Active Noise Cancelling
&
Auditory stimulation in fMRI

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Introduction … you said « sound systems for MRI » ?

The « theoretical » section

Let’s talk a bit about sound

The « practical » section

Our own experience at the MRI Center – INT @ CERIMED

The « state of the art » section

Just to have an approximate idea of existing solutions

The Active Noise Cancelling section

Sound – Noise = Signal of Interest

The « questions ? » section

Let’s talk a bit about the talk

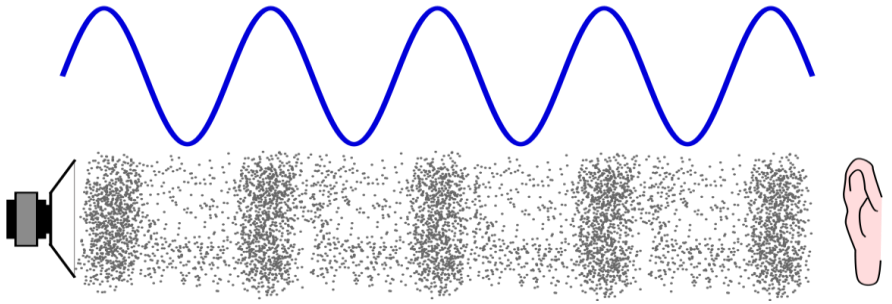
Just to remember … about the sound

Definition

- **sound** is a **vibration** that propagates as an **acoustic wave**, through a **transmission medium**
- **transmission media**: such as a gas, liquid or solid

As a mechanical wave … sound has a mechanical source / origin

- Oscillating system
  - Electronical driving
  - Piezo-electric
  - Electro-dynamic
  - Electro-static
- Biological vibration
  - Wings
  - Voice
- Music



transmission

Just to remember … about the sound

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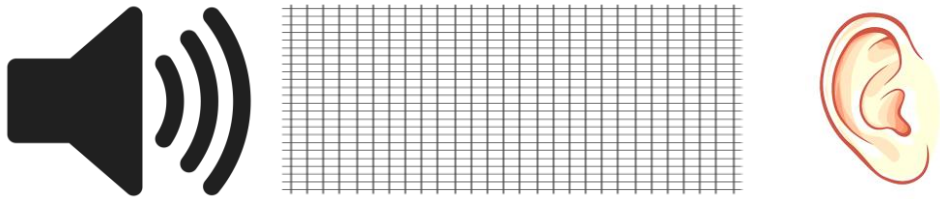


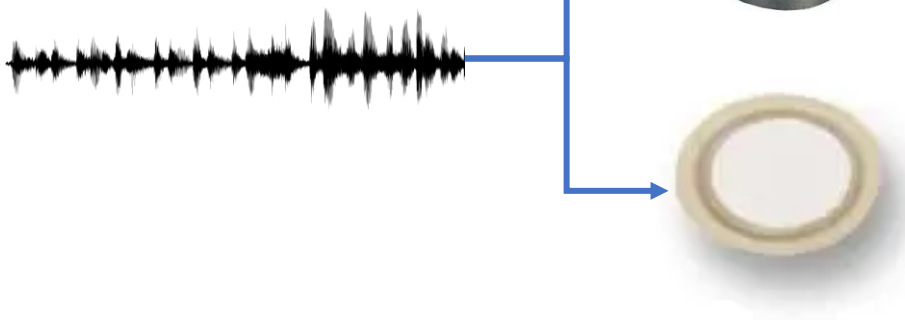
transmission

Instrumentation / effectors / sensors

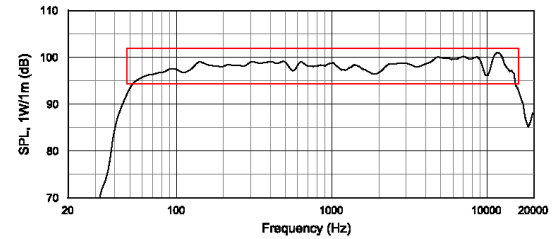
Sound production

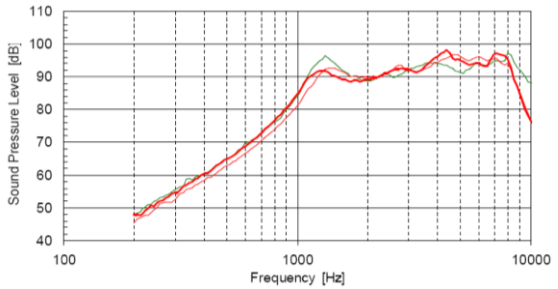
Effectors

Command

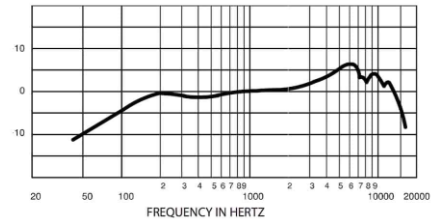


Spectral response





Sensors



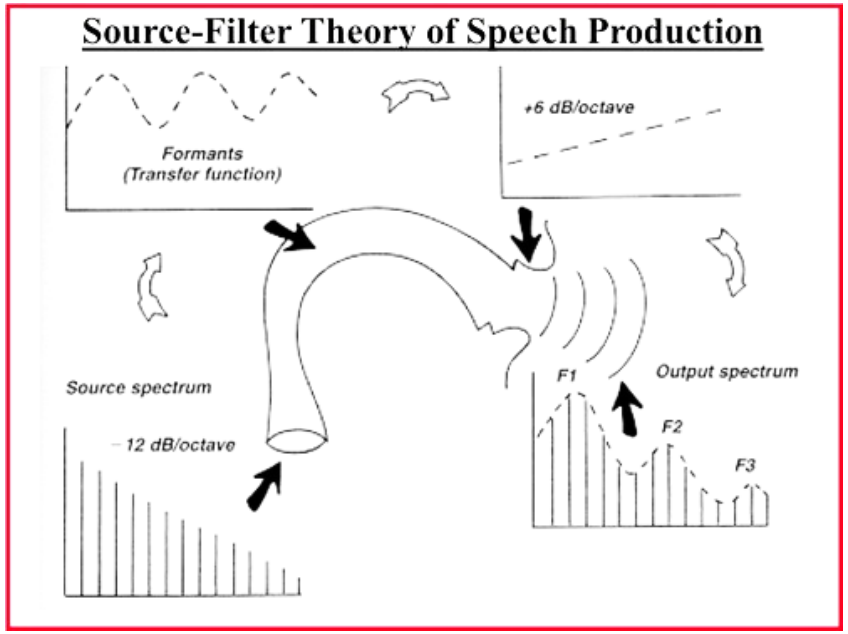
Acoustic impedance

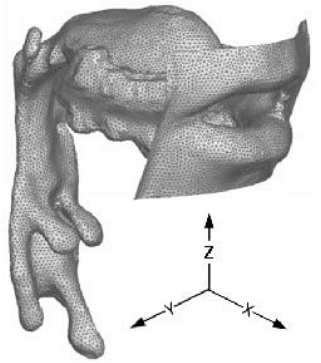
- Definition

  Measurement of the opposition that a system/medium presents to the acoustic flow resulting from an acoustic pressure

- Depends on
  - Pressure
  - Temperature
  - Acoustic component
  - …

The « source / filter » model as a typical illustration



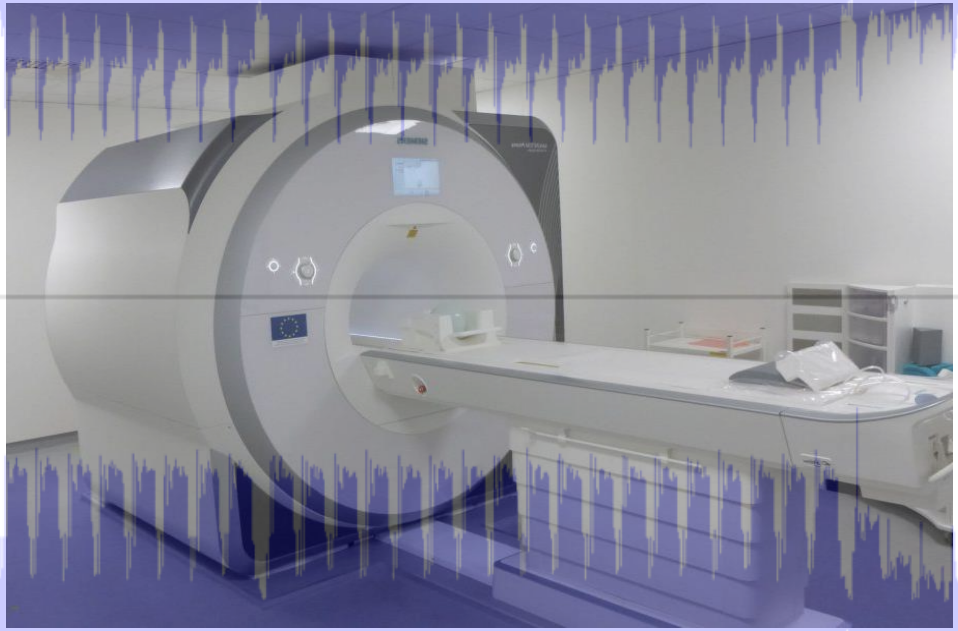


Ingo R. Titze

Nonlinear source–filter coupling in phonation: Theory

J Acoust Soc Am. 2008 May; 123(5): 2733–2749

Now, let’s talk about MRI



Why an auditory system in an MRI ?

Goals / Features

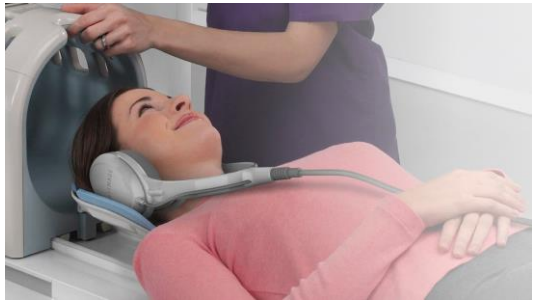
- Communication / Relaxing
- Audio comfort / Noise cancelling
- fMRI / Auditory experiments

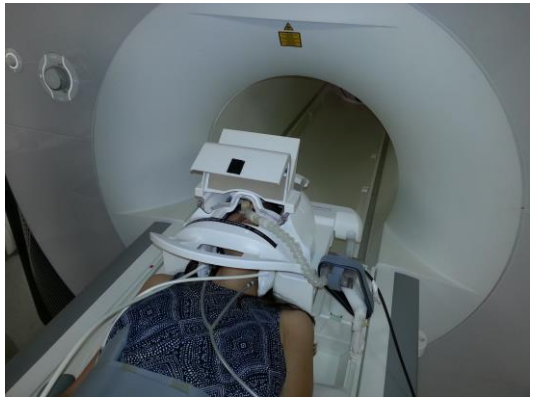
Technologies

- Pneumatic
- Piezo-electric
- Electro-dynamic

Ergonomy

- Earplugs
- Headphones





Specifications

Spectral response

Comfort

Passive attenuation

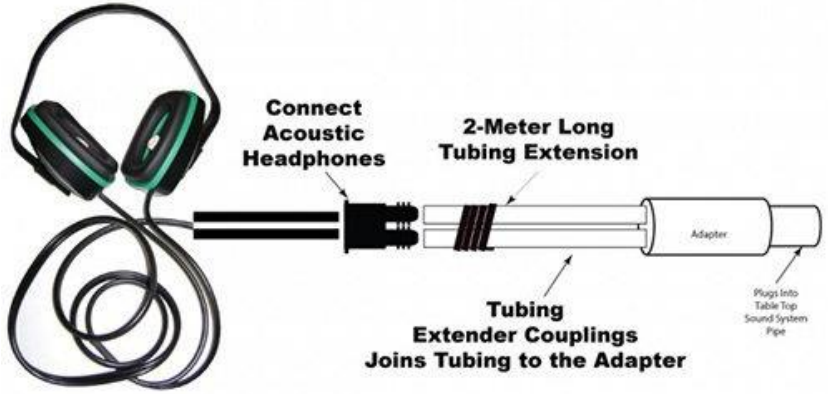
Active attenuation

Build-In manufacturers solutions

Siemens

- Headphones / Earphones
  - Pneumatic technology
  - Mono
  - Easy customization
  - No ANC

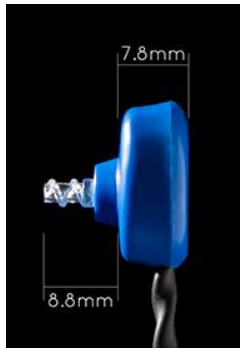
  - Siemens Headphones
  - 3M™ E-A-RLINK™ Foam Eartips
  - MR151 Earphones



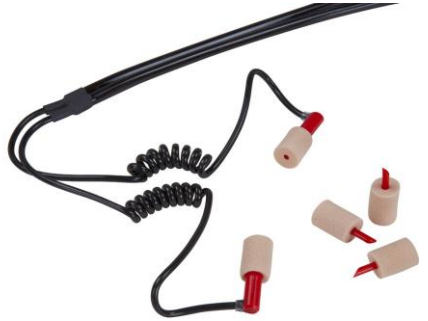
Commercial solutions

Earplugs

- Sensimetrics S14 (3 T) / S15 (3/7 T)
  - Piezoelectric technology
  - Replaceable Comply Canal Tips
  - RF filtering
  - No ANC



- MR PureSound Audio System MK11
  - Pneumatic technology
  - Headphones / earphones
  - No RF filtering needed
  - No ANC



Commercial solutions

Headphones

- MR-Confon
  - Electro-dynamic technology
  - 3T / 7T?
  - RF filtering
  - ANC prototype
  - Slim Piezo headphone

http://www.mr-confon.de/en/products.html



- BOLDfonic
  - Electro-dynamic technology
  - 3T / 7T?
  - RF filtering needed
  - No ANC


https://www.crsltd.com/tools-for-functional-imaging/audio-for-fmri/boldfonic/

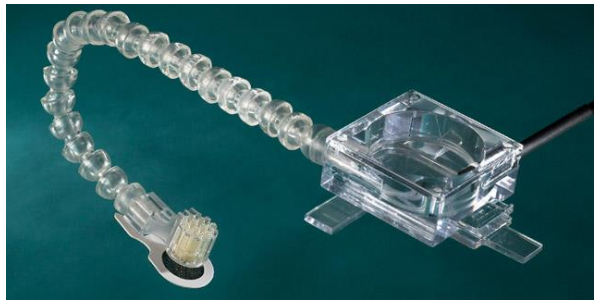
Commercial solutions

Headphones

https://www.optoacoustics.com/medical/optoactive

- OptoActive from OptoAcoustics
  - Optical technology
  - 3T / 7T?
  - No RF filtering
  - ANC

- FOMRI-III ANC microphone
- Optical technology
- No RF filtering needed



Pros & cons

Technologies / performances

	Comfort	Size	LF	MF	HF
Piezo earplugs	-/+	++	--	+	++
Pneumatic earplugs	-/+	++	++	+	-
Electro-dynamic headphones	+/++	-	++	++	++
Pneumatic headphones	+/++	-	++	+	-
Piezo headphones	+/++	+	-	+	++

Some first findings

As usual in MRI, not free lunch … still depending on …

- Magnet field
- Coil system
- Needs
- Budget ☺

Passive vs Active noise cancelling

Passive Noise Cancelling (PNC)

- Earplugs / headphones
- Cancelling between 10 – 30 dB
- Especially efficient on high-frequencies
- Size / Density <----> Cancelling
- Comfort depending on auditive canal size
- Also cancelling / attenuating auditive stimulation

Active Noise Cancelling (ANC)

- Headphones
- Cancelling …..
- Frequency efficiency …..
- Comfort depending on head / coil size
- Good way to communicate with patient / subject
- Auditive stimulation …….

Passive vs Active noise cancelling

Passive Noise Cancelling (PNC)

Attenuation:

Attenuation data for the 3M 1100/1110 Ear Plugs (according to EN24869-1)

F (Hz)	63	125	250	500	1000	2000	4000	8000
Mf (dB)	30.0	33.1	36.3	38.4	38.7	39.7	48.3	44.4
sf (dB)	3.9	5.0	7.4	6.2	5.6	4.3	4.5	4.4
Mf-sf (dB)	26.1	28.1	28.9	32.2	33.1	35.4	43.8	40.0

SNR = 37dB **H** = 37dB **M** = 34dB **L** = 31dB

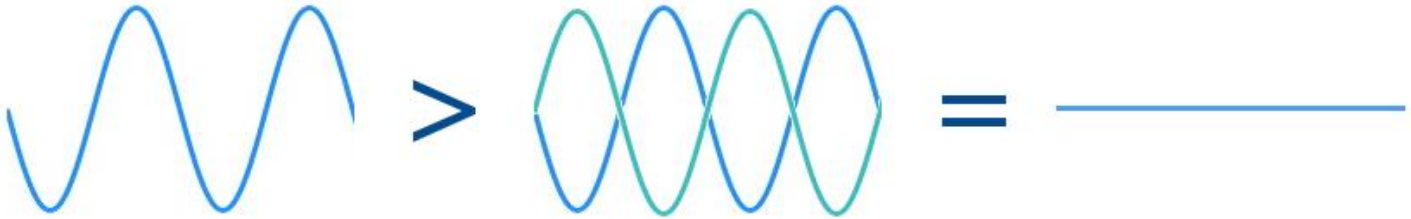
APVf (dB) = Mf -sf(dB)

Active Noise Cancelling … for dummies

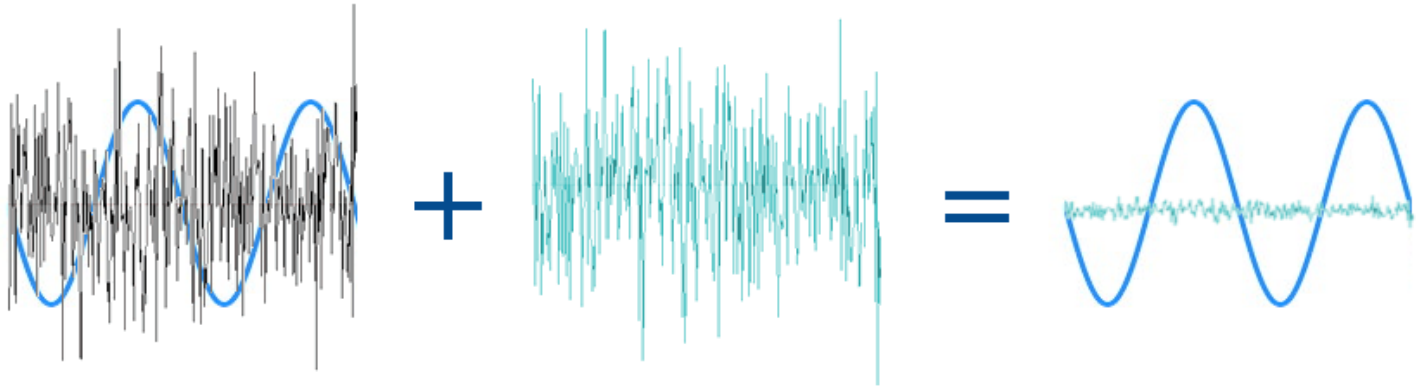
Active Noise Cancelling … for dummies

« Just » based on signal substraction

Waves of equal amplitude and opposite phase cancel out



Recording and inverting noise leaves you with your desired signal



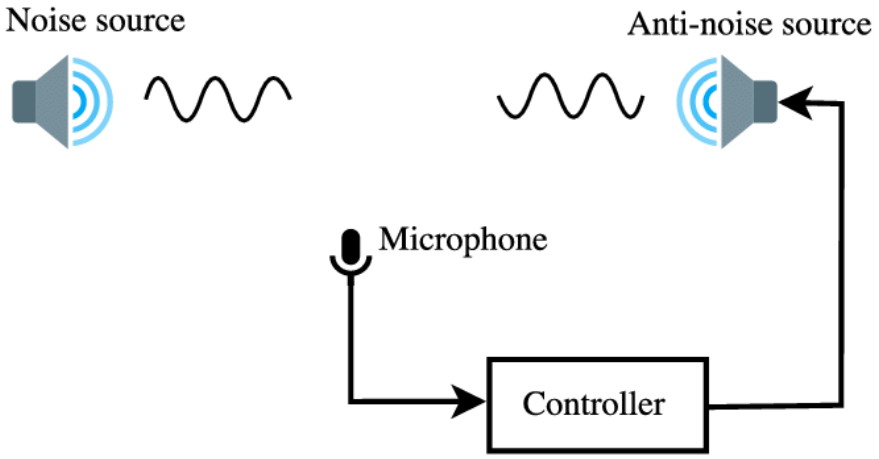
Challenges:

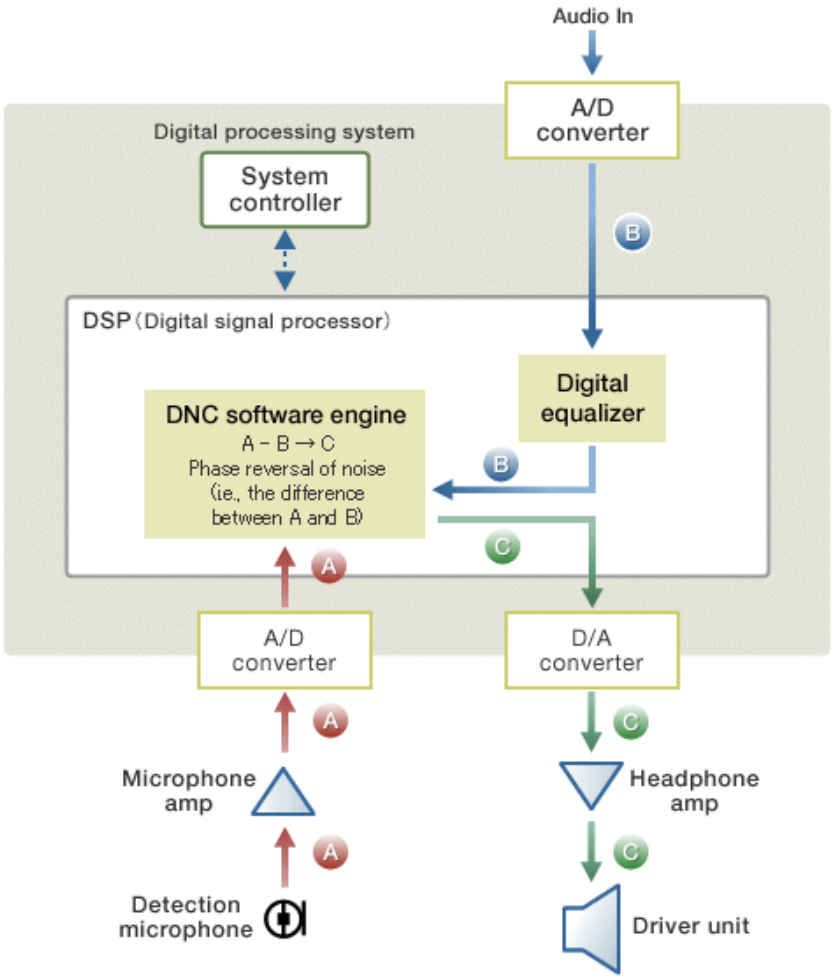
- Record the signal
- Extract the noise
- Compute a « reverse » noise
- Diffuse the reverse noise

Active Noise Cancelling … for dummies

A « 3 stages » instrumentation architecture

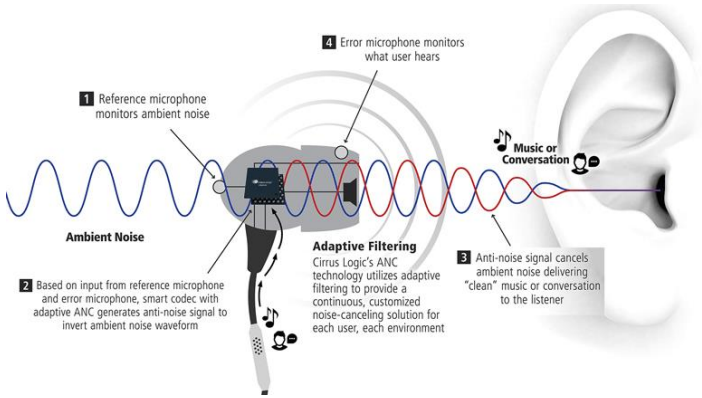
- Microphone
- Controller (DSP)
- Anti-Noise source



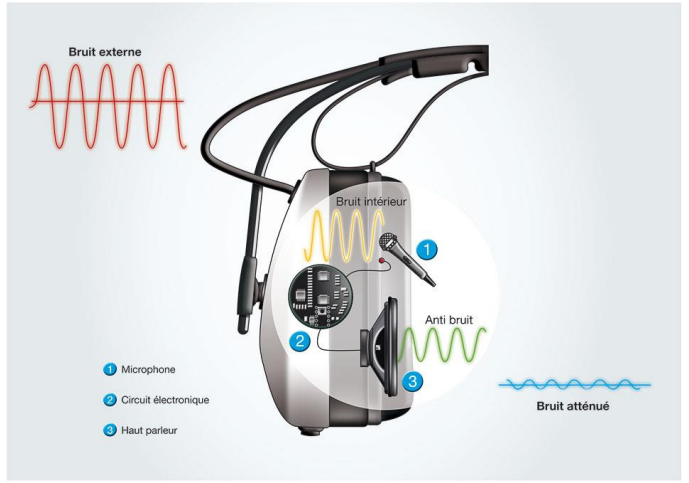


Active Noise Cancelling … Commercial solutions

Nothing to do with MRI



https://www.cirrus.com/products/wm8281/

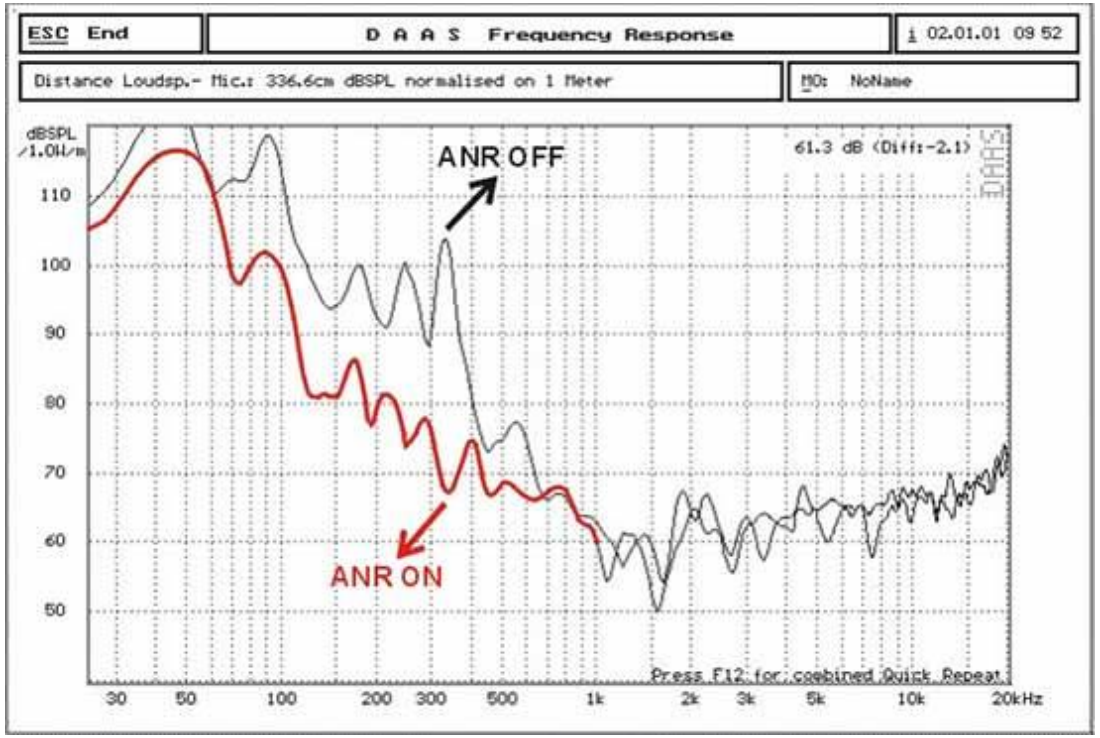


http://www.technofirst.com/fr/noisemaster/

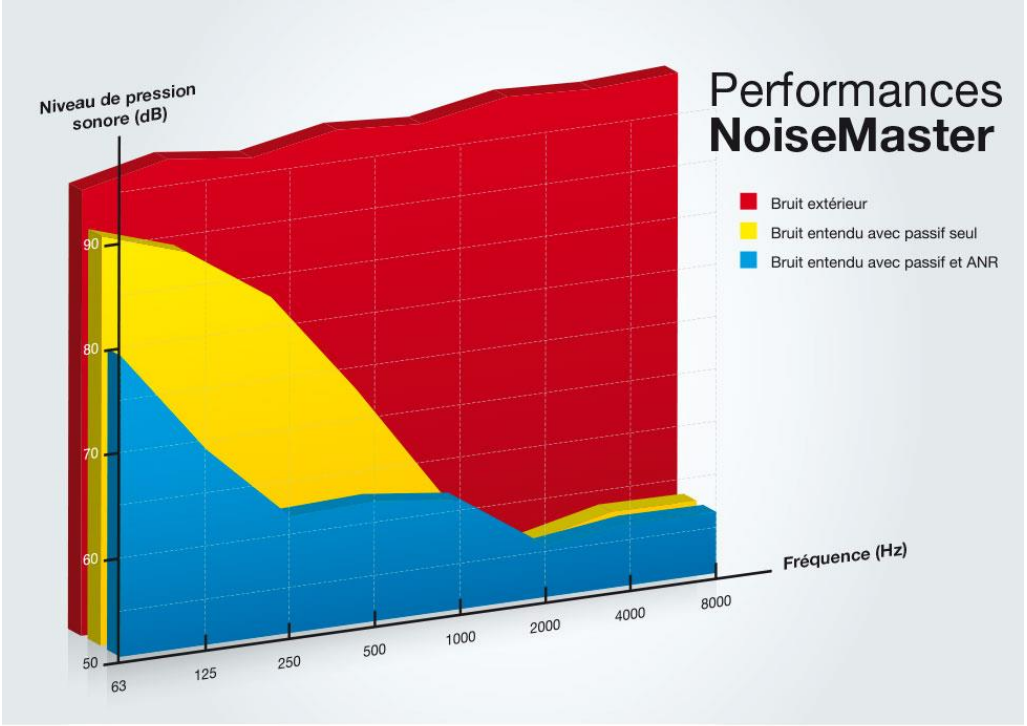
https://www.bose.co.uk/en_gb/products/headphones/earbuds/quietcomfort-earbuds.html

Active Noise Cancelling … actual limits

The main problem: « classical » ANC gives its best in low frequencies



http://www.yueny.com/html_products/active-noise-canceling-headphone-ANC-18-100.html

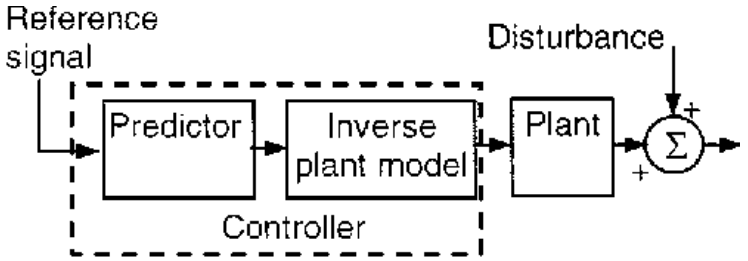


http://www.technofirst.com/fr/noisemaster/

Active Noise Cancelling … actual limitations

The main problem: « classical » ANC gives its best in low frequencies

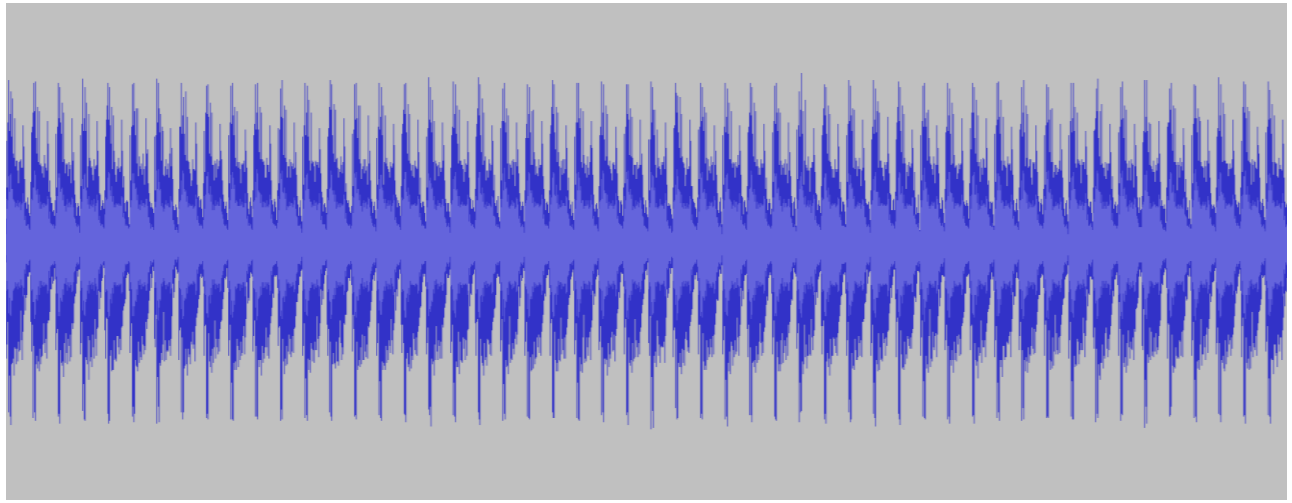
- DSP time processing
- The predictability problem : HF waves are less predictable
- Hard to evaluate and anticipate the next millisecond's signal

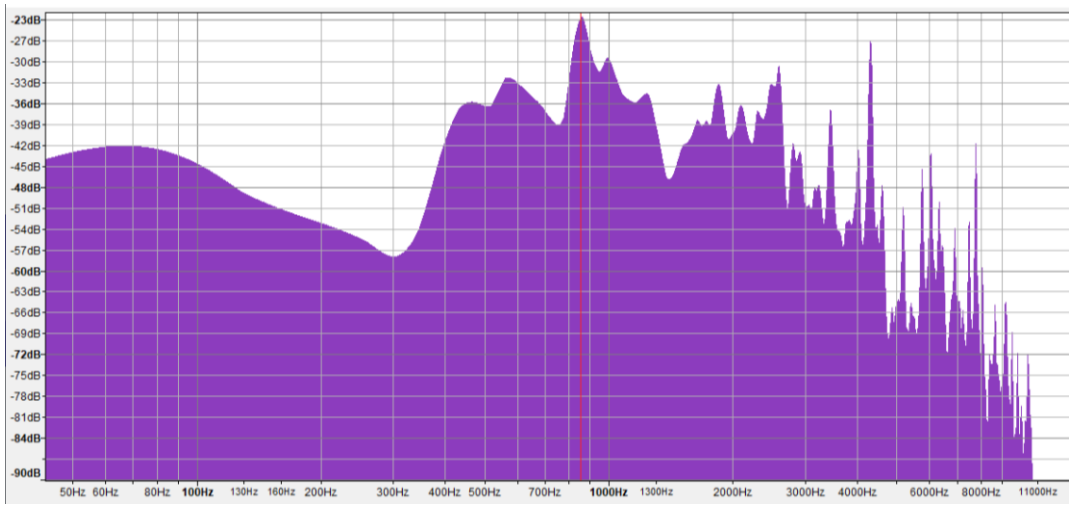


- In MRI, especially BOLD EPI sequences, noise is located around 1000 Hz

BOLD EPI noise

The acoustic wave generated by the gradient coil commutations





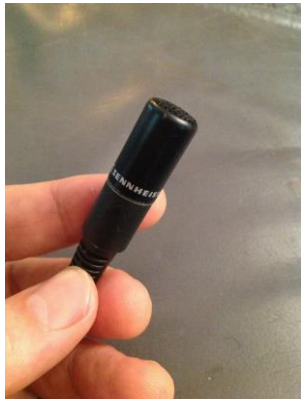
- Hard to evaluate and anticipate the next millisecond's signal

- In MRI, especially BOLD EPI sequences, noise is located around 1000 Hz

A few words about MRI compatibles microphones

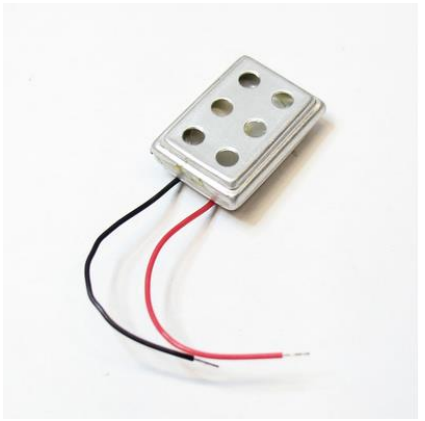
Two different technogies to « catch » a vibration

- Optical microphones



- Piezoelectric microphones

MC-9

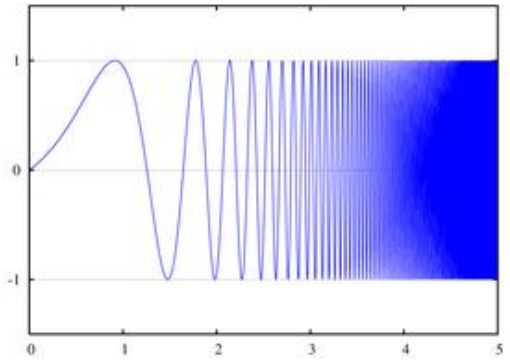


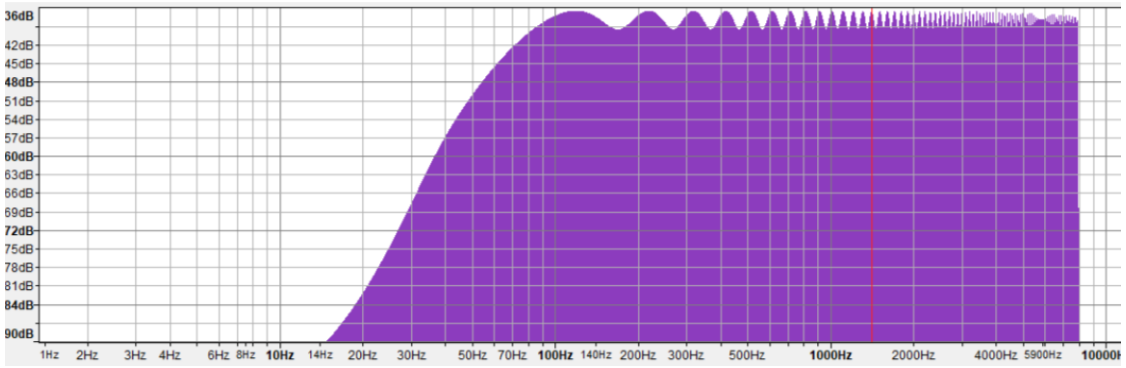
MC-41

System caracterization

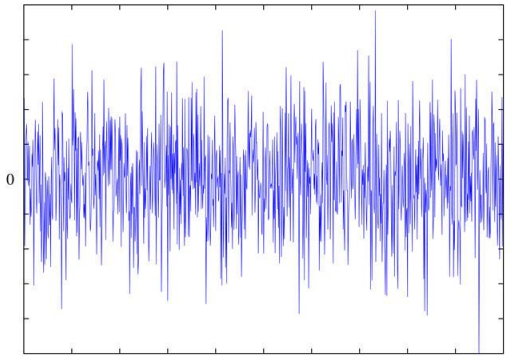
How to evaluate both speaker & microphone spectral responses

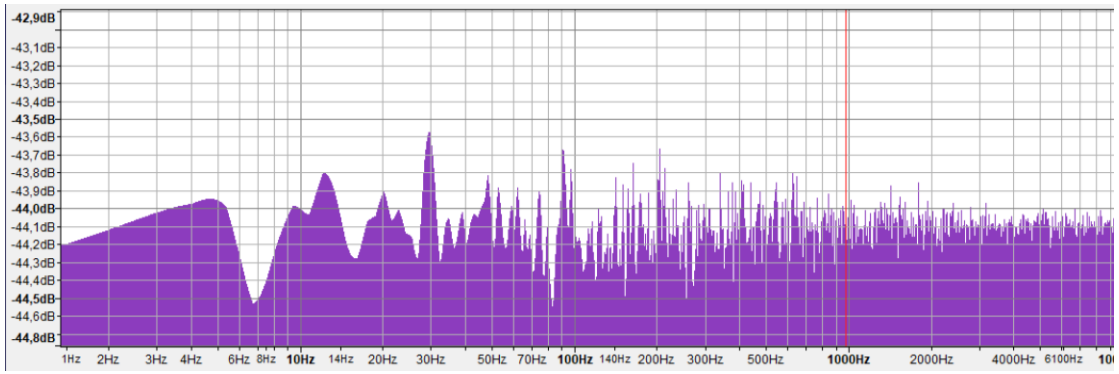
- 20 – 8000 Hz « chirp »





- « white » noise





Active Noise Cancelling in (f)MRI

How to increase HF noise predictability & optimise DSP computing time ?

- Some (f)MRI protocols produce stationnary noise
- Whole ANC system is based on stationnarity
    - Loop sequences
    - **Noise learning stage -> noise model** (buffer)
    - ANC corrected each step

Active Noise Cancelling in fMRI : First trial in Marseille

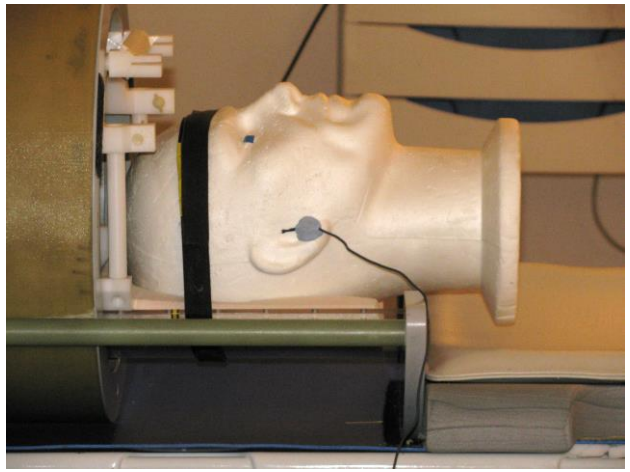
A technical partnership MRI / LMA on the previous Bruker 3T …

- Summary

Active Noise Cancelling in fMRI: First trial in Marseille

A technical partnership MRI / LMA on the previous Bruker 3T …

- The whole instrumental channel (based on the MR-Confon electro-dynamic system)

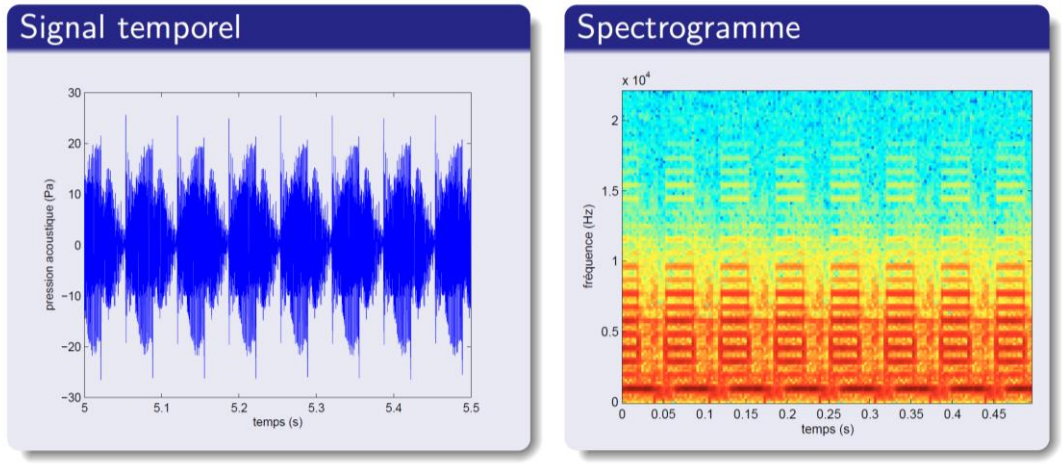


- Noise modelling driven by X/Y/Z gradient commands
- Multi-reference active noise cancelling

Active Noise Cancelling in fMRI: First trial in Marseille

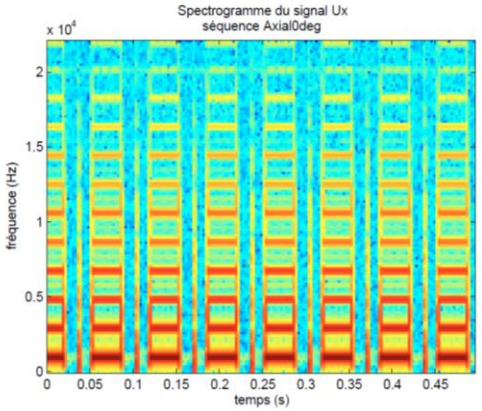
Some results

- Spectral analysis

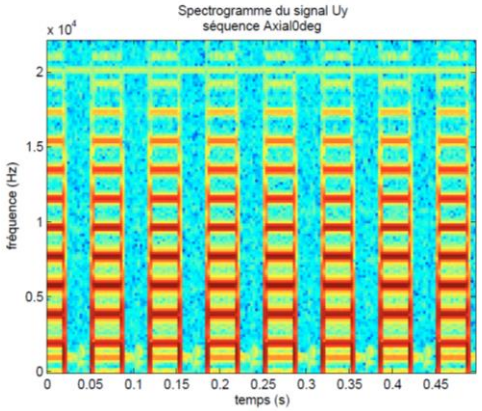


EPI Axial sequence

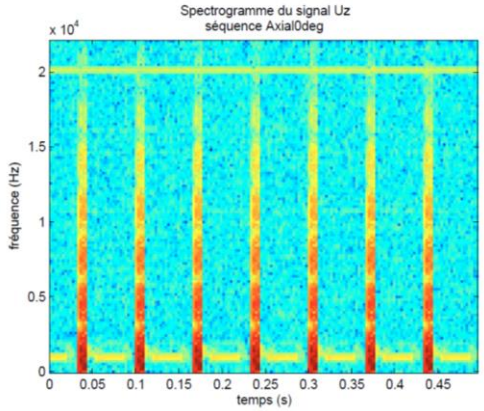
Acoustic wave & spectrogram



X-gradient Voltage command



Y-gradient Voltage command



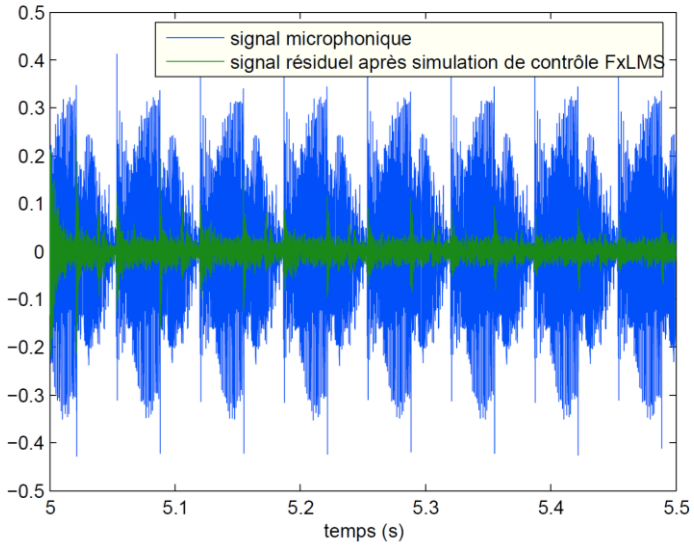
Z-gradient Voltage command

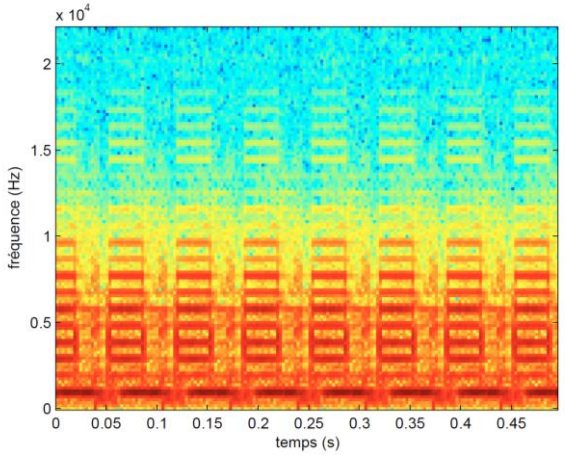
Friot & al. - Contrôle actif multi-références du bruit d'IRM. CFA 2010, Lyon

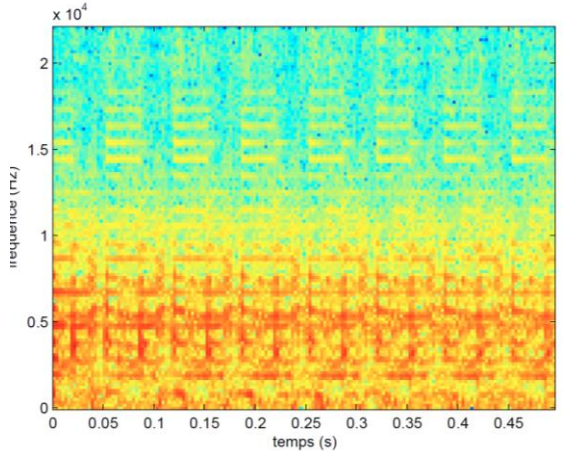
Active Noise Cancelling in fMRI: First trial in Marseille

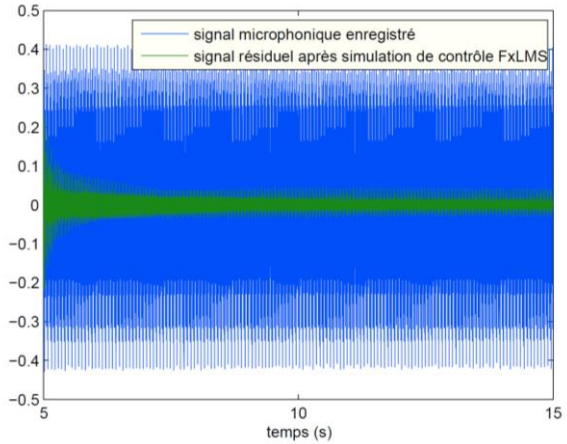
Some results

- Denoising









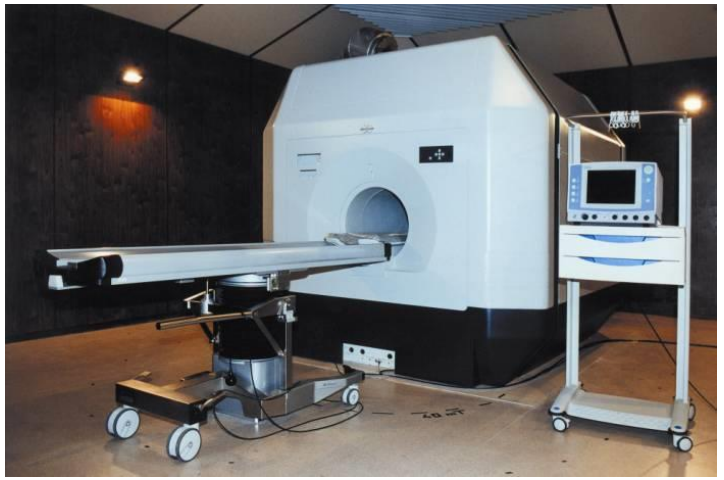
~ 14 dB denoising around 1kHz

Friot & al. - Contrôle actif multi-références du bruit d'IRM. CFA 2010, Lyon

Active Noise Cancelling in fMRI: First trial in Marseille

Partial conclusion

- Technical success
- Based on a low-cost commercial headphone set
- Efficient tool for a better understanding of the ANC challenge



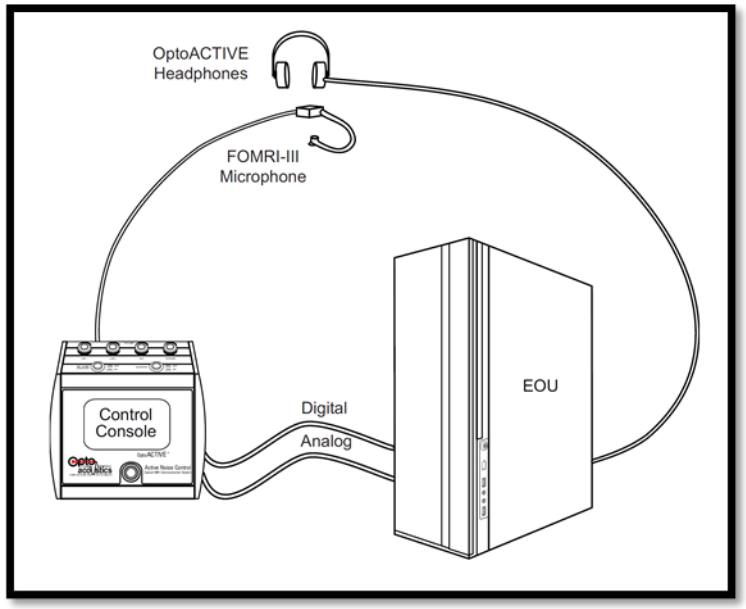
- Heavy & complex instrumentation
- Specific need of reference signals (Gradients commands)

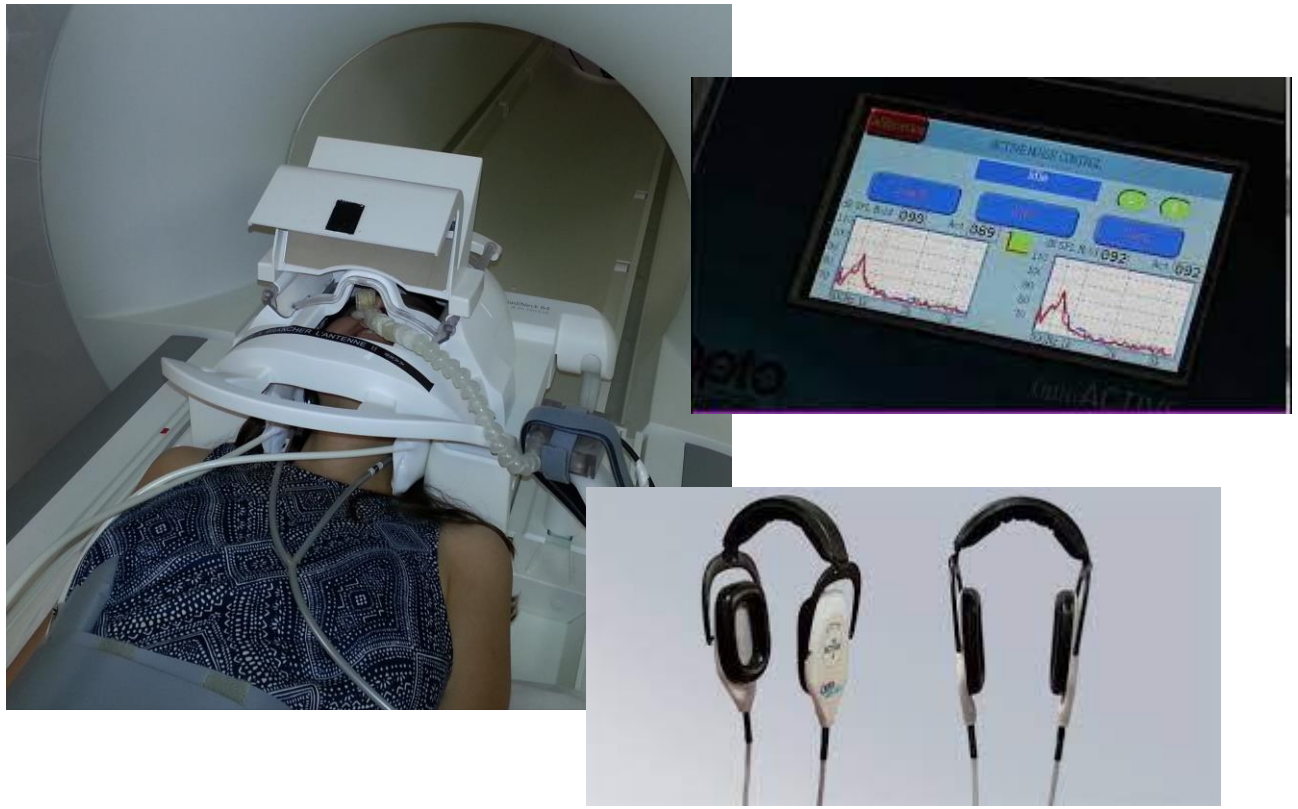
- End of use of the Bruker Avance 3T … RIP

Friot & al. - Contrôle actif multi-références du bruit d'IRM. CFA 2010, Lyon

OptoActive ANC / Headphones system

The one used at the MRI Centrer – INT @ CERIMED



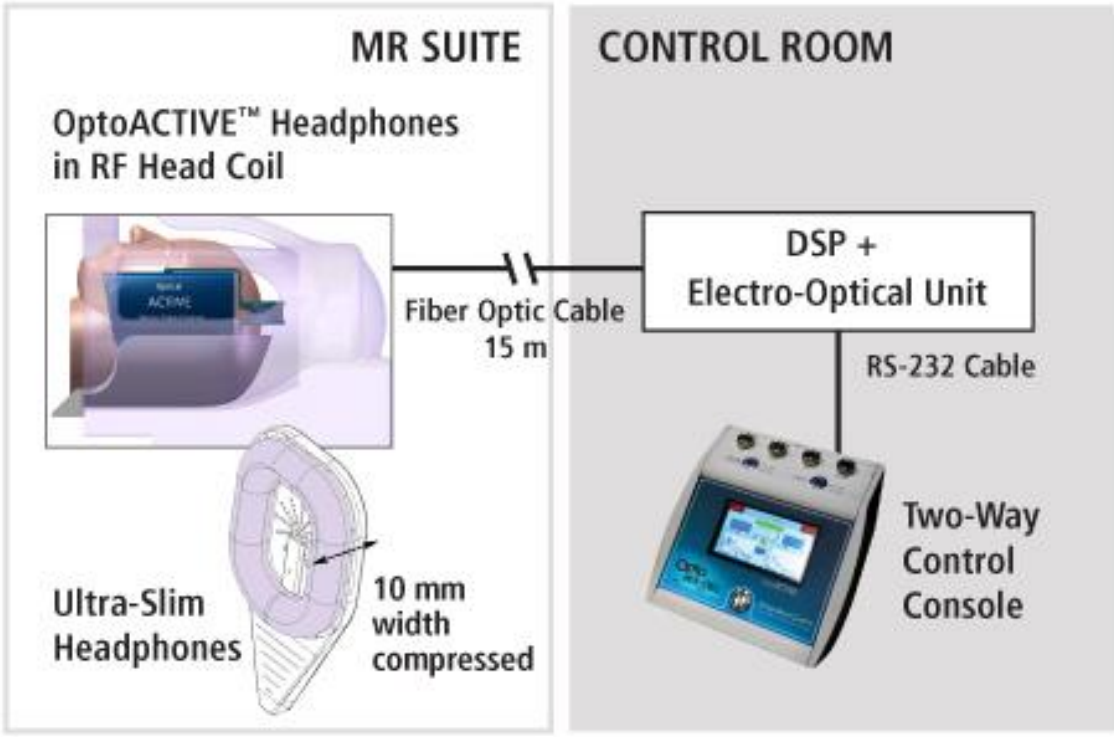


OptoActive ANC / Headphones system

Overview

- Optical powered headphones
- Optical digitilized audio signal
- Optical / analog inputs
- DSP / CPU
- Ergonomic Control Console

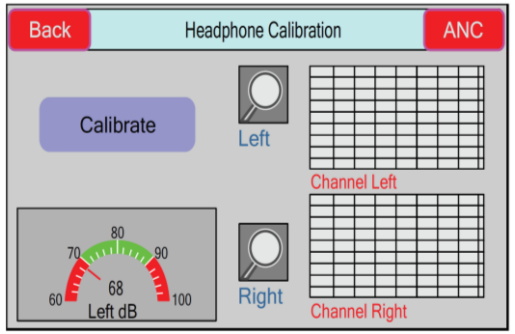
- Optical Microphon FOMRI-III (independant)

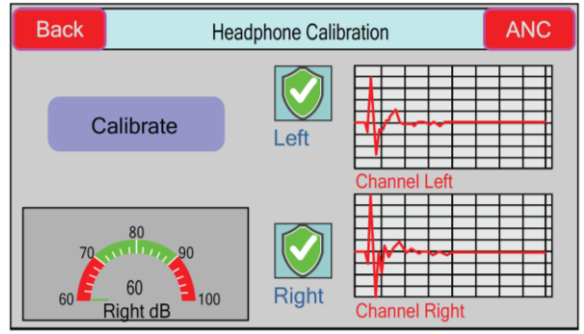


OptoActive ANC / Headphones system

Calibration stage

- White noise binaural analysis
- Spectral response
- Depends on
  - Headphones positionning
  - Patient « local » anatomy
  - Passive earplugs
  - …





OptoActive ANC / Headphones system

Main principles

- Noise learning stage
- Based on MRI triggers to improve predictability
- Re-triggered buffered input / output

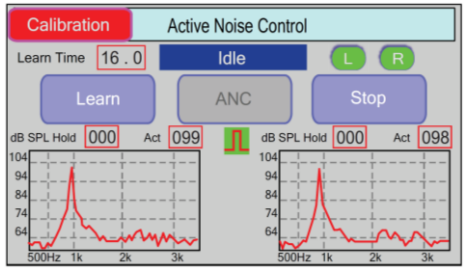
- Used for BOLD EPI sequences
- Only passive attenuation with 3DT1/2 / DTI / Spectro …

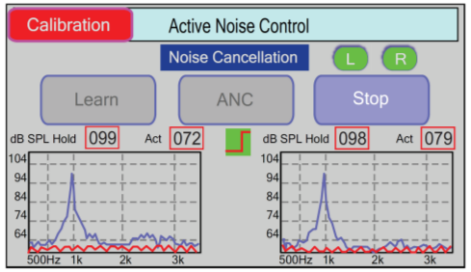
- System clearly dedicated to auditory stimulation in BOLD acquisitions

OptoActive ANC / Headphones system

Learning stage

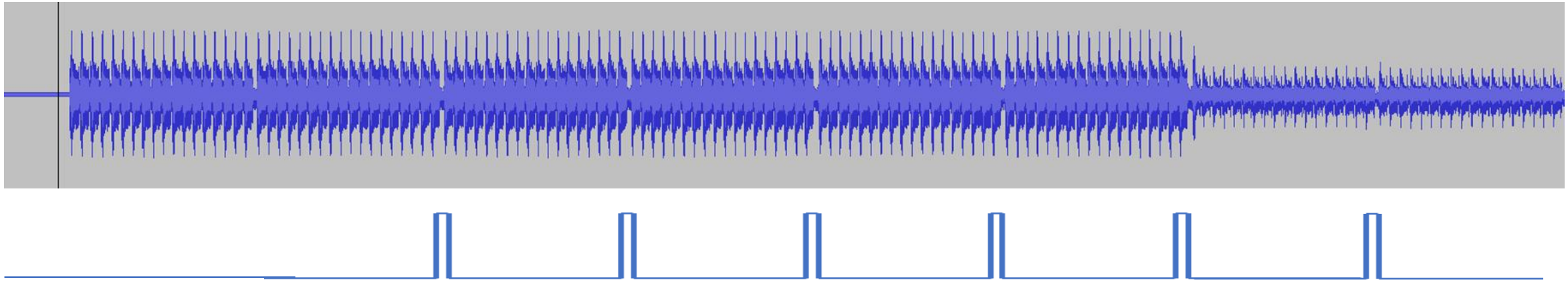
- White noise binaural analysis
- Spectral response
- Depends on
  - Headphones positionning
  - Patient « local » anatomy
  - Passive earplugs
  - …

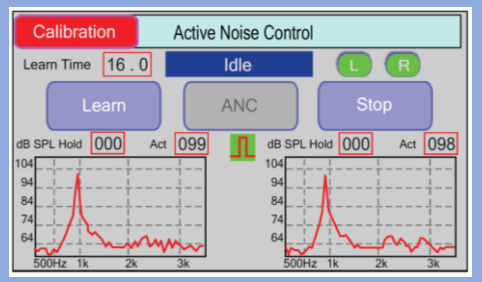




OptoActive ANC / Headphones system

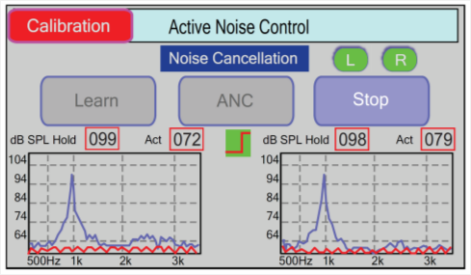
Learning stage & ANC on an EPI BOLD sequence





Dummy scans

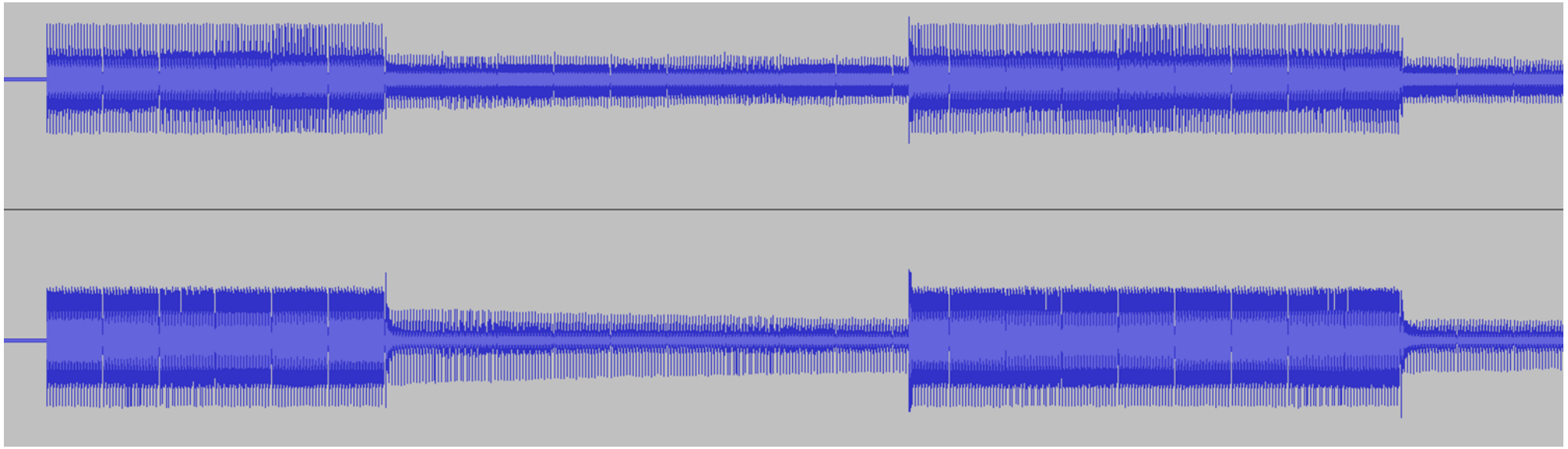
Learning stage – 16 seconds



A N C

OptoActive ANC / Headphones system

Learning stage & ANC on an EPI BOLD sequence



OptoActive ANC / Headphones system

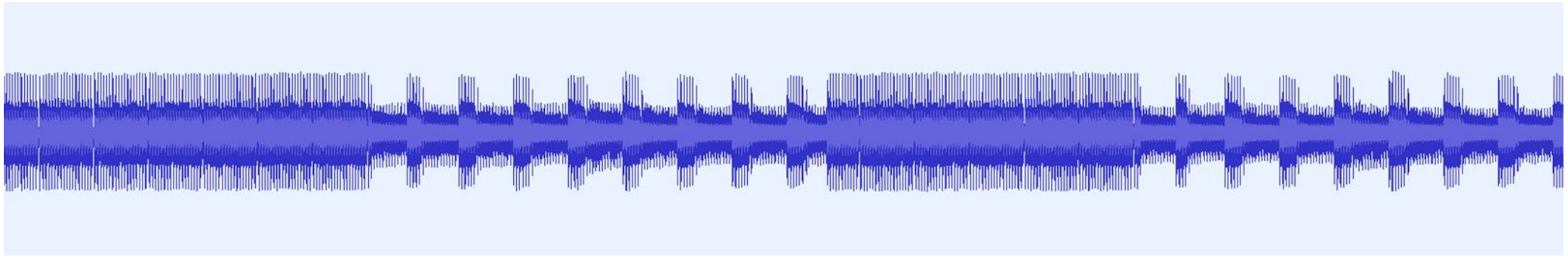
Something about the MR triggers

- Default Siemens EPI sequences provides trigger/volume (RT)
- Minneapolis C2P EPI sequence provides trigger/slice or trigger/volume
- Does not have any effect on learning stage duration (16 seconds)

- LET’S TRY

OptoActive ANC / Headphones system

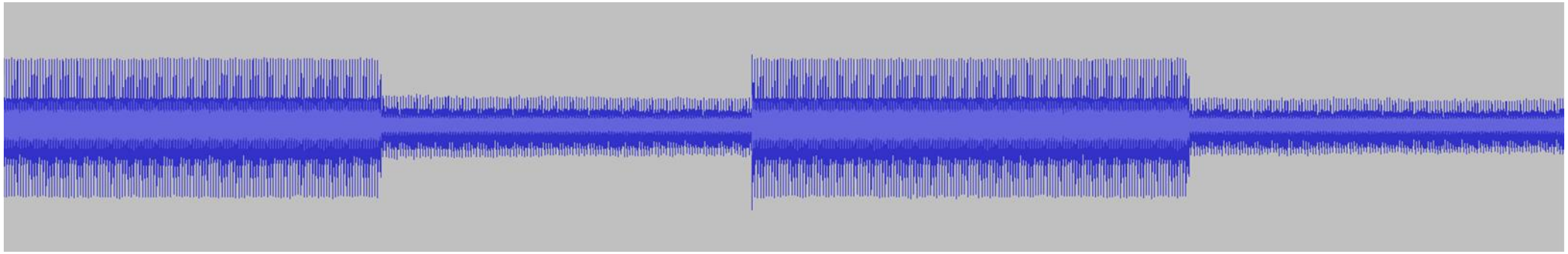
SLICES TRIGGERING



RF adjustment (around 20 ms) each end of RT.

OptoActive ANC / Headphones system

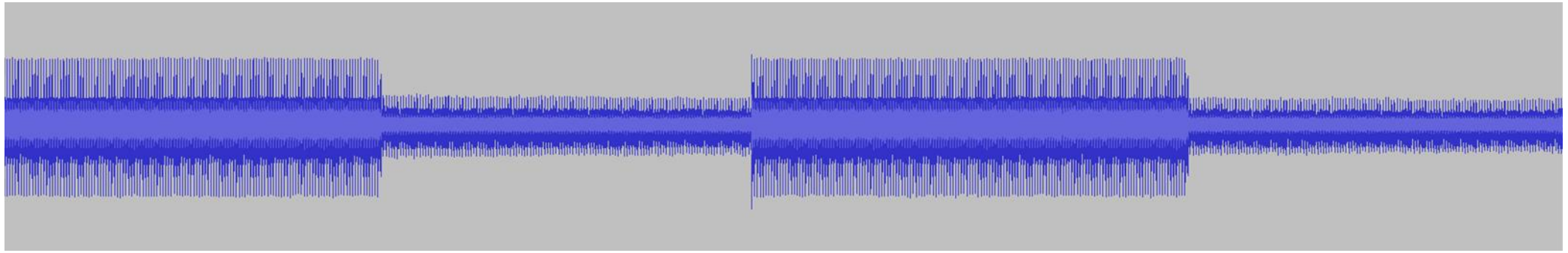
SLICES TRIGGERING

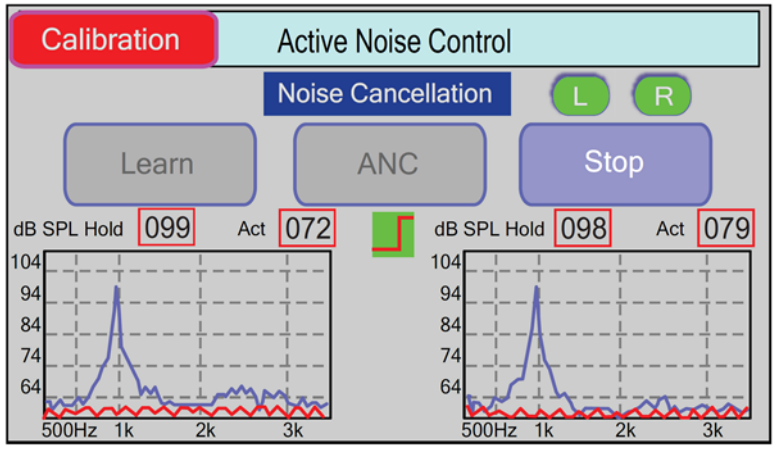


RF adjustment disabled

OptoActive ANC / Headphones system

Noise Cancelling Performance





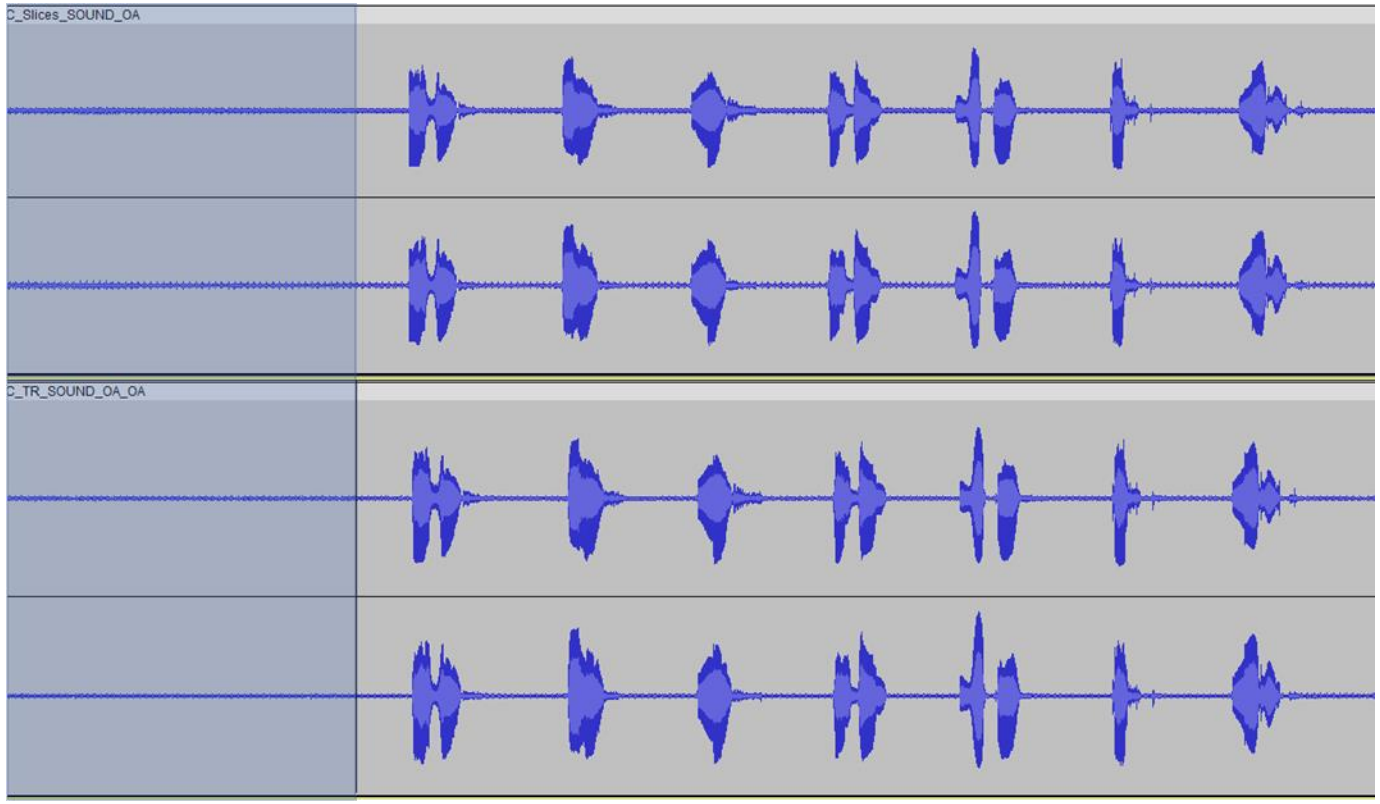
- EPI Noise : ~ 115-120 dB
- Passive attenuation : ~ 90-95 dB
- Active attenuation : ~ 75-80 dB

- **Passive earplug protection : ~ 32 dB**

OptoActive ANC / Headphones system

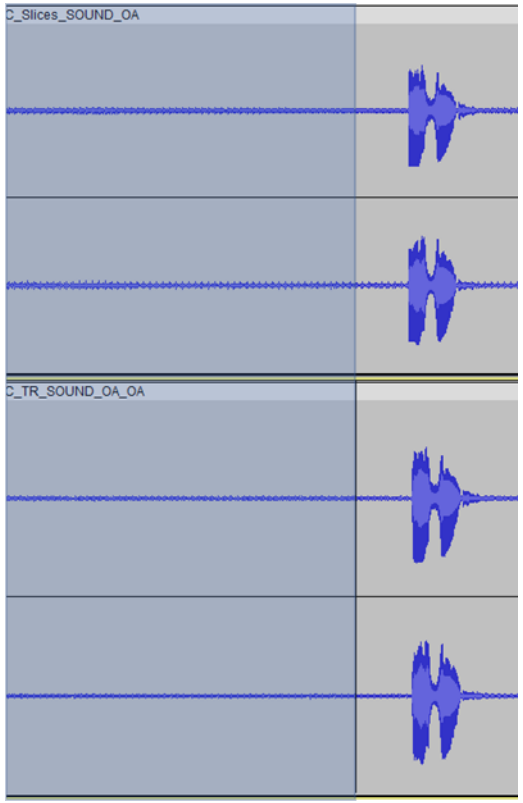
RT Team vs Slices Team

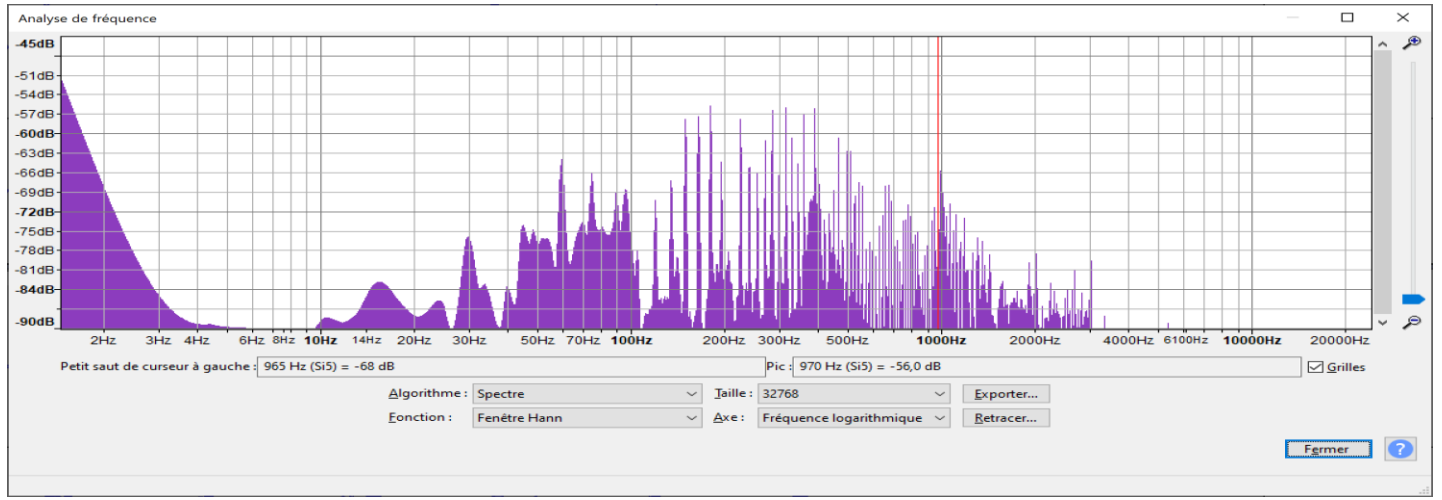
- Let’s see on auditory stimulation
- Try a spectral analysis on residual noise

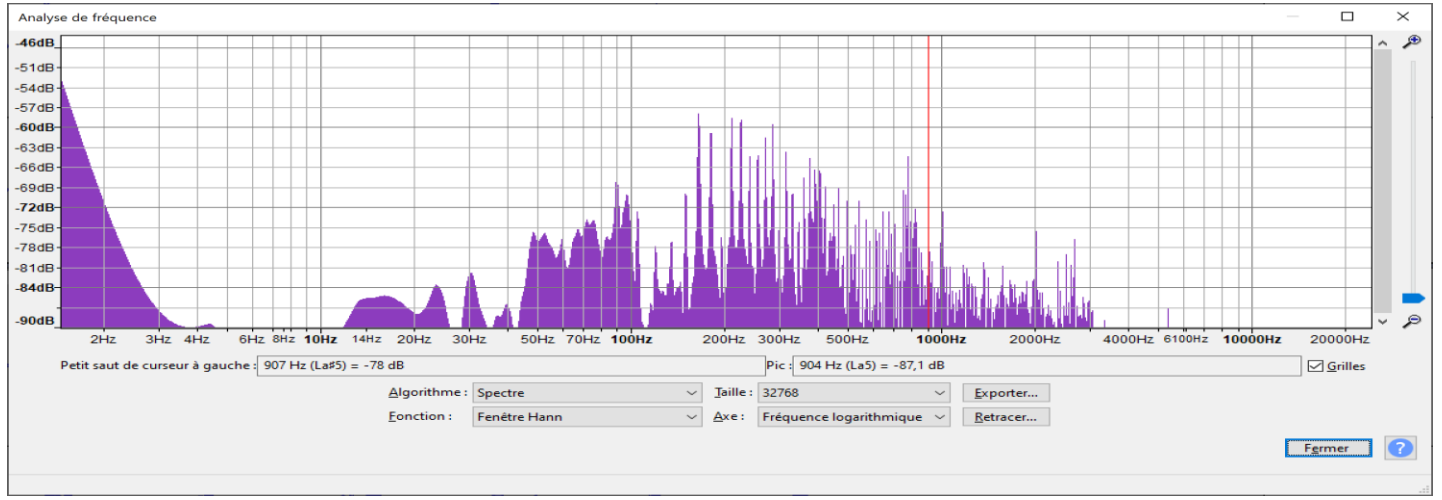


OptoActive ANC / Headphones system

RT Team vs Slices Team

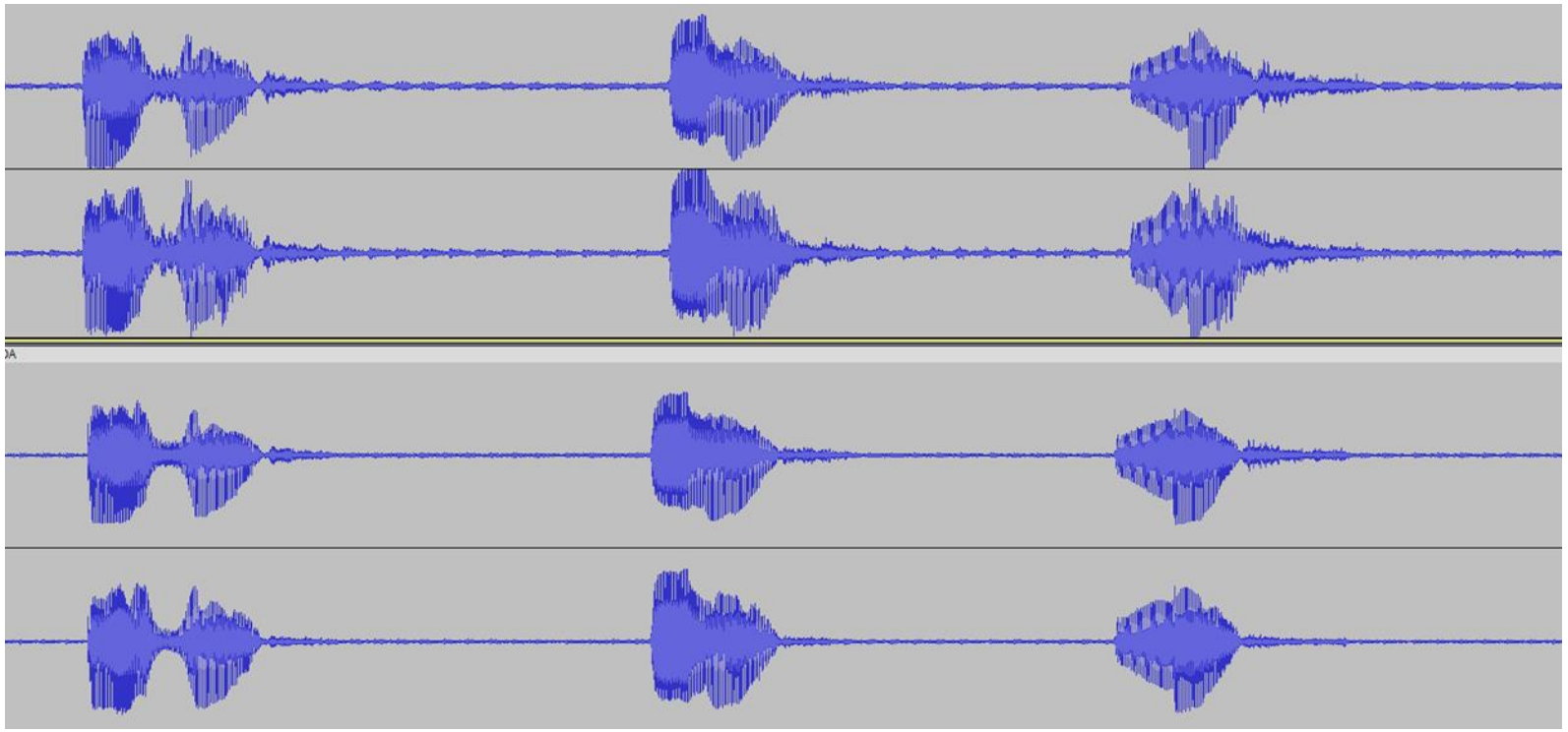






OptoActive ANC / Headphones system

Some strange « reverb » effects



OptoActive ANC / Headphones system

Trying to conclude

- Efficient ANC (~15 dB on EPI main frequencies)
- Easy to set up and use
- What about the passive protection?

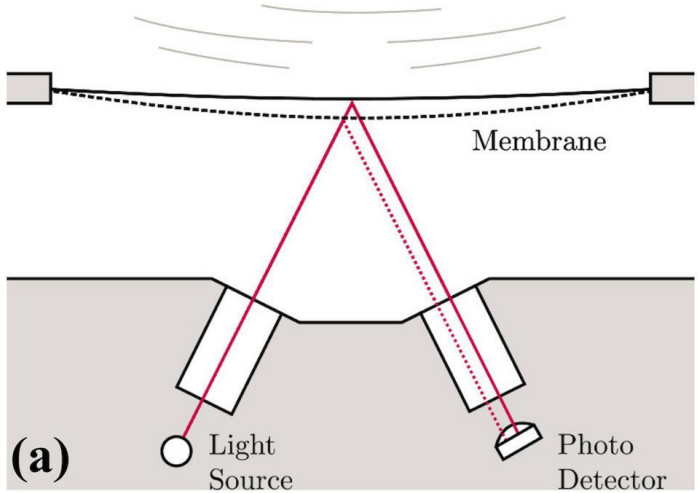
- Good tool for auditory experiments without additional passive protections
- Also a very powerful tool for the « self hearing » feature

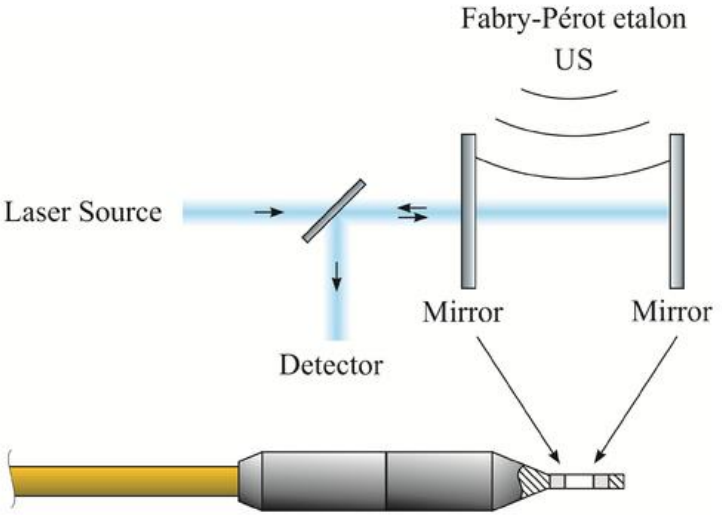
Thank you for … listening

Any questions?

Optical microphons …

… or how to measure a vibration using light





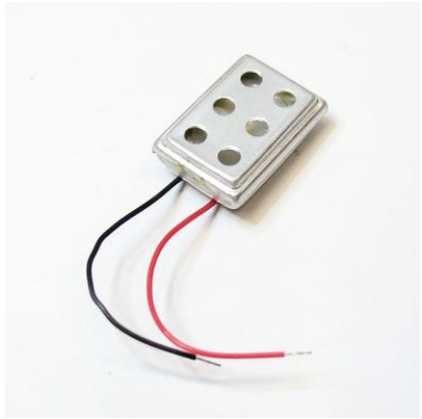
Light source ray (constant)
Incidence ray (variable)

The membrane distorsion
modulates the reflexion angle

Piezoelectric microphones …

… or how to measure a vibration using ceramics

MC-9



MC-41

10 mV/Pa