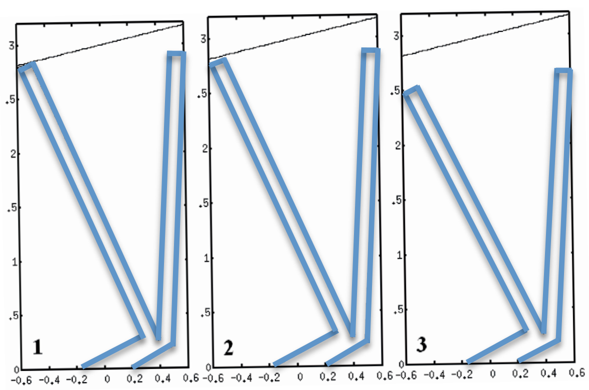
Developments

GA AND BEM IN SHAPE OPTIMIZATION

GREINER ET AL. (2010)

- Single- and multi-objective shape design of Y-noise barriers using evolutionary computation and boundary elements. Advances in Engineering Software **41**, 368-378.



OVERVIEW

- Both a single- and a multi-objective Y-shaped design optimization is carried out.
- Single-objective problem: to fit the Y-IL graph to a given reference one (inverse problem).
- Multi-objective problem: to both fit the Y-IL graph to the given reference and minimize the overall lenght of the barrier boundary intended to be optimized

Optimization Protocol

ACOUSTIC EFFICIENCY OF THE BARRIER

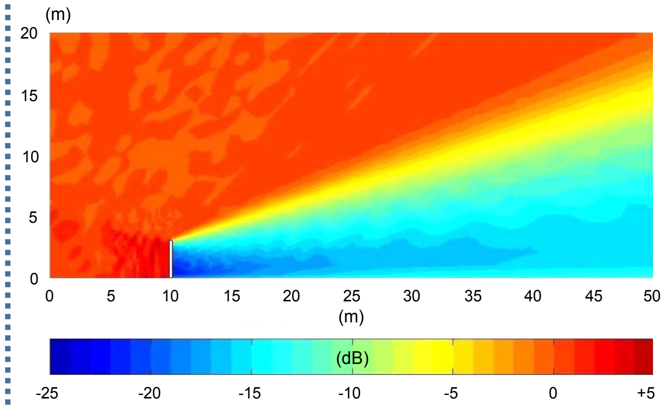
INSERTION LOSS COEFFICIENT (IL)

- Difference in acoustic pressure levels before and after the inclusion of the barrier.
- Measured in decibels (dB).
- Broadly used in the evaluation of noise control measures.
- Expression:

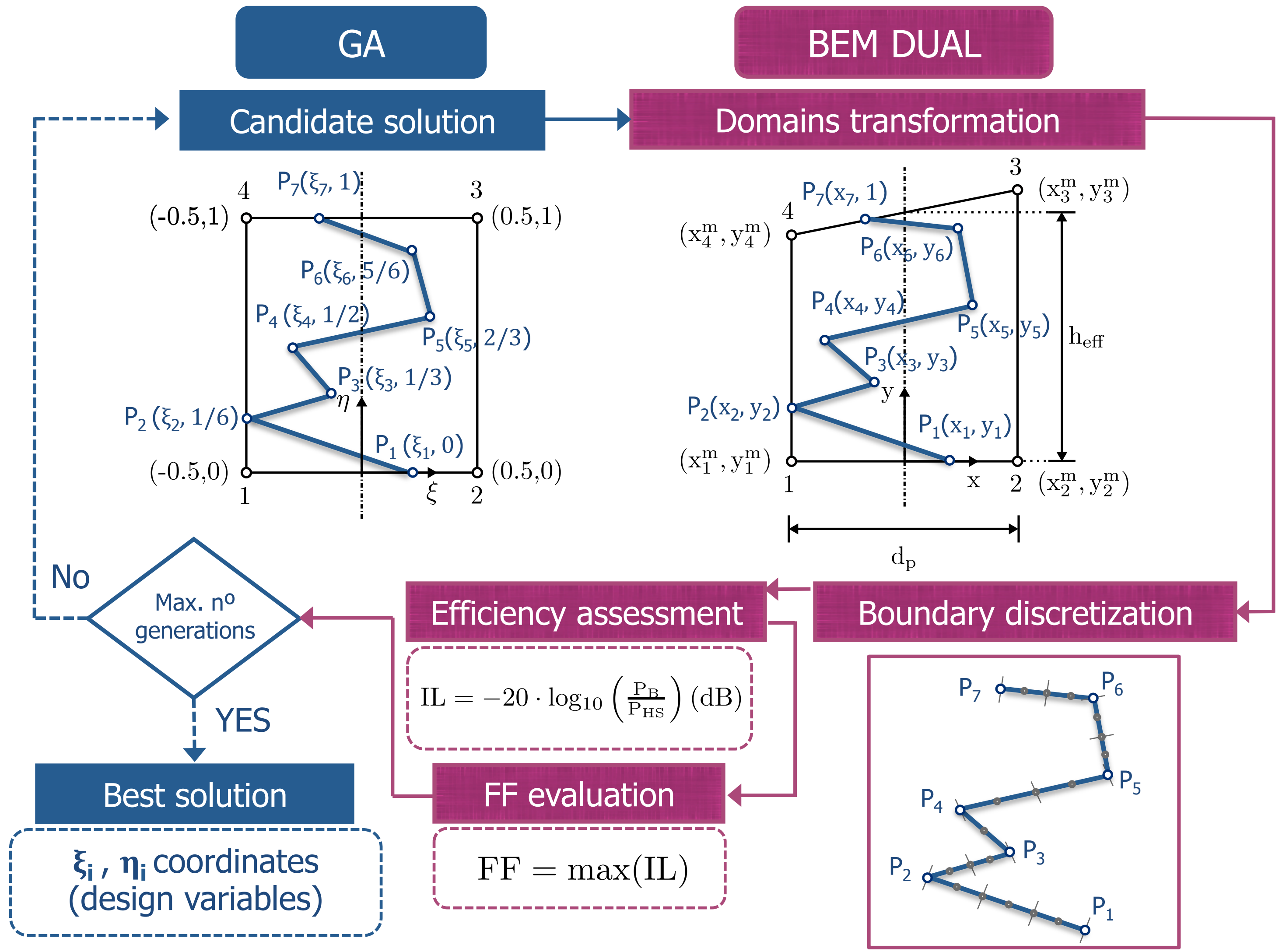
$$\mathrm{IL} = -20 \cdot \log_{10}\left(\frac{\mathrm{P_B}}{\mathrm{P_{HS}}}\right)\ (\mathrm{dB})$$

EFICIENCY ASSESSMENT

- IL values collected for certain points of the domain (receivers):



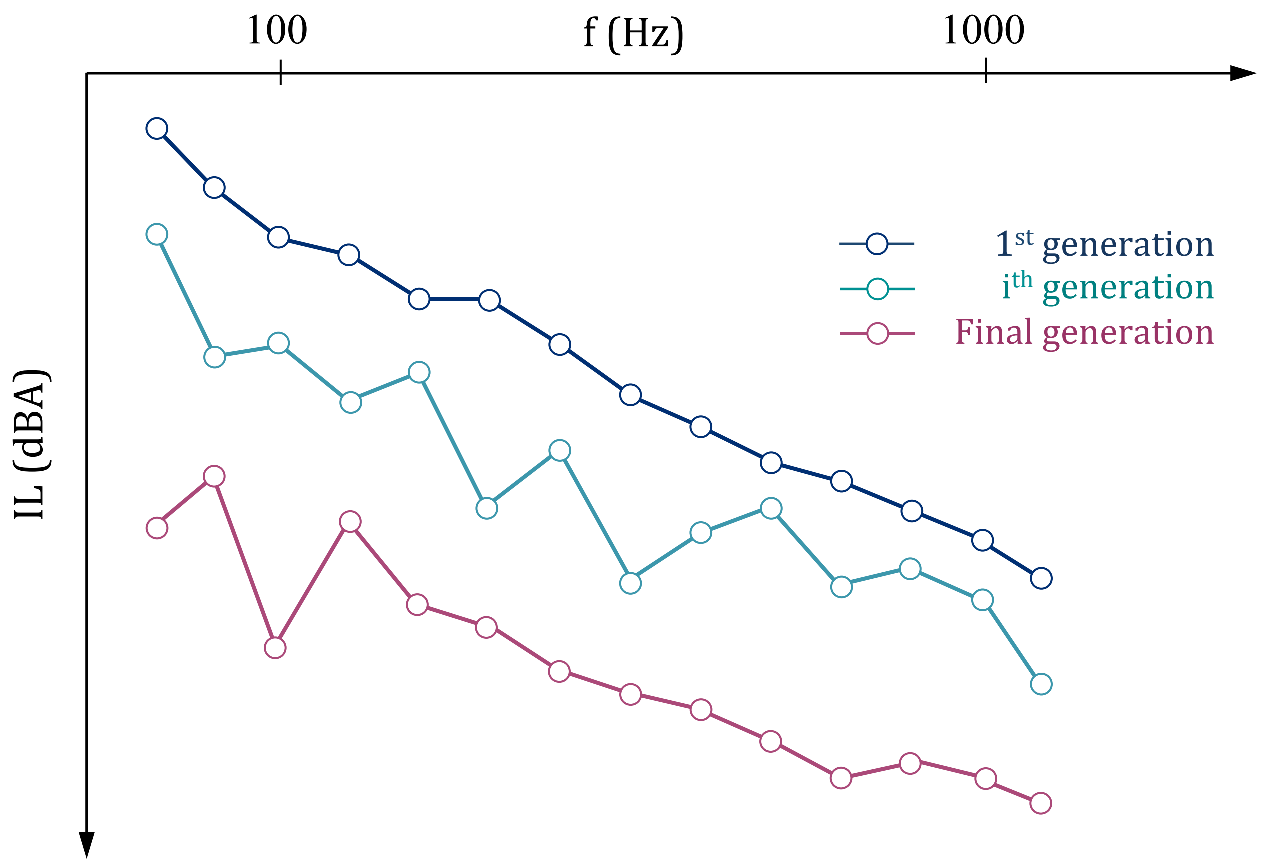
Optimization Protocol



Optimization Protocol

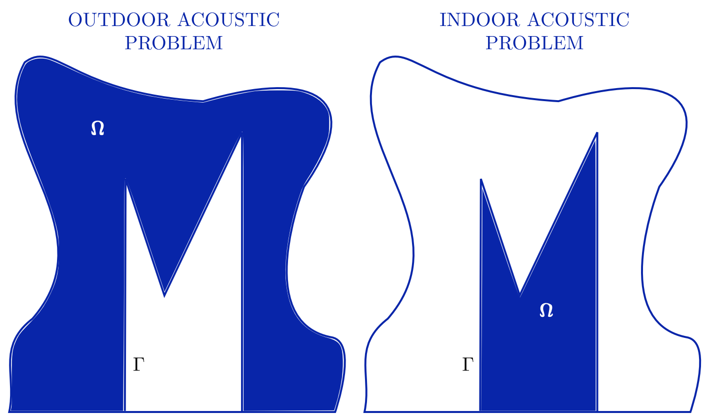
IL ASSESSMENT THROUGH OPTIMIZATION

Individuals proposed by the GA



Boundary Elements Method (BEM)

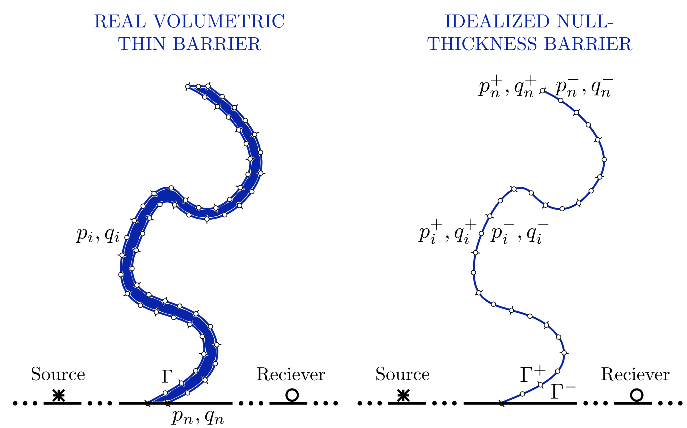
DEALING WITH LARGE GEOMETRIES



PROBLEMS RELATED

- Spurious frequencies (eigenfrequencies) related to the indoor acoustic problem arise.
- The acoustic efficiency of the barrier is seriously affected.

DEALING WITH THIN-CROSS SECTION CONF.



PROBLEMS RELATED

- Numerical integration problems may arise for volumetric thin barriers.
- The acoustic efficiency of the barrier is affected.

Boundary Elements Method (BEM)

DUAL FORMULATION. NULL-TICHKNESS BOUNDARIES

SINGULAR FORMULATION

$$\frac{1}{2}\cdot\Sigma\mathbf{p}_i+\sum_{j=1}^{NE}\mathbf{H}_j^{+}\cdot\Delta\mathbf{p}_j=\sum_{j=1}^{NE}\mathbf{G}_j^{+}\cdot\Sigma\mathbf{q}_j+\mathbf{p}_0^{*}$$

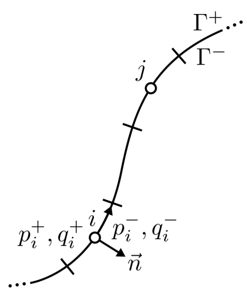
HYPER-SINGULAR FORMULATION

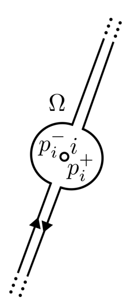
$$\frac{1}{2}\cdot\Delta\mathbf{q}_i+\sum_{j=1}^{NE}\mathbf{M}_j^{+}\cdot\Delta\mathbf{p}_j=\sum_{j=1}^{NE}\mathbf{L}_j^{+}\cdot\Sigma\mathbf{q}_j+\frac{\partial\mathbf{p}_0^{*}}{\partial\mathbf{n}_i}$$

RESULTING SYSTEM OF EQUATIONS

$$\begin{bmatrix}\frac{\mathbf{I}}{2}-\mathbf{G}^{+}\mathrm{A}^{+} & \mathbf{H}^{+}-\mathbf{G}^{+}\mathrm{A}^{-}\\ \frac{\mathrm{A}^{-}}{2}\mathbf{I}-\mathbf{L}^{+}\mathrm{A}^{+} & \frac{\mathrm{A}^{+}}{2}\mathbf{I}+\mathbf{M}^{+}-\mathbf{L}^{+}-\mathrm{A}^{-}\end{bmatrix}\begin{bmatrix}\Sigma\mathbf{p}\\ \Delta\mathbf{p}\end{bmatrix}=\begin{bmatrix}\mathbf{p}_o^{*}\\ \frac{\partial\mathbf{p}_o^{*}}{\partial\mathbf{n}_i^{+}}\end{bmatrix}$$

PRESSURE AND FLUX AT BOTH SIDES





Problem Presentation

PROBLEM DEFINITION

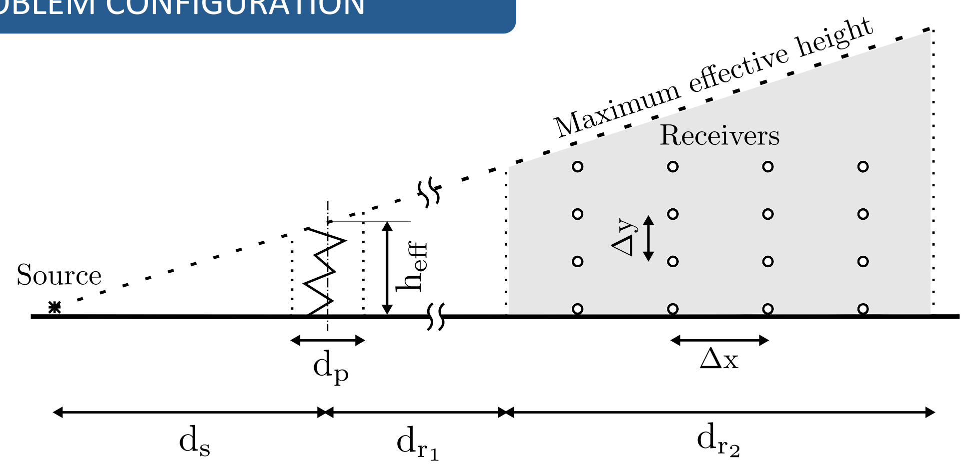
- Perfectly reflective both barrier and ground surface (β_s=β_p=0).
- Feasible region defined by effective height (h_{eff}=3 m) and horizontal projection on the ground (d_p=1 m).
- Source laid on the ground at d_s=10 m.
- Two receivers configurations: 4 rec. on the ground and 4x4 grid of receivers.

RECEIVERS PLACEMENT

- Three regions in terms of closeness to the barrier are studied:

Region	d_s	d_p	d_{r_1}	d_{r_2}	Δx	Δy
1			0.5	10	2	1
2	10	1	10.5	40	8	2
3			50.5	50	10	5

PROBLEM CONFIGURATION



Problem Presentation

APPLIED SPECTRA

- A-weighted normalized traffic noise spectra of vehicle by CTE (ISO 717.2).
- Study conducted for third octave frequencies ranging 100-2000 Hz.

$$\overline{\mathrm{IL}} = -10 \cdot \log_{10} \left(\frac{\sum_{i=1}^{NF} 10^{(A_i - IL_i)/10}}{\sum_{i=1}^{NF} 10^{A_i/10}} \right) \text{(dBA)}$$

FITNESS FUNCTION (FF)

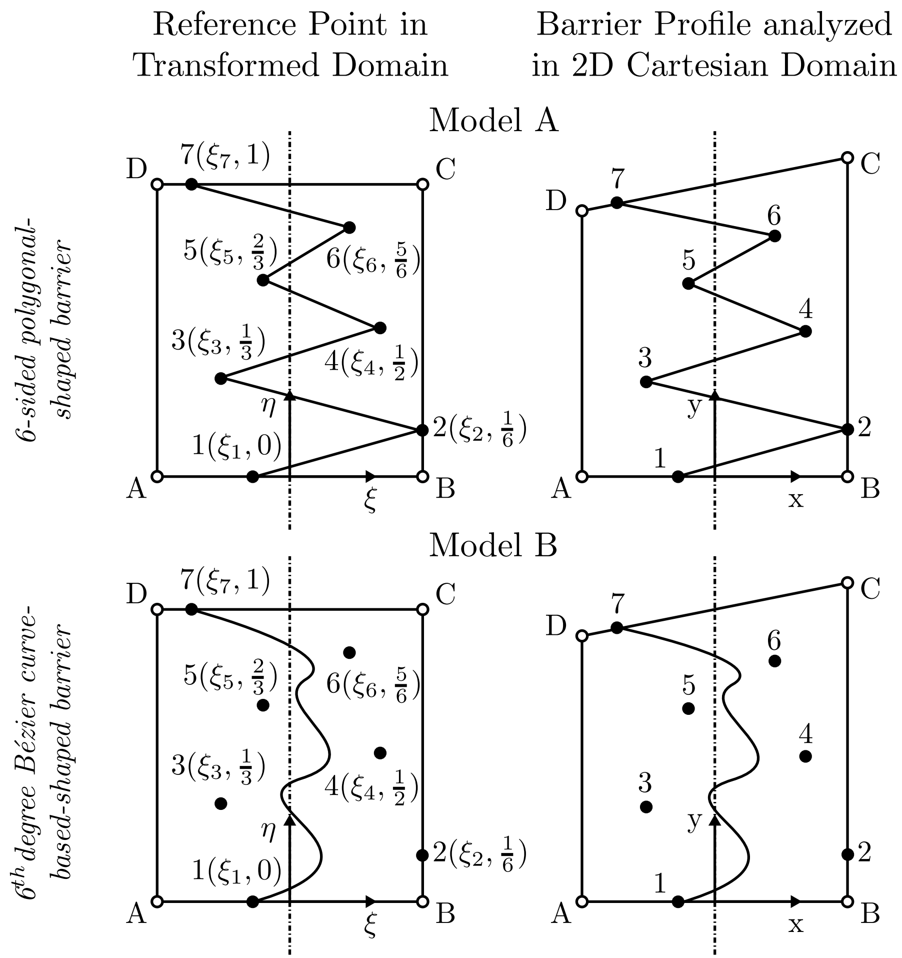
- Shape optimization based on the IL average at receiver points:

$$\mathrm{FF} = \sum_{j=1}^{NR} \overline{\mathrm{IL}}_j / \mathrm{NR}$$

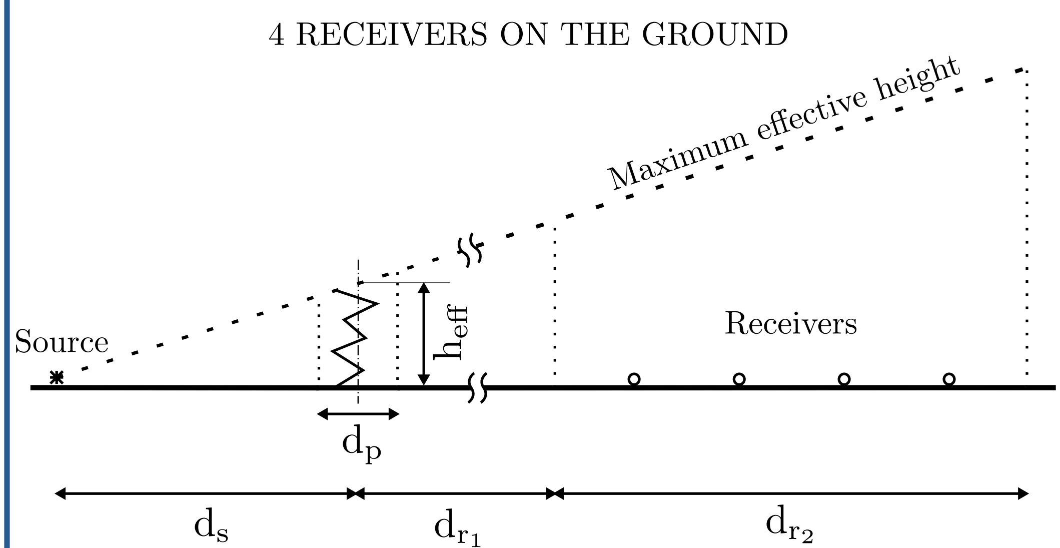
- The aim is to maximize the FF value (the higher its value the higher the acoustic efficiency of the proposed barrier).

Problem Presentation

DESIGNS UNDER STUDY



'Ca' receivers configuration

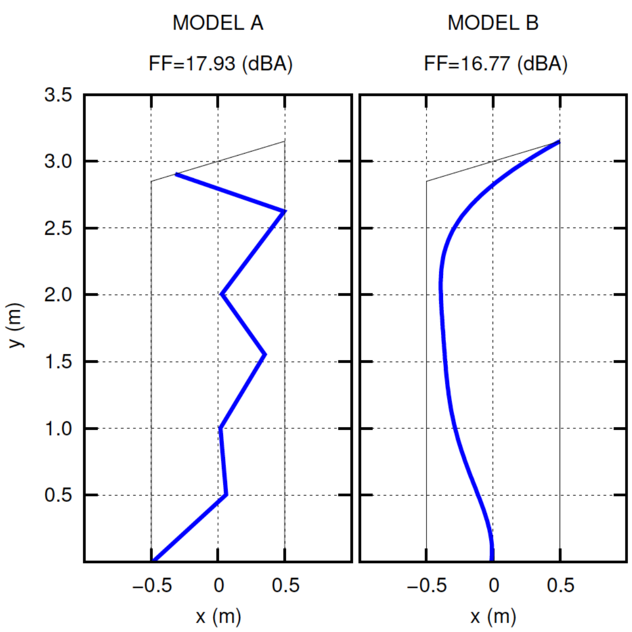


	Region		
	1	2	3
d_s		10.0	
d_p		1.0	
d_{r_1}	0.5	10.5	50.5
d_{r_2}	10.0	40.0	50.0
Δx	2.0	8.0	10.0

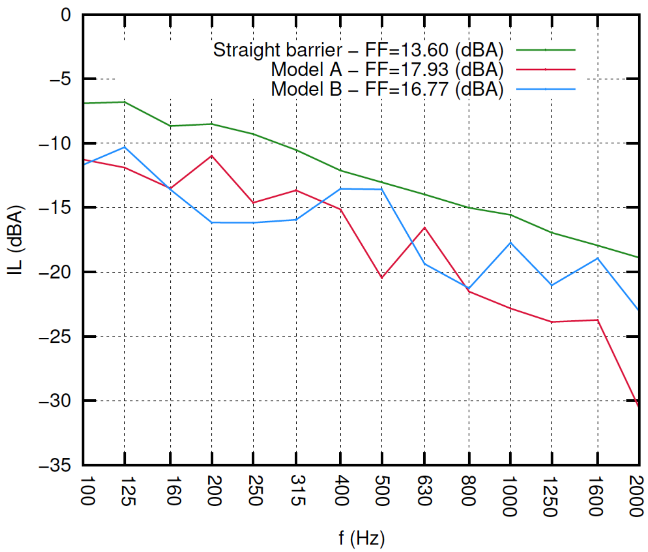
Results. 'Ca' receivers configuration

REGION 1 (NEAR REGION)

SHAPE OPTIMIZED DESIGNS



AVERAGE IL EVOLUTION



Results. ‘Ca’ receivers configuration

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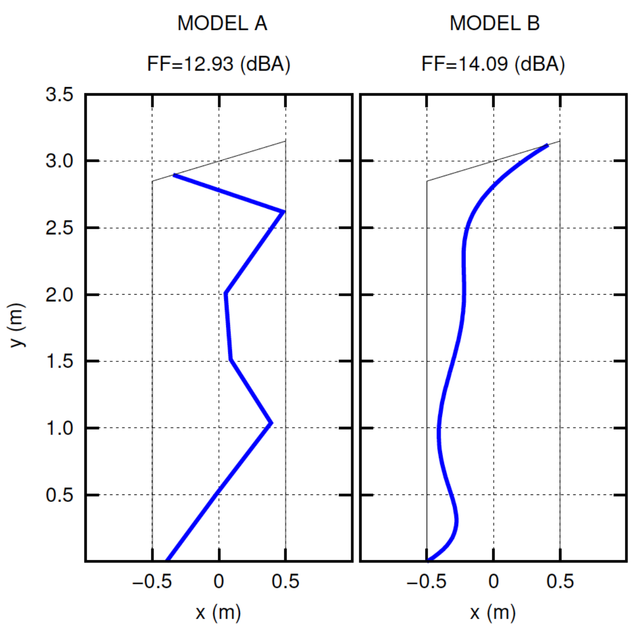
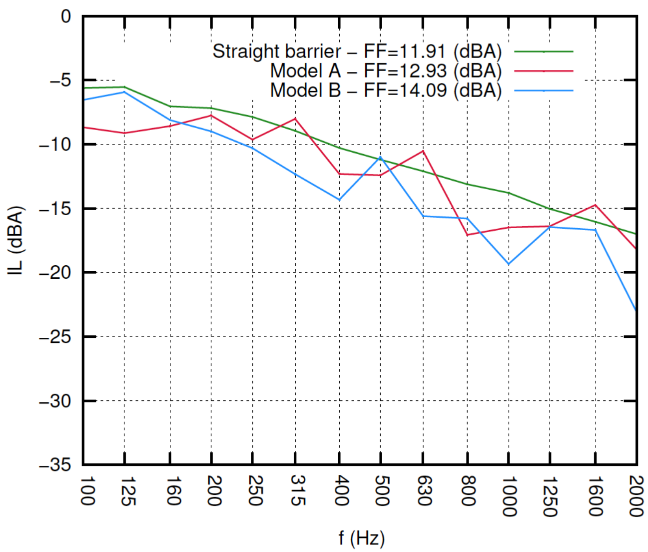
REGION 2 (INTERMEDIATE REGION)

SHAPE OPTIMIZED DESIGNS



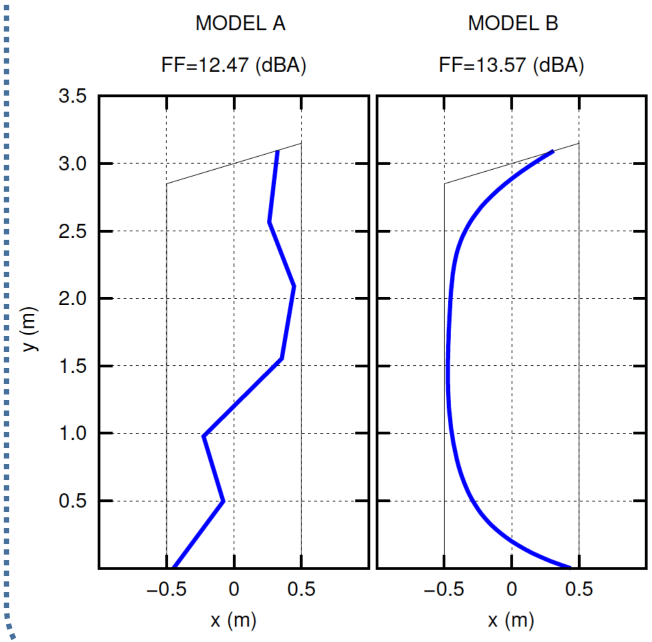
AVERAGE IL EVOLUTION



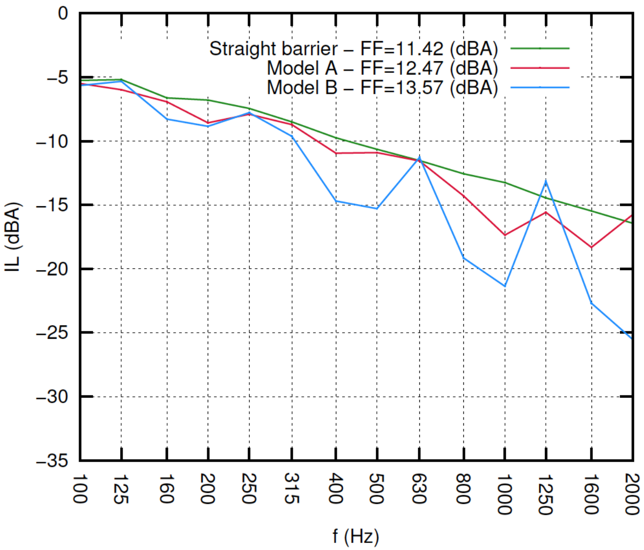
Results. 'Ca' receivers configuration

REGION 3 (FAR REGION)

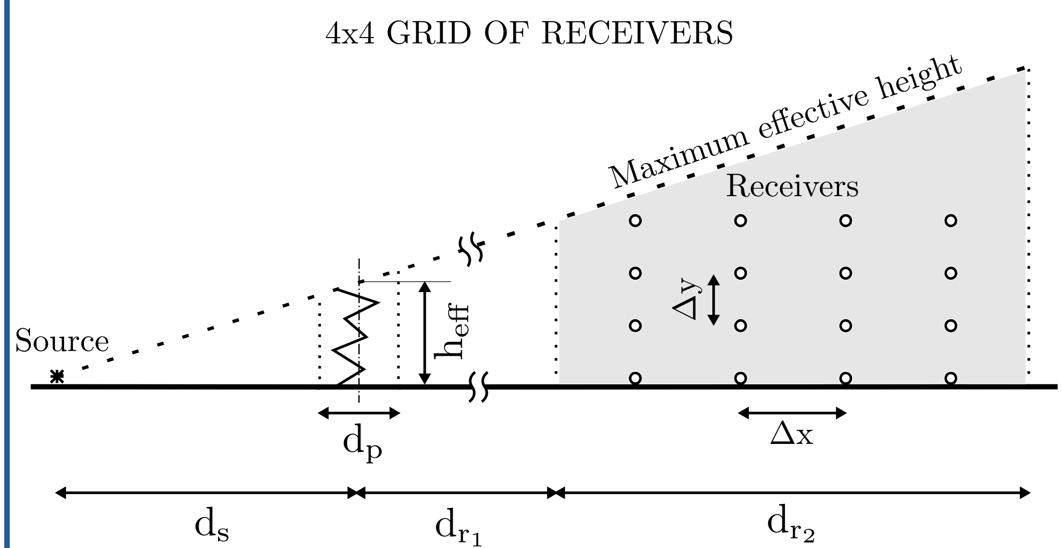
SHAPE OPTIMIZED DESIGNS



AVERAGE IL EVOLUTION



‘Cb’ receivers configuration

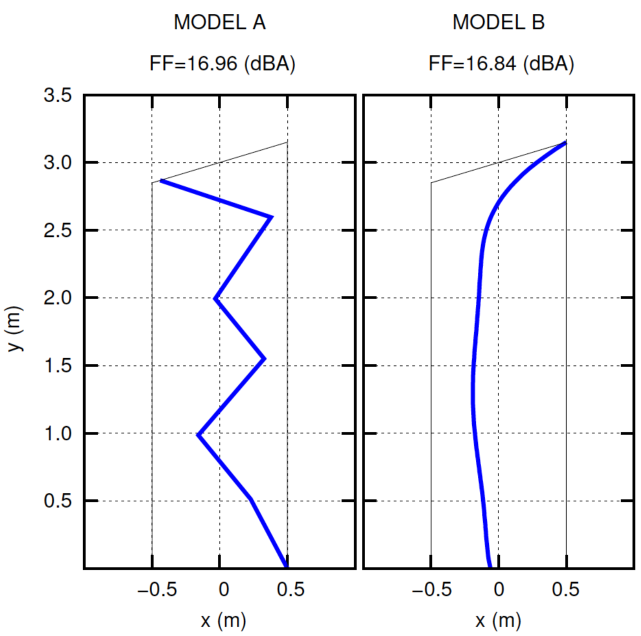


	Region		
	1	2	3
d_s		10.0	
d_p		1.0	
d_{r_1}	0.5	10.5	50.5
d_{r_2}	10.0	40.0	50.0
Δx	2.0	8.0	10.0
Δy	1.0	2.0	5.0

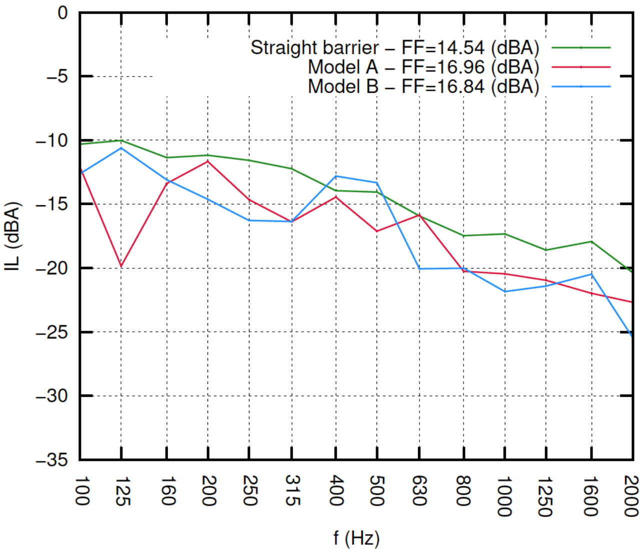
Results. 'Cb' receivers configuration

REGION 1 (NEAR REGION)

SHAPE OPTIMIZED DESIGNS



AVERAGE IL EVOLUTION



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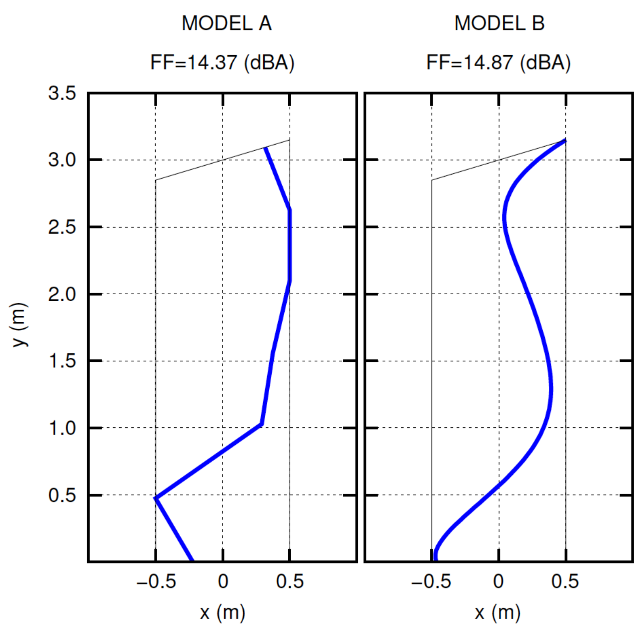
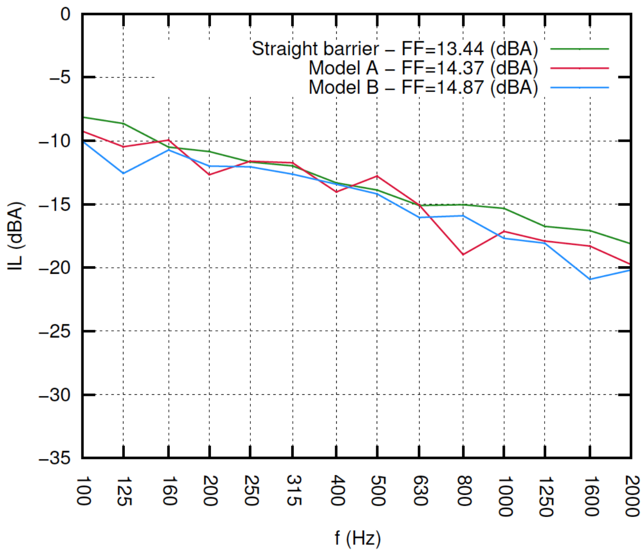
Results. 'Cb' receivers configuration

REGION 2 (INTERMEDIATE REGION)

SHAPE OPTIMIZED DESIGNS



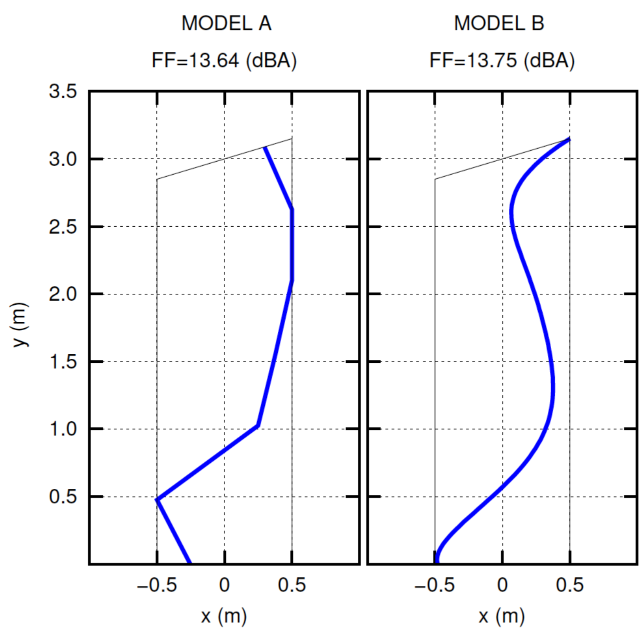
AVERAGE IL EVOLUTION



Results. 'Cb' receivers configuration

REGION 3 (FAR REGION)

SHAPE OPTIMIZED DESIGNS



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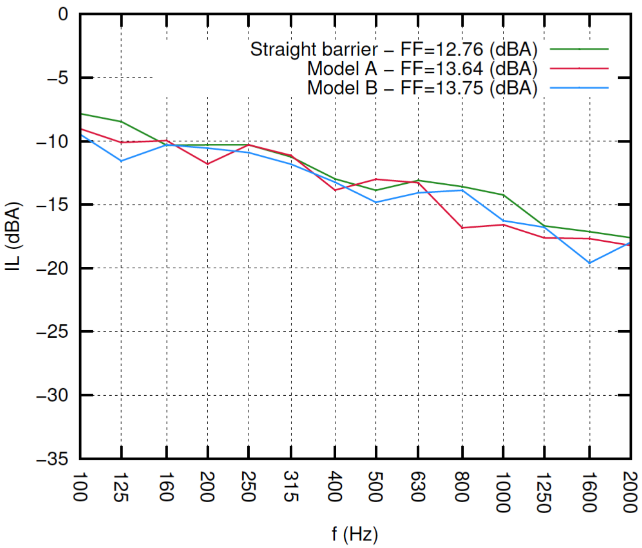
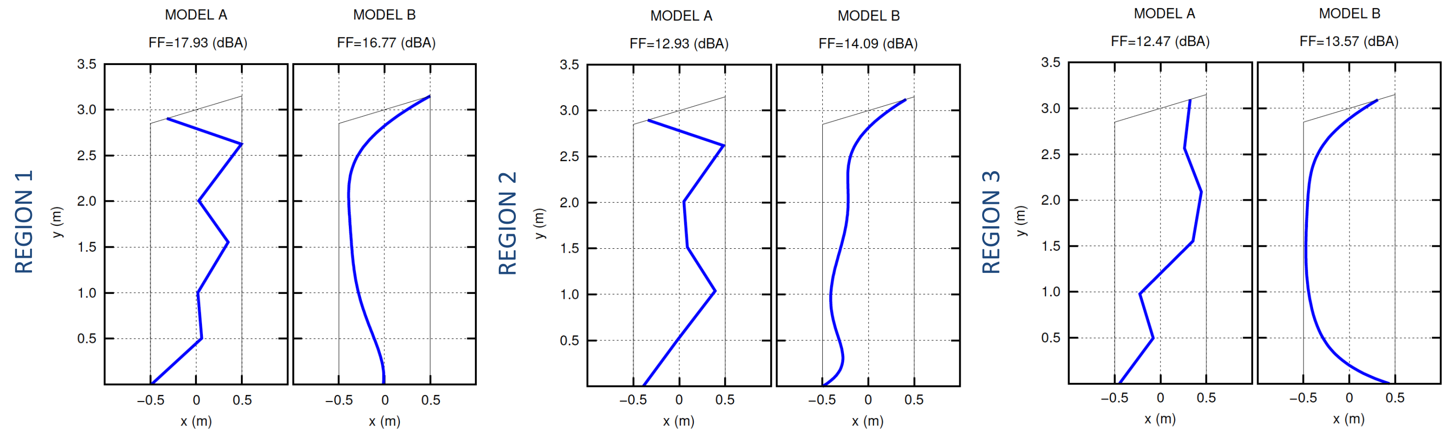


Results. 'Ca' receivers configuration

SHAPE OPTIMIZED DESIGNS PER REGION



ACOUSTIC EFFICIENCY OF THE MODELS

RC*	Region	Model	L_c(m)	ΔL_c(m)	FF_{best}(dBA)	ΔFF_{best}(dBA)
Ca	1	A	4.08177	+1.08177	17.92628	+4.32966
		B	3.60547	+1.60547	16.77495	+3.17833
	2	A	3.97839	+0.97839	12.93384	+1.02711
		B	3.51863	+0.51863	14.08611	+2.17938
	3	A	3.52785	+0.52785	12.46634	+1.04716
		B	3.84417	+0.84417	13.57048	+2.15130
Cb	1	A	4.10065	+1.10065	16.95941	+2.41822
		B	3.41333	+0.41333	16.83553	+2.29434
	2	A	3.63842	+0.63842	14.36767	+0.92615
		B	3.71865	+0.71865	14.87088	+1.42936
	3	A	3.60034	+0.60034	13.64344	+0.88584
		B	3.68994	+0.68994	13.75215	+0.99450

*Receiver configuration.

Results. 'Cb' receivers configuration

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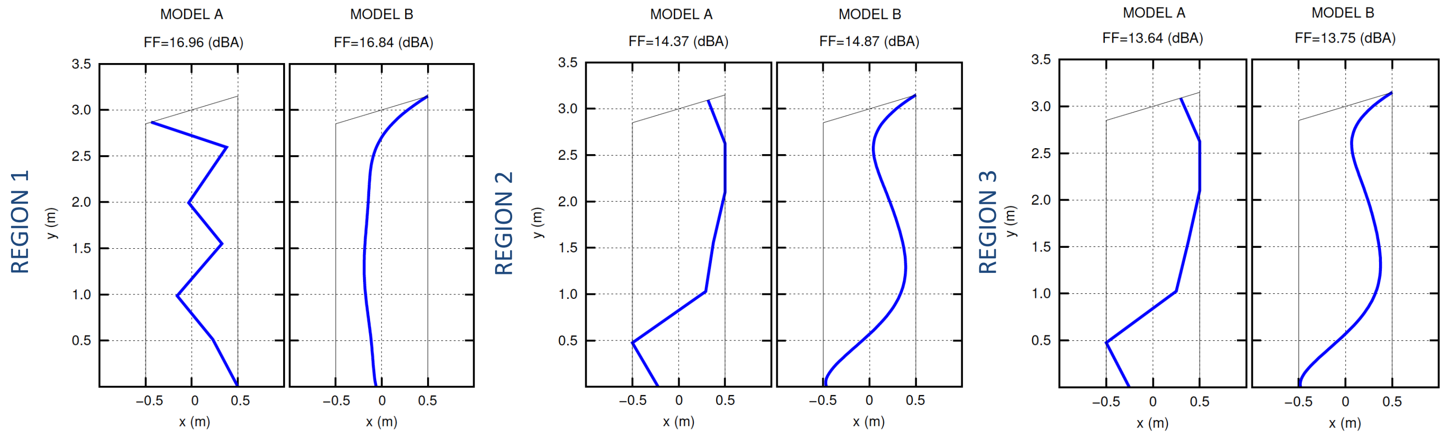
SHAPE OPTIMIZED DESIGNS PER REGION



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		B	3.68994	+0.68994	13.75215	+0.99450

*Receiver configuration.

Results

RESULTS DISCUSSION

MODELS COMPARISON

- The polygonal-shaped barrier (model A) shows a better performance for near regions when receivers are placed on the ground (Ca).
- However, the 6th degree Bézier curve-shaped barrier (model B) performs a better acoustic behaviour for non-near regions (over 1 dBA) .
- Both models display a similar acoustic performance when a grid of receivers is considered.

MODELS VS. STRAIGHT

- Models studied herein clearly outperform the acoustic efficiency of the straight barrier for all regions and receivers configurations.
- The need to study alternatives designs to the vertical screen is suggested, even for far regions.

Conclusions

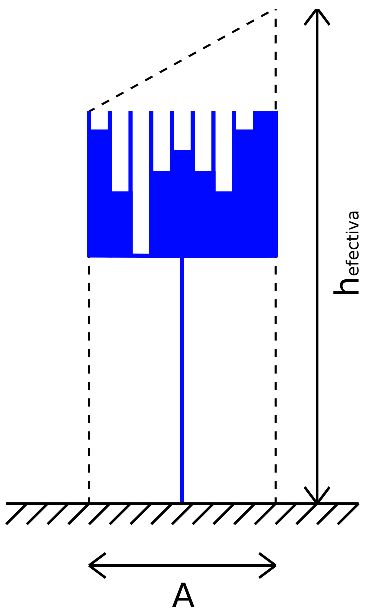
- A methodology for the optimization of the performance assessment of complex thin noise barriers designs by idealizing their profiles as null thickness boundaries has been presented.
- Two noise barrier models has been studied to validate the method.
- The range of applications of the procedure is broad and enables the study of diverse topological solutions, including those involving curve geometries.
- Idealizing complex thin-cross section barrier configurations as null boundary thickness-like models strongly ease the topological validation of the individuals proposed by the GA, yielding conclusions difficult to be drawn without the application of this methodology.

Future Developments

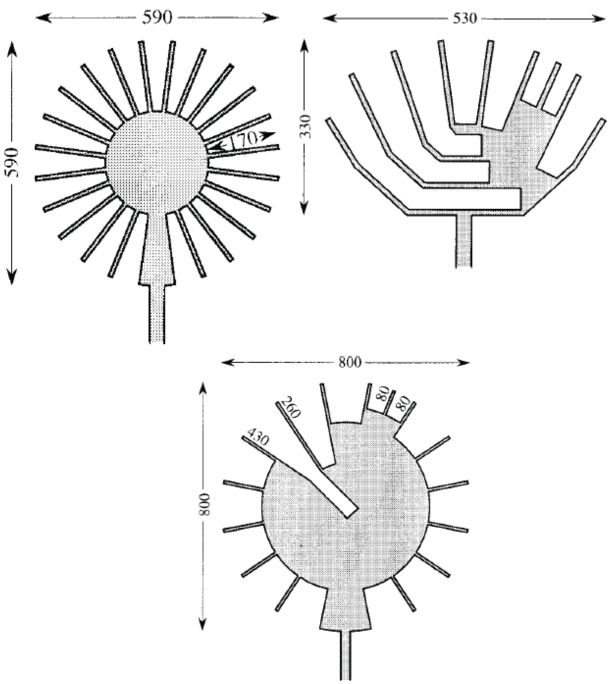
HYBRID-BOUNDARIED NOISE BARRIERS

QUADRATIC RESIDUE DIFFUSER (QRD)

- Optimization of configurations with a certain number of wells.



OTHER CONFIGURATIONS



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