Simulating Hearing Loss Using a Transmission Line Cochlea Model

Delft University of Technology

Leo Koop

October 28, 2015

Outline

Simulating Hearing Loss

- Applied Mathematics Department at TU Delft
- Supervisor: Kees Vuik

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Simulating Hearing Loss

- An incas^3 project
- Supervisor: Peter van Hengel

Motivation - Hearing Loss, Becoming more Prevalent

World Health Organization

entre | Publications | Countries | Programmes | Governance | About WHO

Media centre

1.1 billion people at risk of hearing loss

WHO highlights serious threat posed by exposure to recreational noise

Press release

27 FEBRUARY 2015 | GENEVA - Some 1.1 billion teenagers and young adults are at risk of hearing loss due to the unsafe use of personal audio devices, including smartphones, and exposure to damaging levels of sound at noisy entertainment venues such as nightclubs, bars and sporting events, according to WHO. Hearing loss has potentially devastating consequences for physical and mental health, education and employment.

Motivation - Uses of a Hearing Loss Simulator

- Education

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- Hearing loss prevention

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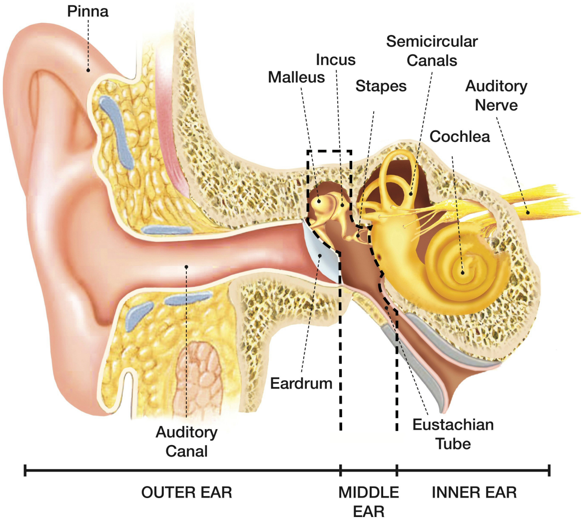
- Education
- Hearing loss prevention
- Simplifying hearing aid development and testing

The Ear



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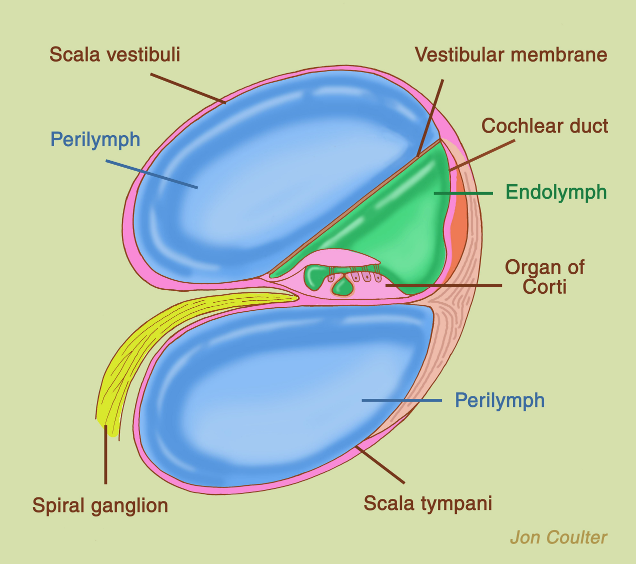
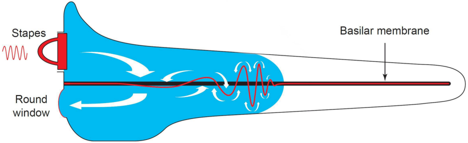
The Cochlea, a Cross Section



The Cochlea



Next Subsection

Modeling the Cochlea

The Main Equation

$$\frac{\partial^2 p}{\partial x^2}(x,t) - \frac{2\rho\partial^2 y}{h\partial t^2}(x,t) = 0, \quad 0 \leq x \leq L, \quad t \geq 0 \qquad (1)$$

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- $y(x,t)$: The excitation of the oscillator
- $p(x,t)$: Pressure on the cochlear partition
- ρ: Density of the cochlear fluid
- h: Height of the scala
- L: Length of the cochlea
- t: Time

Modeling the Cochlea

The pressure term

$$p(x,t) = m\ddot{y}(x,t) + d(x)\dot{y}(x,t) + s(x)y(x,t) \tag{2}$$

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The pressure term

$$p(x,t) = m\ddot{y}(x,t) + d(x)\dot{y}(x,t) + s(x)y(x,t) \qquad (2)$$

- m: Mass of the membrane
- $d(x)$: Position dependent damping
- $s(x)$: Position dependent stiffness

The Stiffness Term

Linear stiffness term (theoretical)

$$s(x) = s_0 e^{-\lambda x}$$

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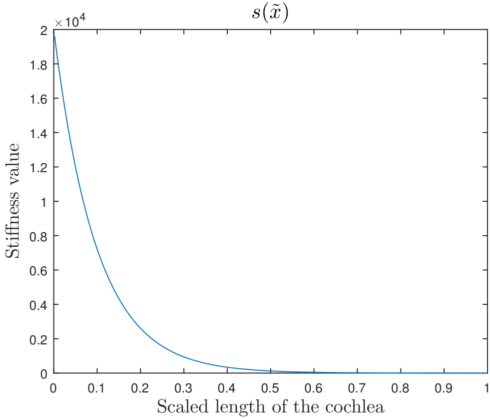

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The Damping Term

Linear damping term (theoretical)

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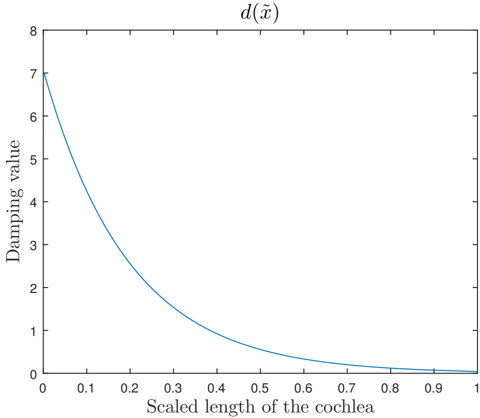

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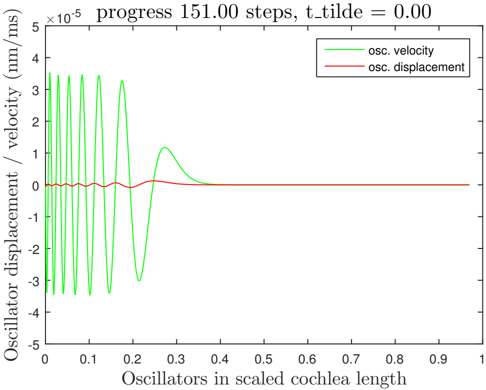
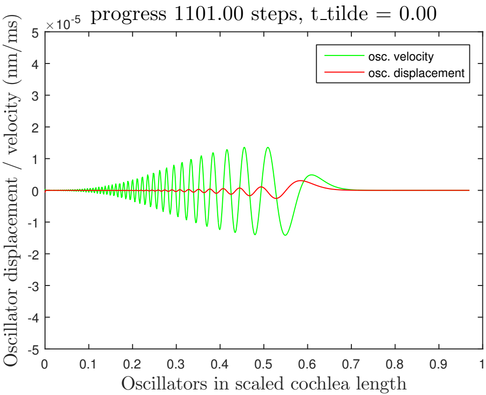
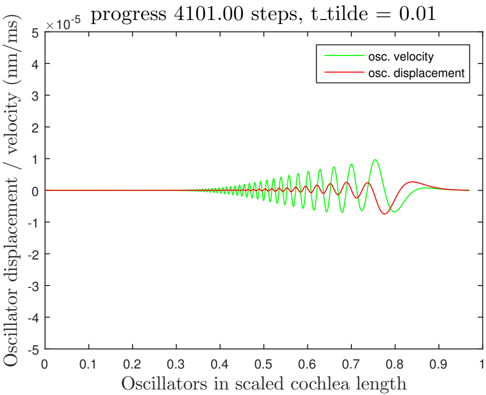
Model Output



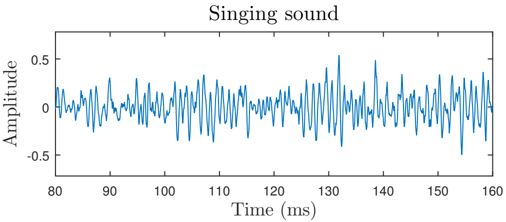
Model Output

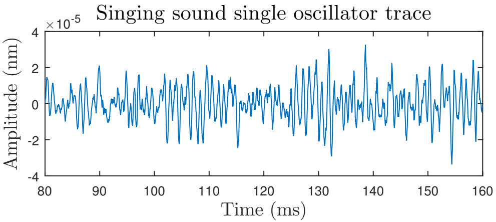


Model Output



Model Input and Output





Next Subsection

Simulation Approach

- We have a model of the normal cochlea
- Can we find the Cause given the Effect?

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Idea

Find a method to get back the original sound from the model of a healthy ear. Use this method on a model of a damaged ear to simulate hearing loss

Next Subsection

Inverse Filter Approach for a Single Oscillator

If the original sound is a and a result from the model is c then an oscillator in the model is b

$$c(t) = a(t) * b(t)$$

This in the frequency domain is:

$$C(f) = A(f) \cdot B(f)$$

A change in basic operation from convolution to multiplication

Finding the Inverse Filter

- $b(t)$ is the impulse response of an oscillator
- $B(f)$ is the frequency response of an oscillator

In the frequency domain $B^{-1}(f)$ is easily found:

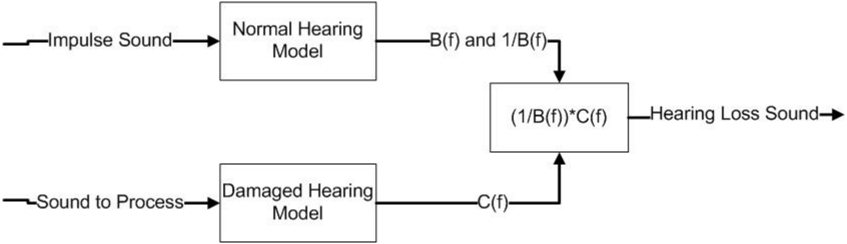
$$B^{-1}(f) = \frac{1}{B(f)}$$

Given $C(f)$ and $B(f)$, $A(f)$ is:

$$A(f) = C(f) \cdot B^{-1}(f)$$

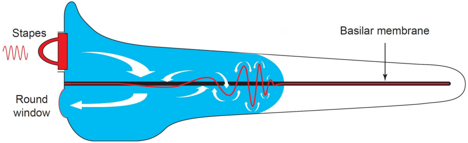
An inverse Fourier transform yields $a(t)$

The Idea

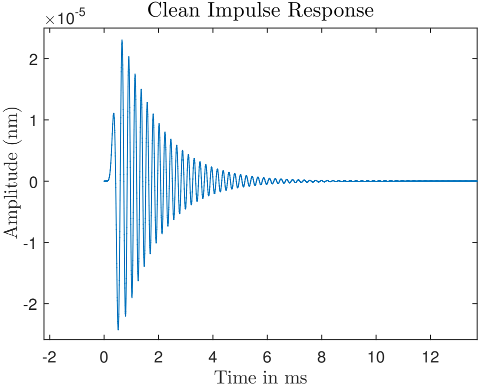

Impulse Sound
Normal Hearing Model
B(f) and 1/B(f)
(1/B(f))*C(f)
Hearing Loss Sound
Sound to Process
Damaged Hearing Model
C(f)

Next Subsection

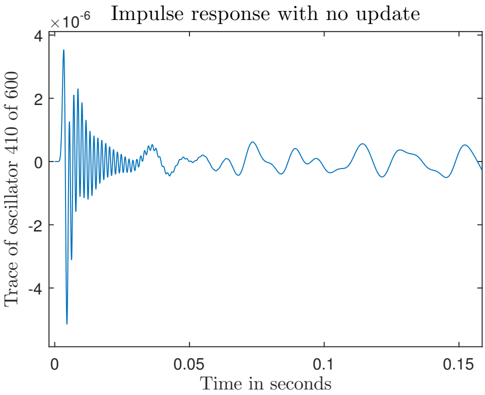
The Cochlea



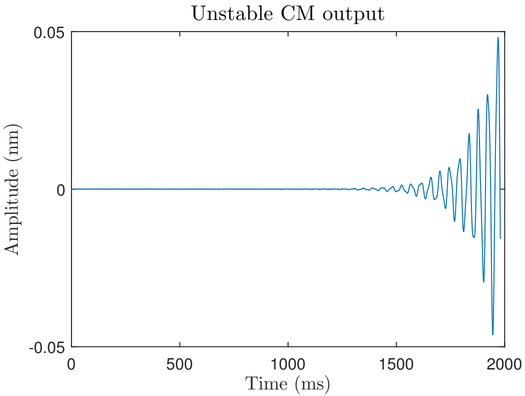
A Good Impulse Response



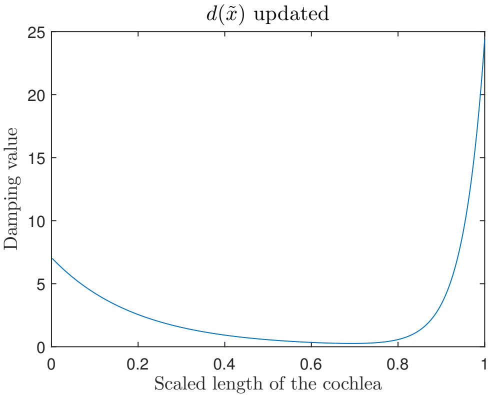
Non-Finite Impulse Response



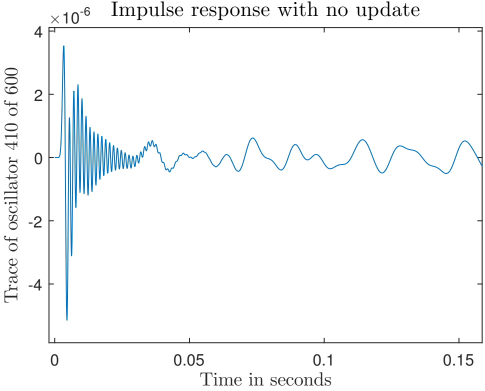
Energy Build-up in the Model



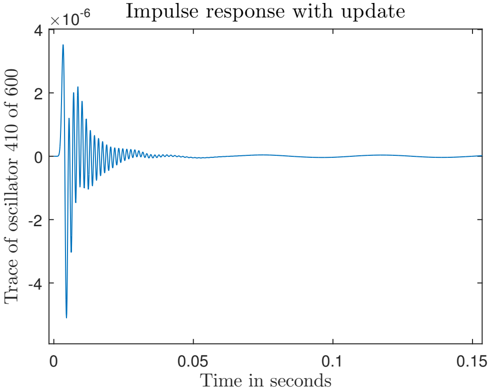
The Solution



A Better Impulse Response



A Better Impulse Response



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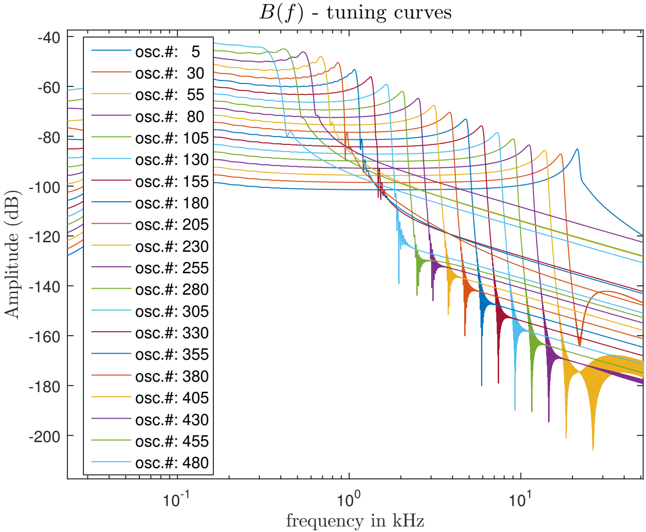
Tuning Curves



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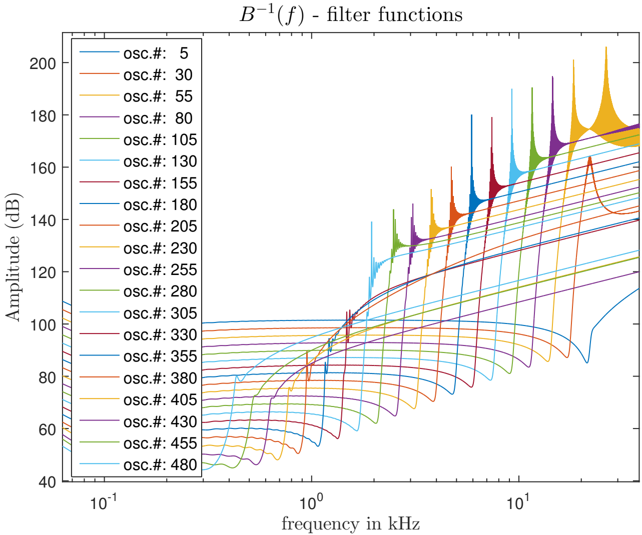
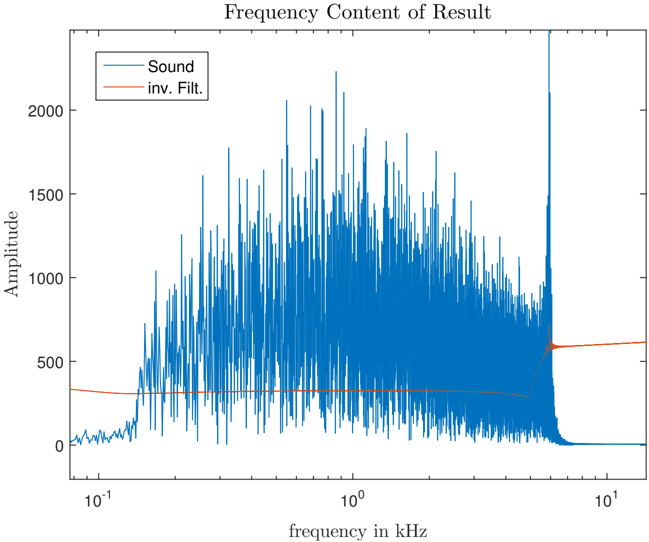
The Inverse Filters



Error Amplification



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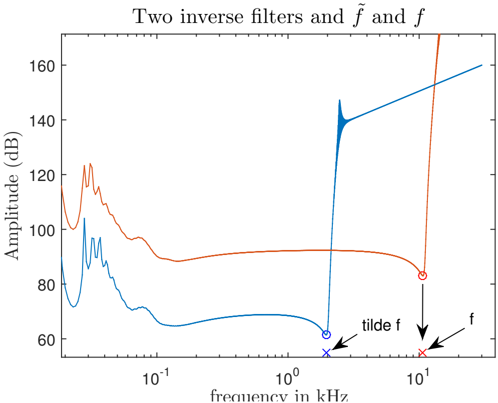
Choosing Contribution Bounds per Inverse Filter



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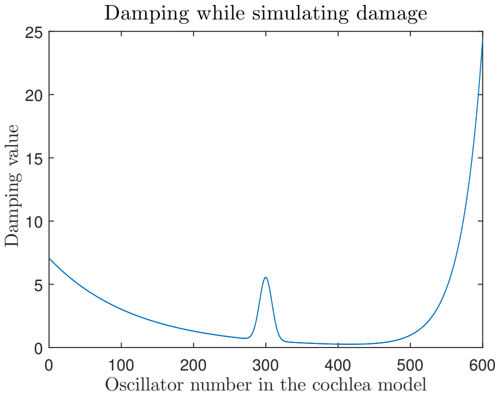
Modifying the Damping Term



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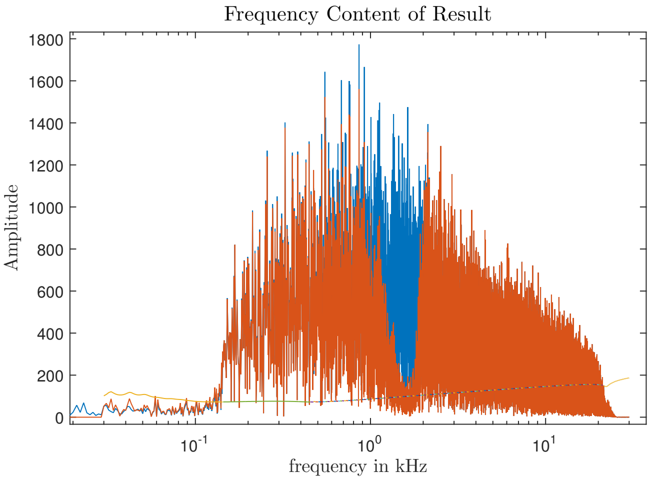
The Resulting Sound



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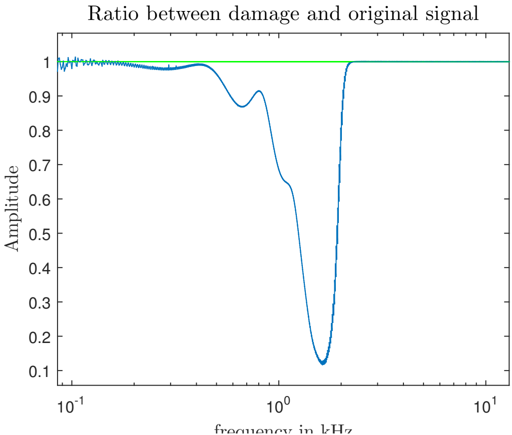

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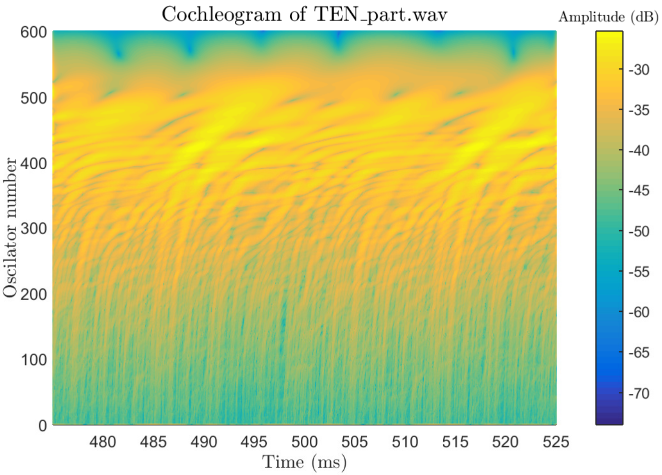
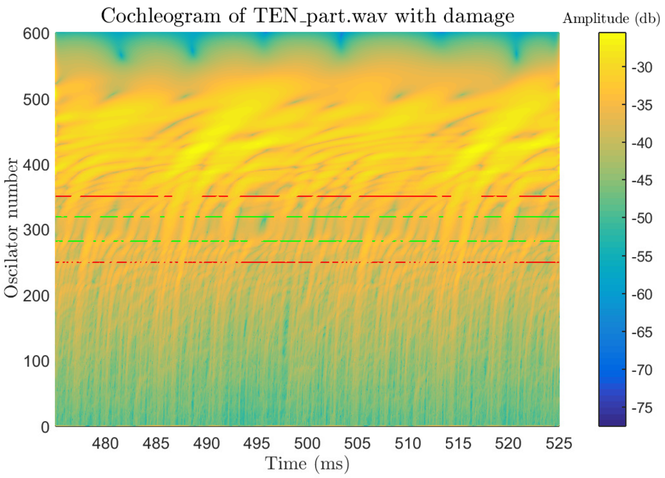
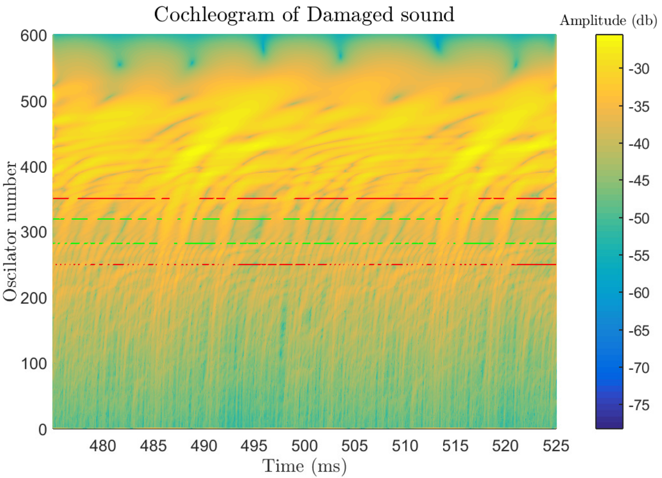
A Normal Cochleogram



Simulating Damage



Cochleogram in Response to Damaged Sound



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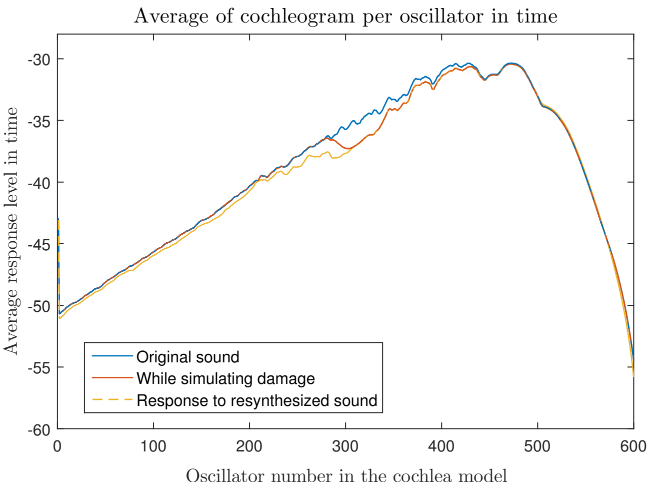
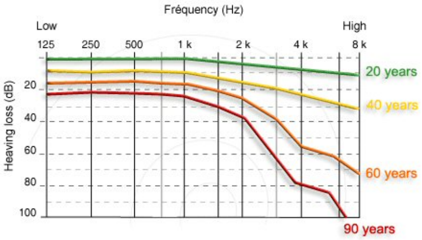
Comparing the Cochleograms



Sound Samples



- "1, 2, 3" From the TIDigits database
- "1, 2, 3 w/ noise" With background noise
- "1, 2, 3 w/ noise" Resynthesized without simulating damage
- "1, 2, 3 w/ noise" Approximate hearing loss of a 40 year old
- "1, 2, 3 w/ noise" Approximate hearing loss of a 60 year old
- "1, 2, 3 w/ noise" Approximate hearing loss of a 90 year old

Accomplishments

- Fixed an energy reflection problem in the model

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- Found a way to combine contributions from different oscillators

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- Fixed an energy reflection problem in the model
- Found a way to combine contributions from different oscillators
- A transmission line cochlea model can now be used to simulate hearing loss

Recommendations

- Sound resynthesis from a nonlinear transmission line cochlea model

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- Sound resynthesis from a nonlinear transmission line cochlea model
- The best method to solve the energy reflection problem

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- Sound resynthesis from a nonlinear transmission line cochlea model
- The best method to solve the energy reflection problem
- How to best modify the cochlea model to simulate various kinds of hearing loss

The End

"He who has an ear, let him hear..."

- Revelation 2:17