

Bionic Ears



Introduction into State-of-the-Art
Hearing Aid Technology

28c3
Berlin, Dec 28th 2011
Helga Velroyen
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<http://www.hackandhear.com>

Abstract



In many social situations being hearing impaired is a serious handicap, not only for elderly people. Today's hearing aids are tiny computers that do a decent job in signal processing. During the last years, the progress in this technology was significant, amongst other things by switching from analog to digital devices. Since this field becomes more and more related to computer technology, there is even more improvement to be expected. In particular, it turns into a more and more interesting playground for hackers.

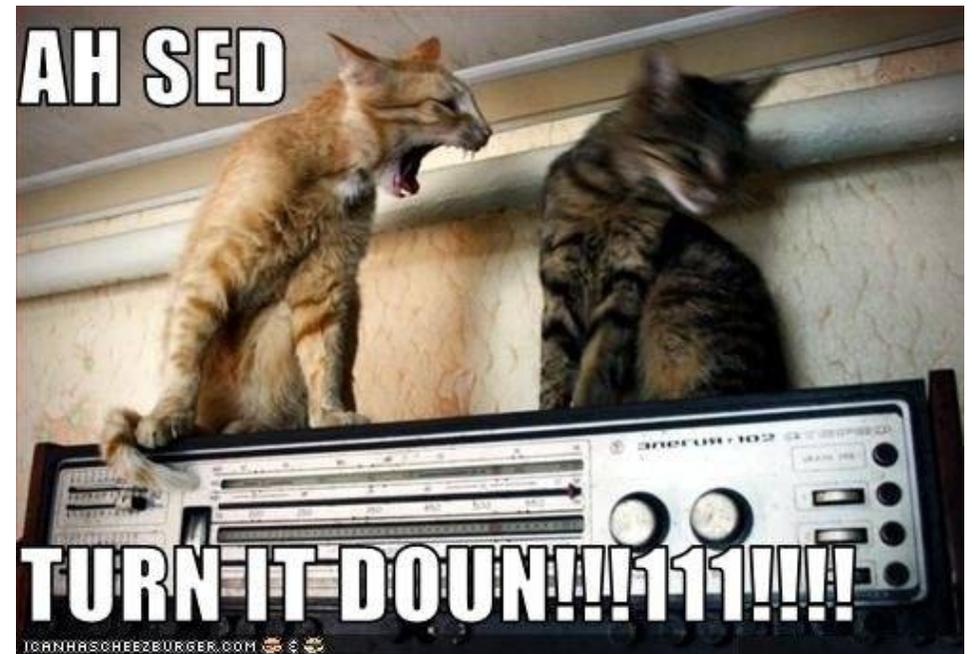
Unfortunately, we are still quite far away from what was promised as the future in that 70es TV series "The Bionic Woman" [1]. Starting with a brief introduction about audiology, I will present current technical solutions (and political non-solutions) for hearing aids. Besides the hearing aids themselves, there exist a couple of interesting peripheral solutions for specific situations such as using the phone, listening to concerts and talks, or just consuming music with an mp3 player. All these not only enhance the user's life, they also open the door for creative hacks. Although the hearing-aid hacking community is still rather small, I will present some current projects and ideas for future ones.

[1] http://en.wikipedia.org/wiki/The_Bionic_Woman

Documentation of this Talk



- slides soon available on <http://hackandhear.com>
- detailed speaker notes
- recording (hopefully) available
- (maybe) subtitles

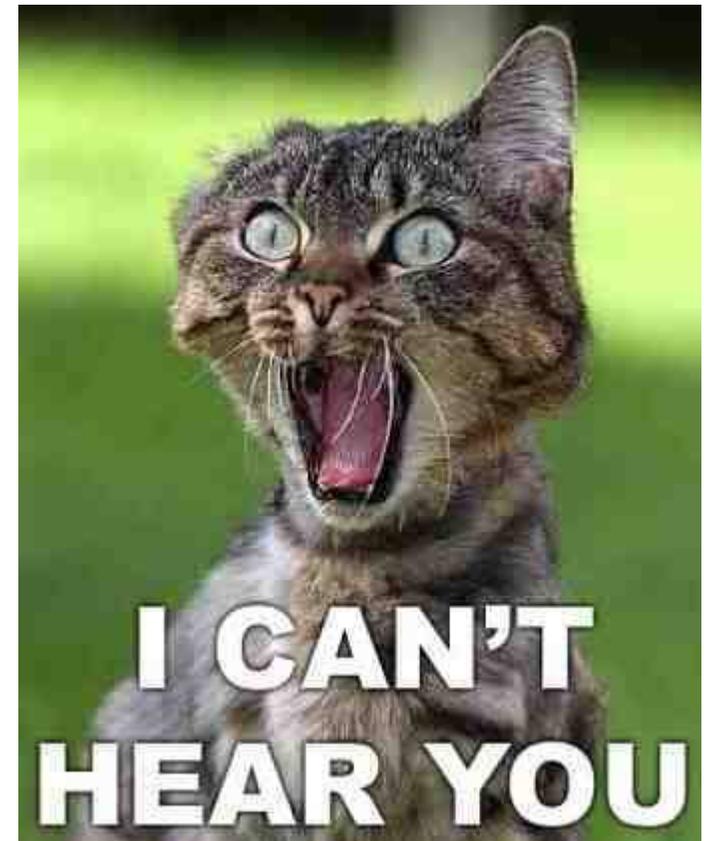


Me

- software engineer
- based in Munich
- software geek, not a hardware hacker
- signal processing / datamining background
- medical engineering background
- don't work for hearing aid company
- hearing-impaired for 3.5 years

Disclaimer:

This is a personal pet project.
I am here on my own terms and not
on behalf of my employer.



What's this about?

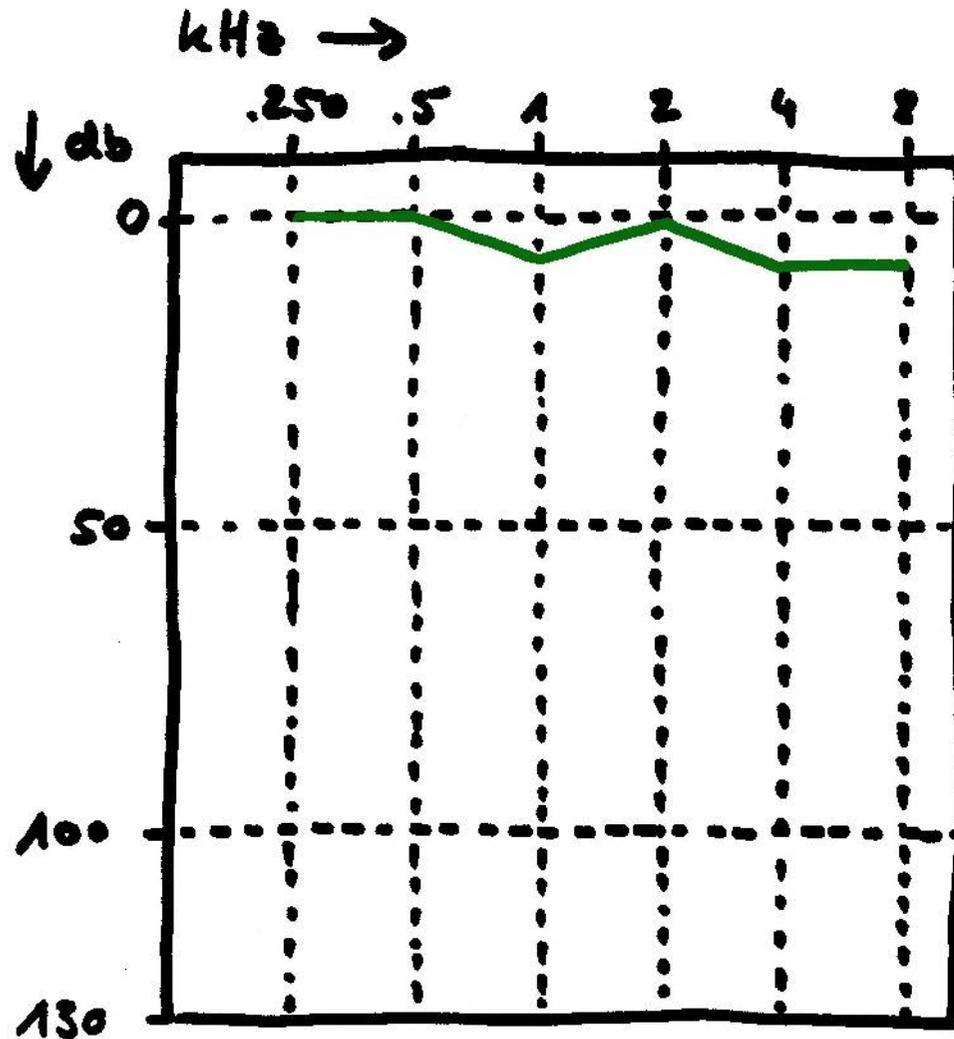
- Audiology
- Getting hearing aids
- Hearing aid models and features
- Peripheral hardware
- Hacking
- Self-tuning
- Conclusions





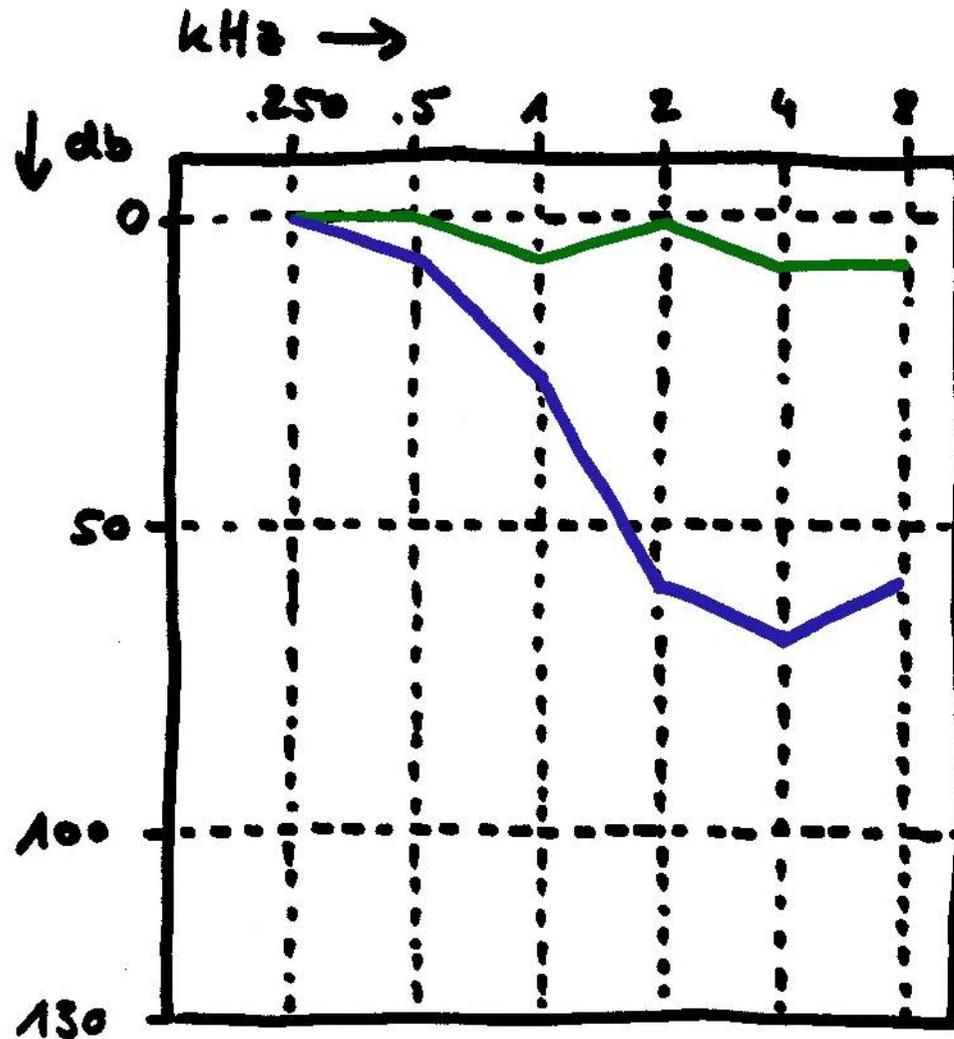
Audiology

Audiogram



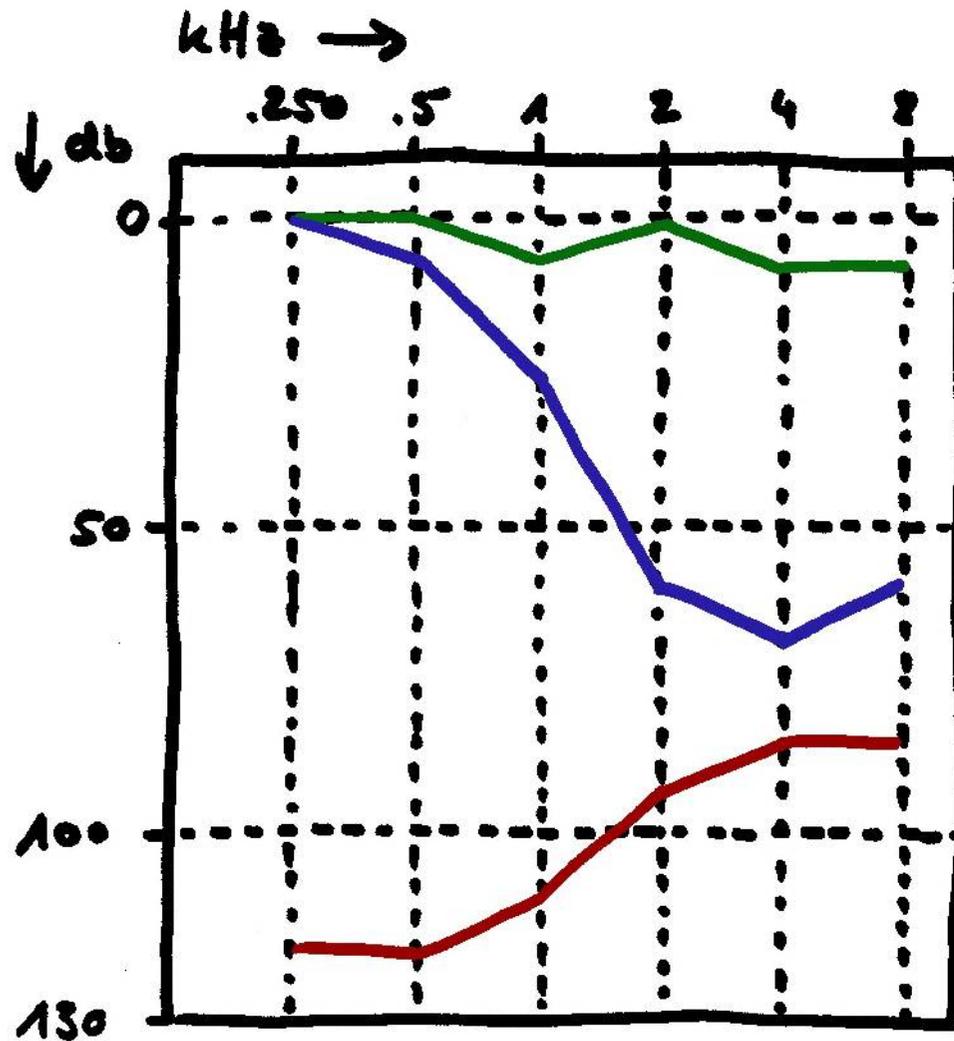
- x-axis: frequency in kHz
- y-axis: volume of signal in db
- healthy person

Audiogram



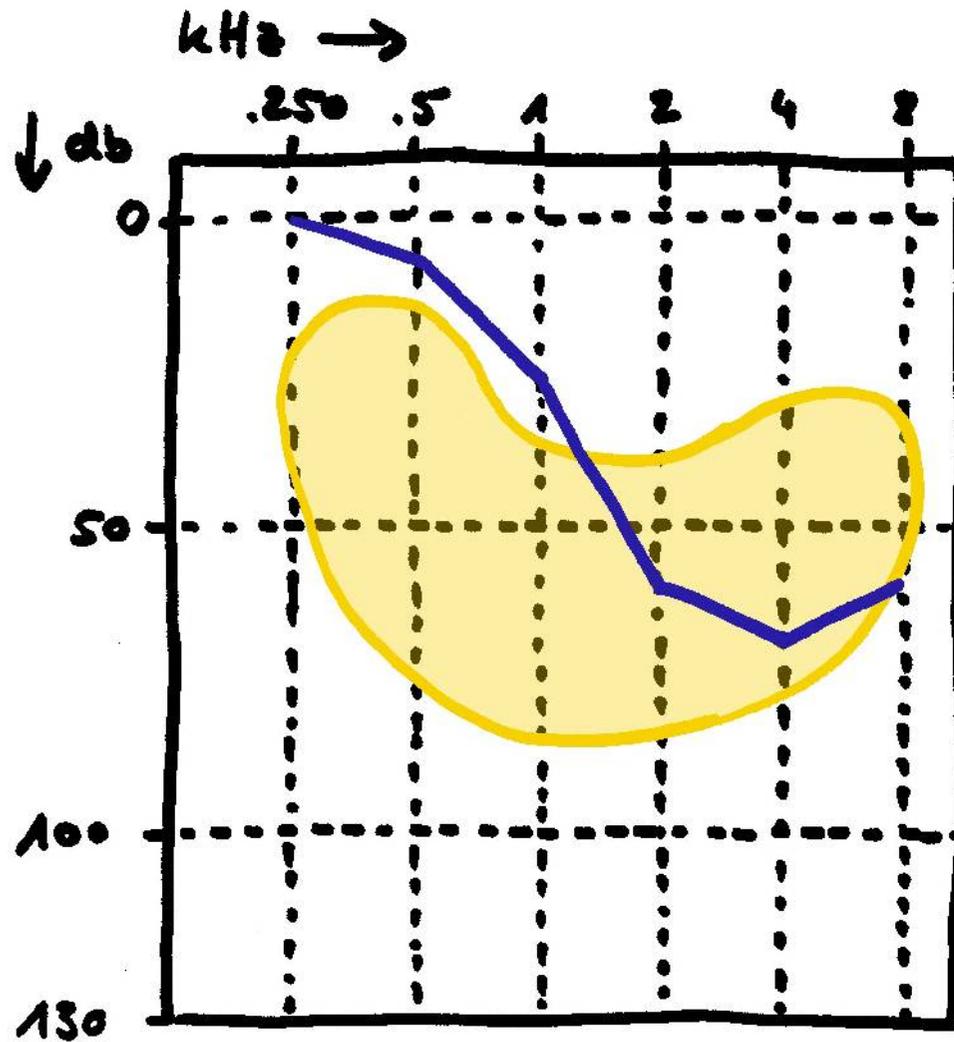
- green: healthy person
- blue: typical hearing impaired

Audiogram



- green: healthy person
- blue: typical hearing impaired
- red: level of discomfort for hearing impaired

Audiogram



- blue: typical hearing impaired
- yellow: area where speech happens
- hearing aids focus on compensating loss in speech banana

Source: http://en.wikipedia.org/wiki/Speech_banana

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Bionic Ears

10 of 64

How I Hear (Example)



- Song “Sad Robot” by Pornophonique

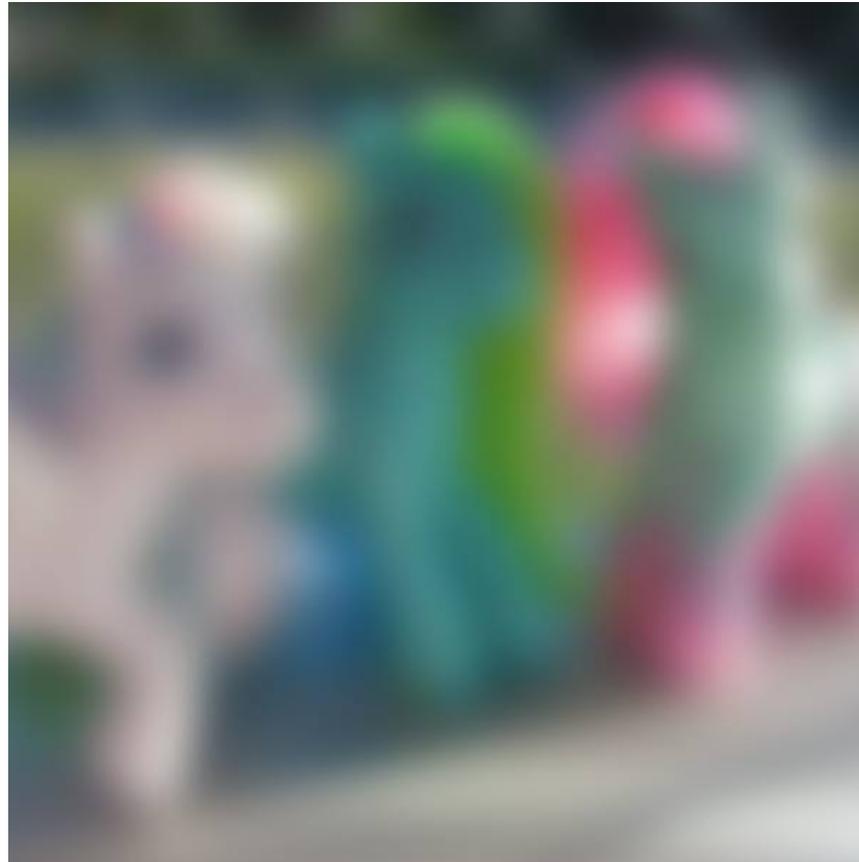
Source of “Sad Robot”: <http://www.pornophonique.de>

Source of tinnitus sounds: <http://www.ata.org/sounds-of-tinnitus>



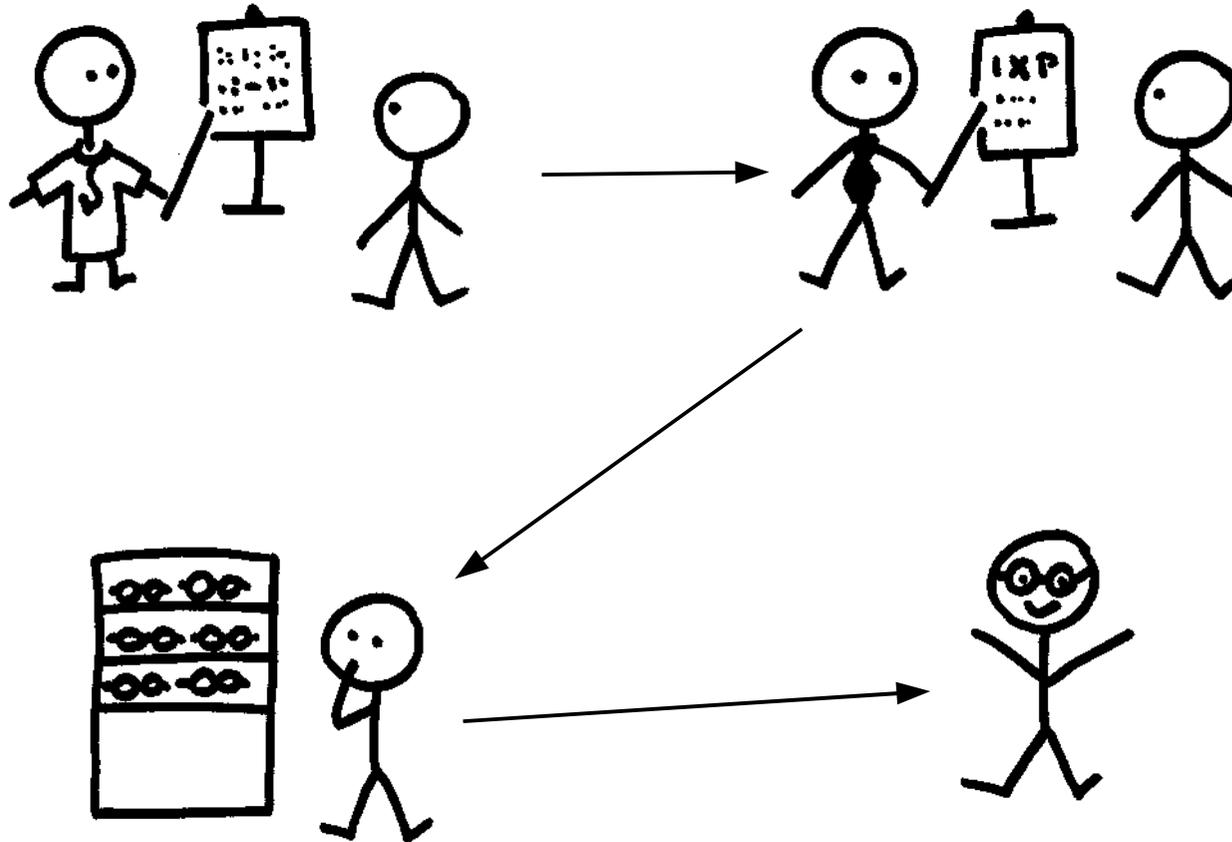
Getting Hearing Aids

Need Glasses?



Source of image: <http://www.flickr.com/photos/dreamcicle/3630841638/sizes/l/in/photostream/>

Getting Glasses



Ponies!



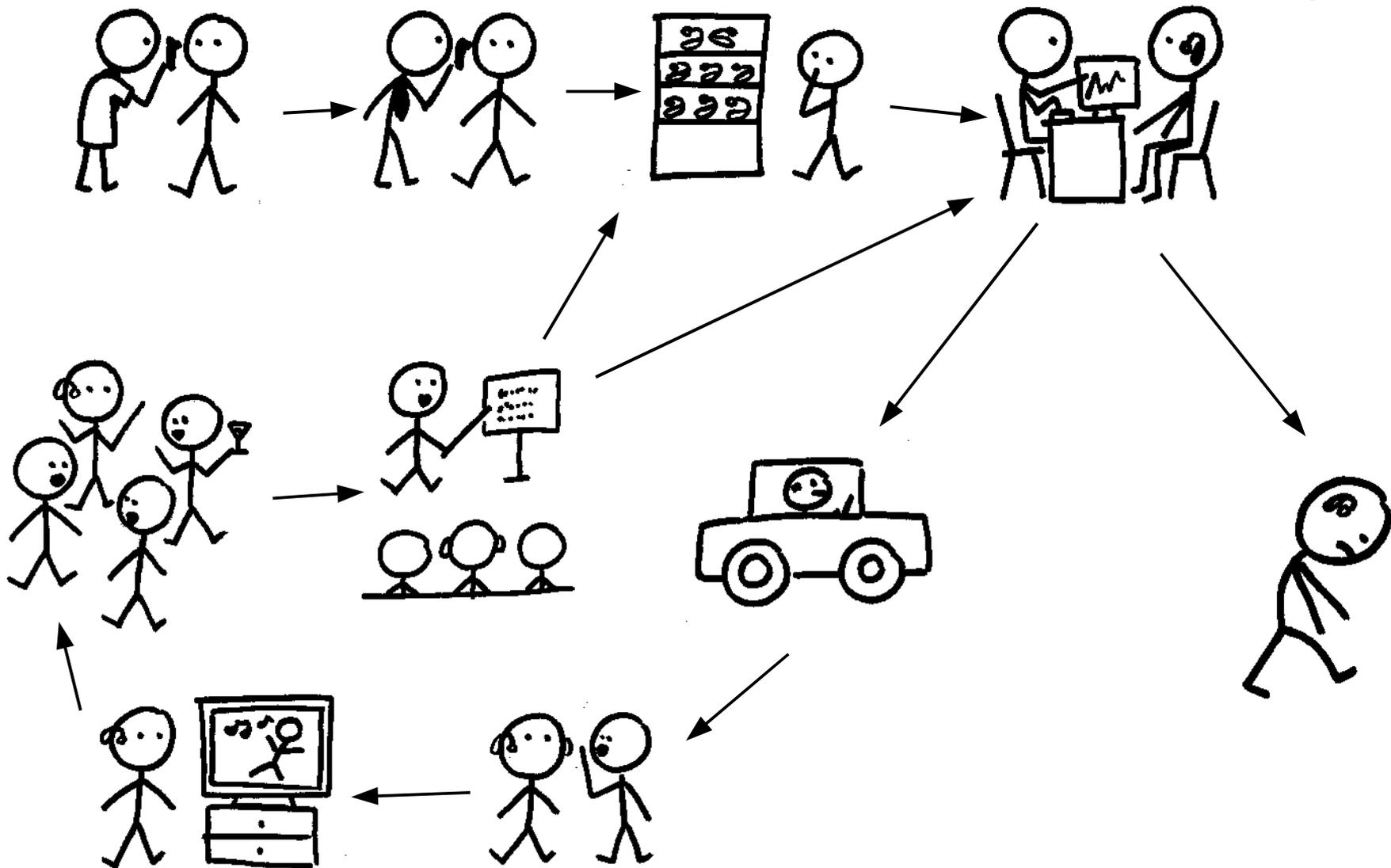
Source of image: <http://www.flickr.com/photos/dreamcicle/3630841638/sizes/l/in/photostream/>

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Bionic Ears

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Getting Hearing Aids





Hearing Aid Models and Features

Models of Hearing Aids



In-Ear



Behind-Ear



Cochlear Implant

Source of images:

http://www.flickr.com/photos/portland_mike/2993507037/

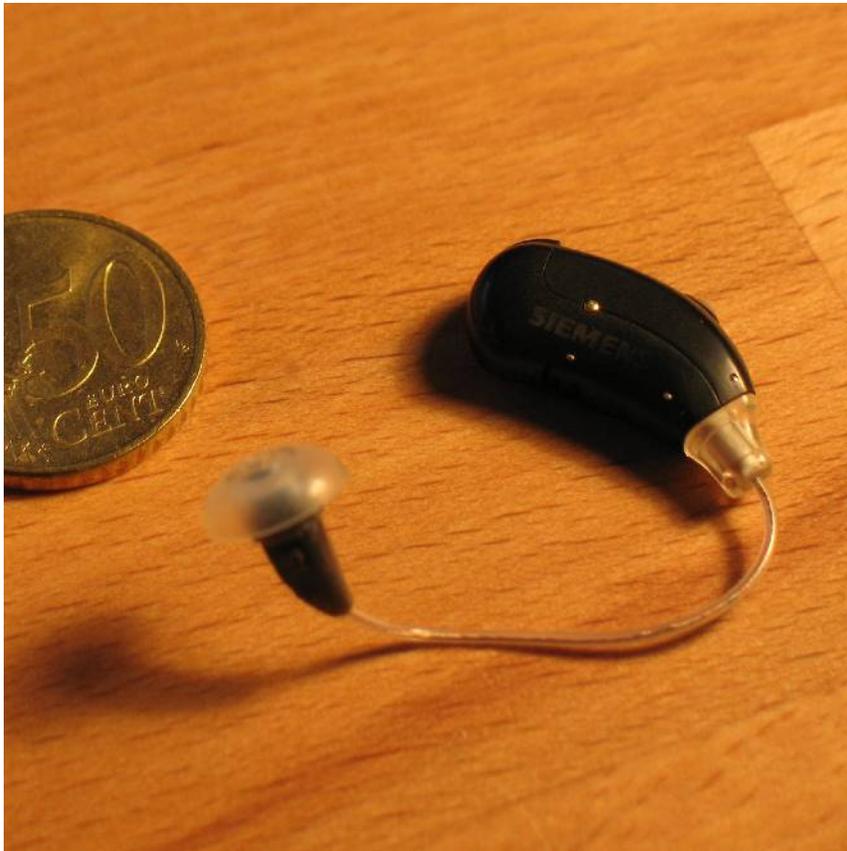
<http://www.flickr.com/photos/umhealthsystem/5494712579/sizes/o/in/photostream/>

http://www.flickr.com/photos/oaspetele_de_piatra/4581664897/sizes/o/in/photostream/

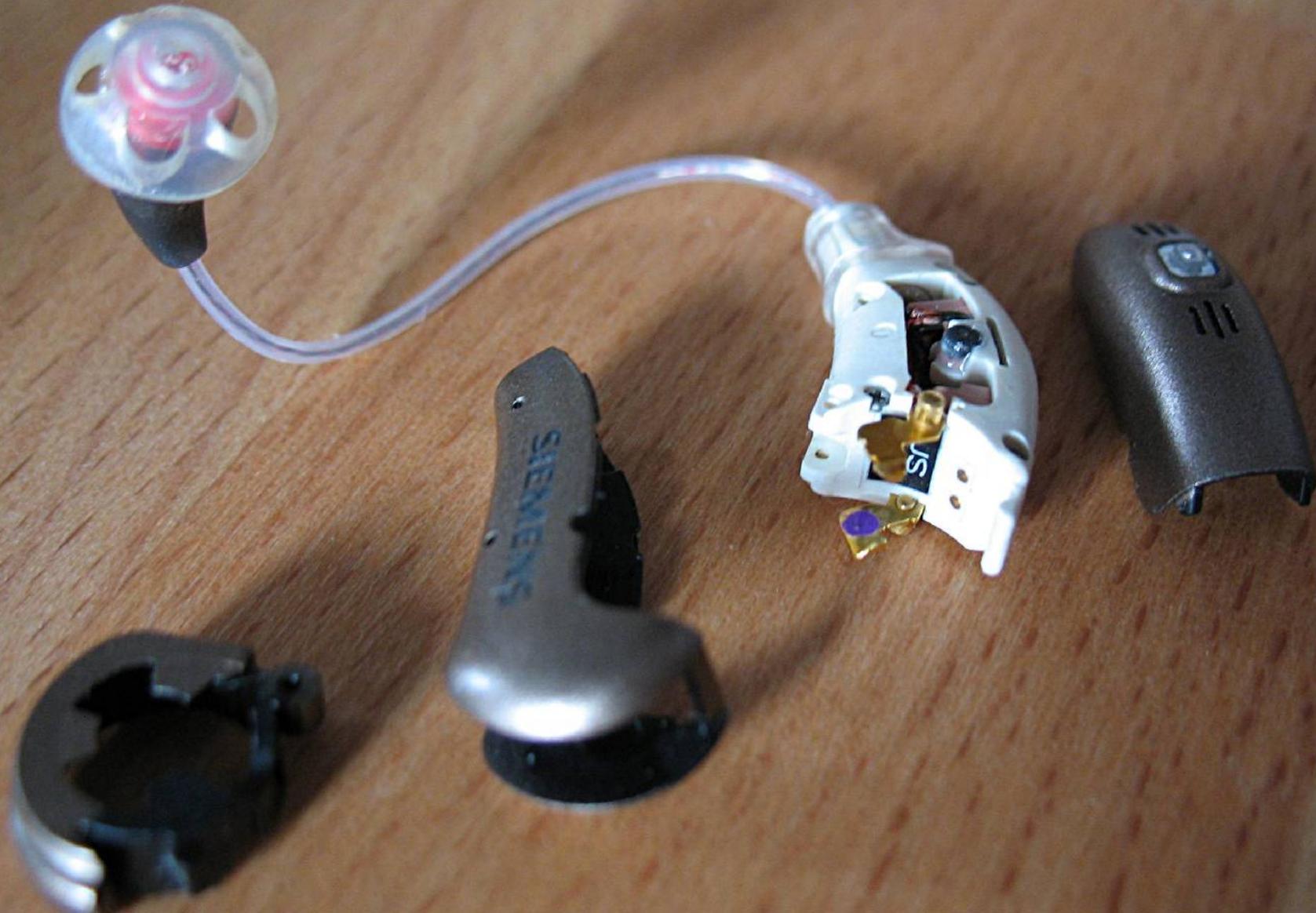
Visibility of Hearing Aids



Size of Hearing Aids



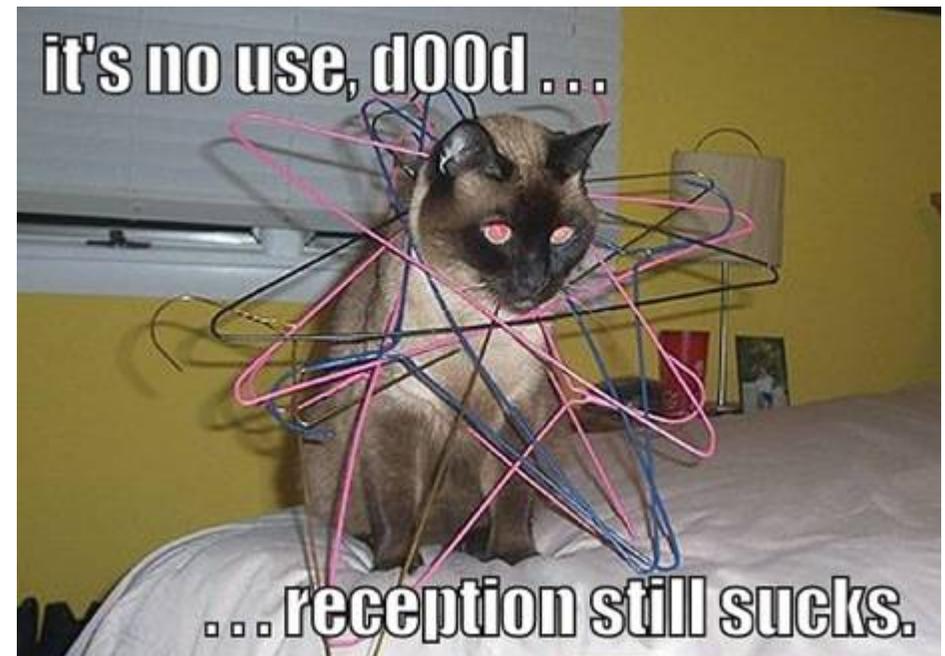
Hearing Aids



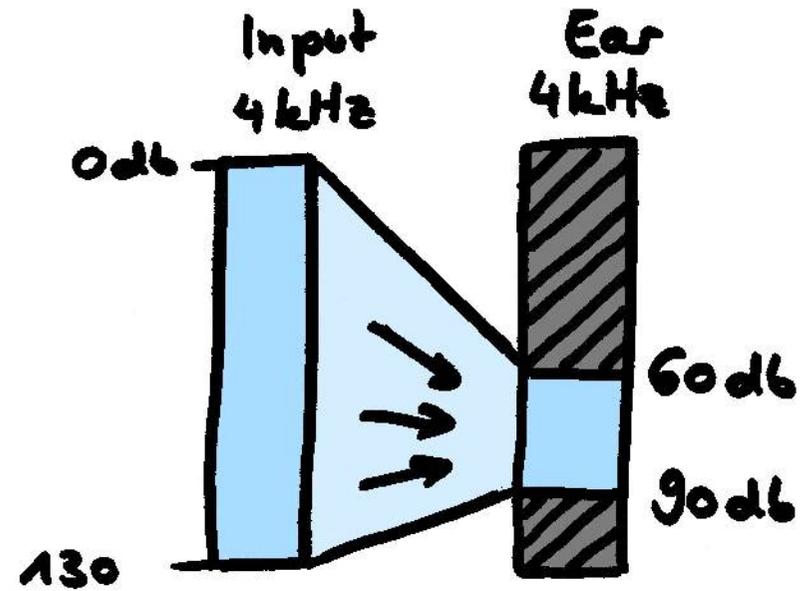
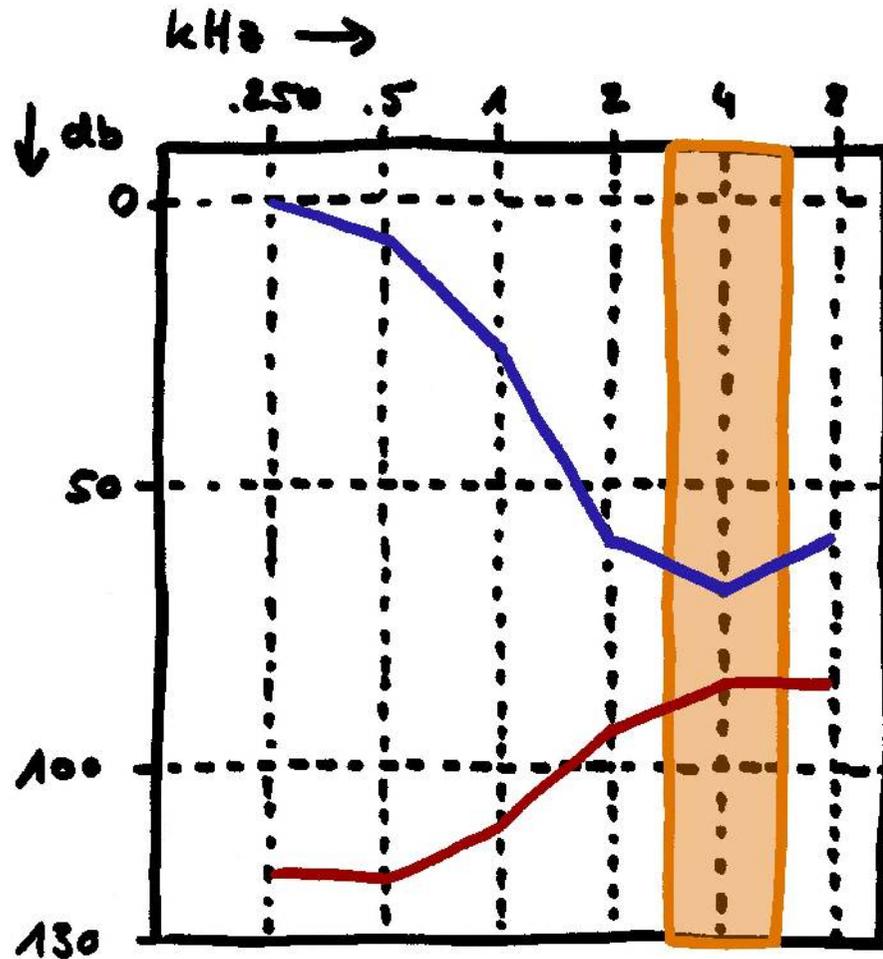
Digital Hearing Aids



- Standard in first world countries
- Make a lot more features possible
- Real time sound processing
 - analyze signal and react to it instantly



Compression



Frequency Shaping



CONNEXX - CONNEXX6

File Edit Fitting View Settings Help

Sound examples not installed

CONNEXX ClinicalFit

Pure 700 S 108/45

75% 75%

Pure 700 S 108/45

1 Universal

2 Bluetooth Phon...

3 Tek (Audio/TV) ...

4 Music (modified)

5 Universal (mo...)

Frequency Shaping

Gain

-1dB 1dB 4dB 6dB 24dB 41dB 32dB 10dB

0.1 0.5 1.4 3.5 8kHz

Maximum Power Output

Broadband Multichannel

-9dB -9dB -12dB -9dB

0.1 0.5 1.4 3.5 8kHz

Compression

Sound Management

Microphone / Bluetooth

Instrument Settings

Frequency Shaping

Gain

-1dB 2dB 6dB 18dB 38dB 40dB 33dB 8dB

0.1 0.5 1.4 3.5 8kHz

Maximum Power Output

Broadband Multichannel

-12dB -12dB -12dB -12dB

0.1 0.5 1.4 3.5 8kHz

Compression

Sound Management

Microphone / Bluetooth

Instrument Settings

1 Universal

2 Bluetooth Phon...

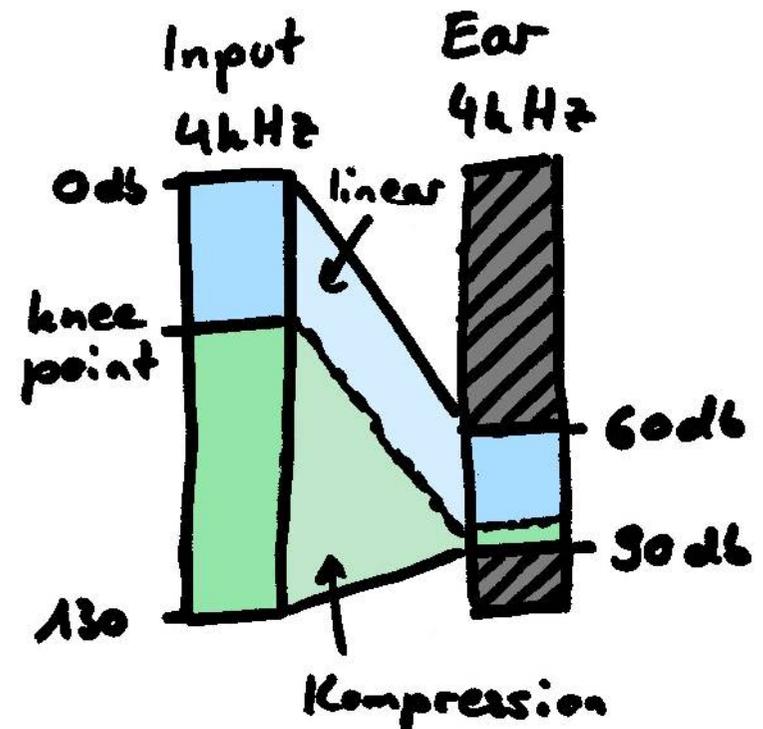
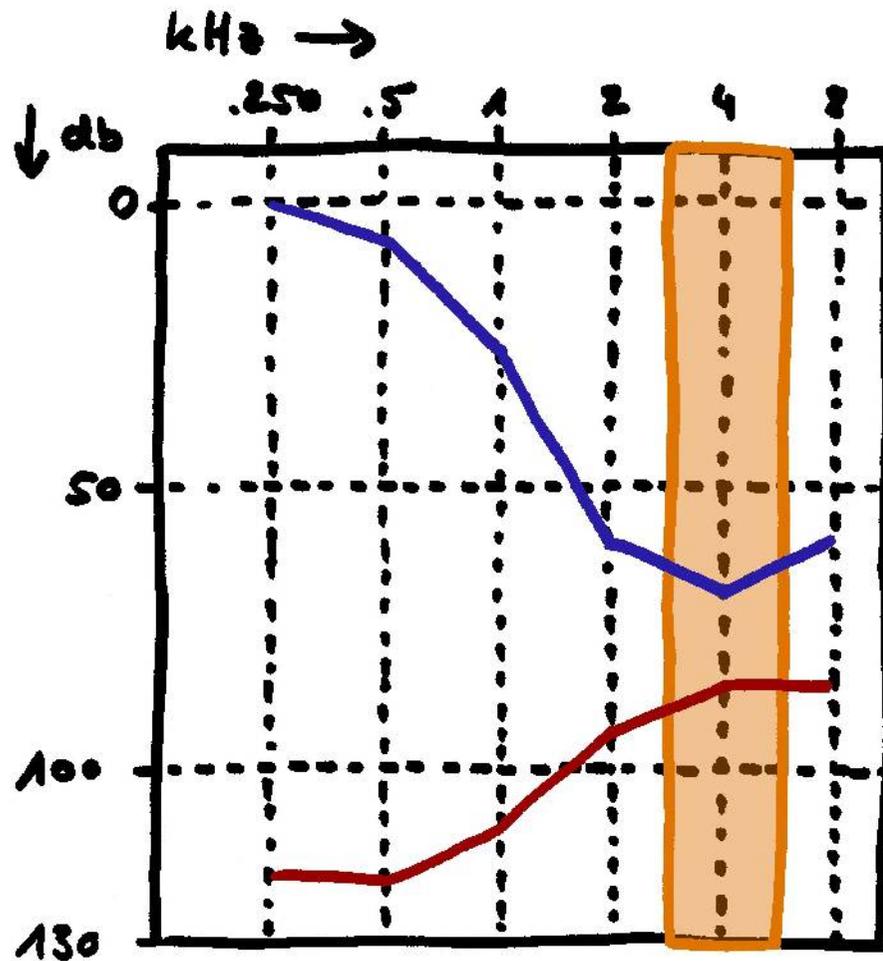
3 Tek (Audio/TV) ...

4 Music (modified)

5 Universal (mo...)

Audiogram Hearing Instruments Basic Tuning **Fine Tuning** Documentation

Compression



Compression



CONNEXX - CONNEXX6

File Edit Fitting View Settings Help

Sound examples not installed

CONNEXX ClinicalFit

Pure 700 S 108/45

75% Off 75%

1 Universal

2 Bluetooth Phon...

3 Tek (Audio/TV) ...

4 Music (modified)

5 Universal (mo...)

**Frequency Shaping
Compression**

<< show gain controls

Kneepoints and Ratios (CK, CR)

69dB	75dB	63dB	66dB	69dB	54dB	54dB	57dB	48dB
4.00	4.00	1.36	1.52	1.68	1.36	1.49	1.83	1.68
Syll.	Dual							

0.1 0.5 1.4 ▶

Sound Management

Microphone / Bluetooth

Instrument Settings

1 Universal

2 Bluetooth Phon...

3 Tek (Audio/TV) ...

4 Music (modified)

5 Universal (mo...)

Audiogram

Hearing Instruments

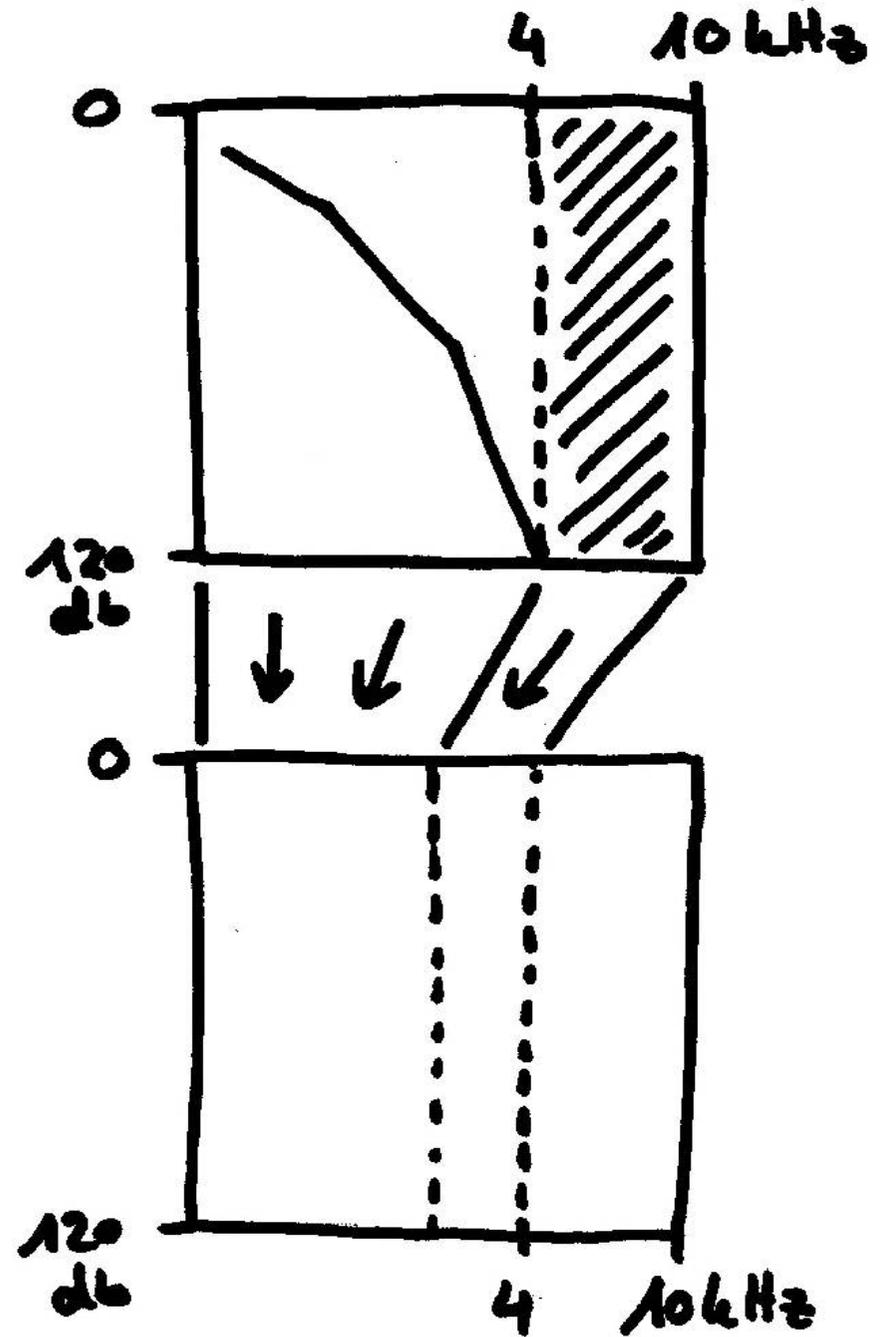
Basic Tuning

Fine Tuning

Documentation

Frequency Compression

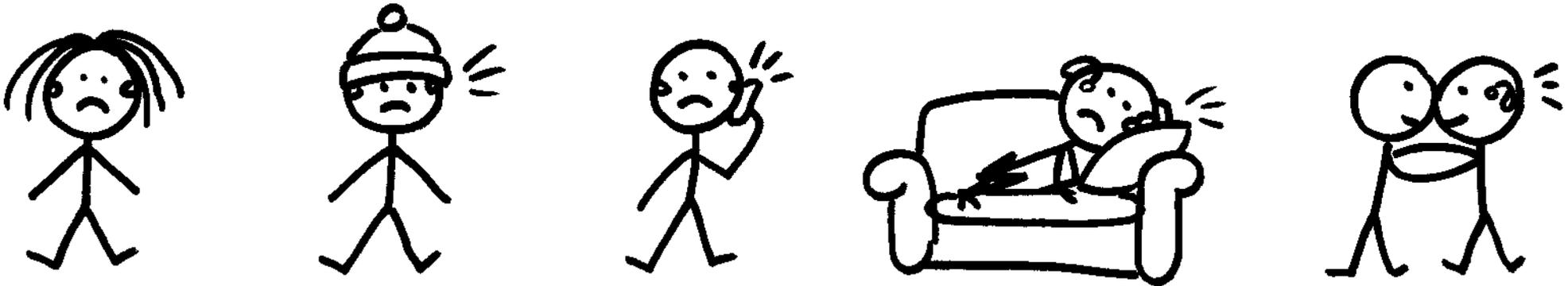
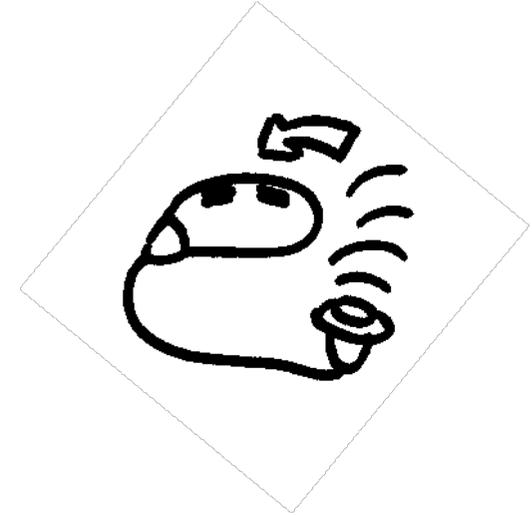
- what if complete loss on one band?
- compress the frequency space
- works only with closed hearing aids
- only one brand (phonak)



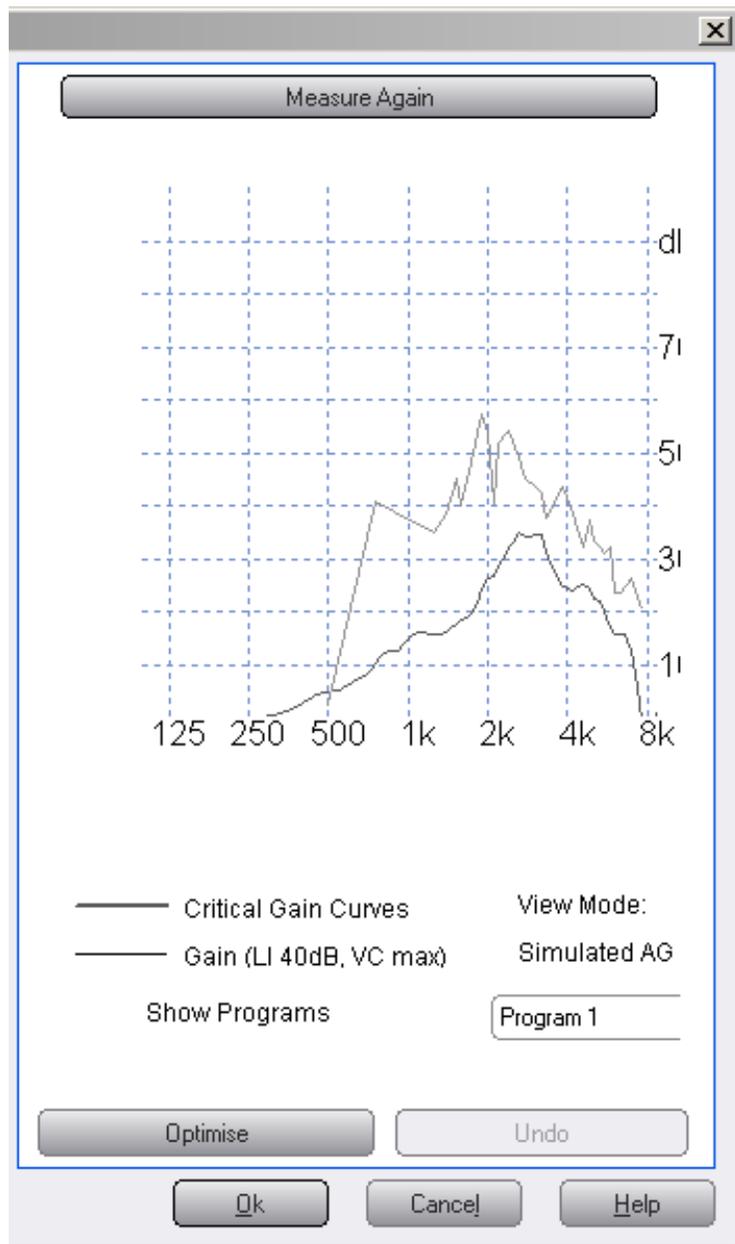
Problem: Feedback Loops



- Hearing aid amplifies its own signal
- Whenever something gets close to the hearing aids
- Especially for open hearing aids

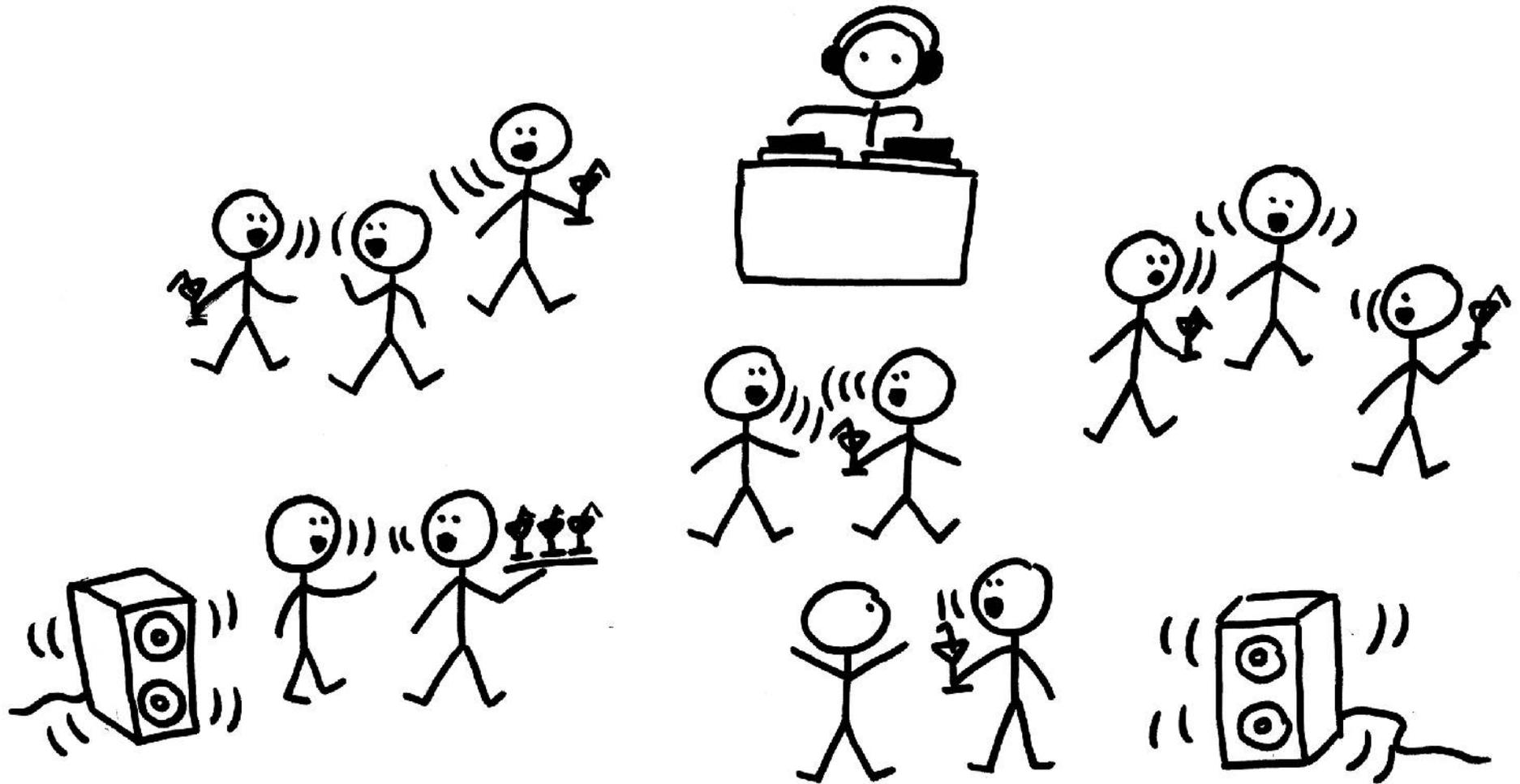


“Solution” for Feedback Loops



- Detect “clear” sinus signals
- Send an unhearable flag
- Damp affected frequencies
- Adapt in real time
- Problems:
 - music contains clear sinus signals
 - damped frequencies are needed for speech recognition
- Analog hearing aids did not have a measure against it

Cocktail Party Problem



Directional Hearing



- **Human ear:**

- Use two ears + brain
- Uses the pinna



- **Hearing aids:**

- 2 microphones per ear
- inter-hearing-aid communication
- situation recognition / different programs
- automatic focus
- use the pinna (in-ear hearing aids only)

Source: [http://en.wikipedia.org/wiki/Pinna_\(anatomy\)#Pinna_notch](http://en.wikipedia.org/wiki/Pinna_(anatomy)#Pinna_notch)

Directional Hearing



Real Time Display

5 Universal (modified) ● Pure 700 S 108/45 ○ Pure 700 S 108/45

Audibility

Noise Reduction

Adaptive Directional Microphone

Adaptive Signal Processing

- Off
- On

0°

270°

90°

180°

dB SPL Mic. Input

Volume

95 -

80 -

65 -

50 -

35 -

Calibrate

Play Pause Stop Refresh

Help Close

The image shows a software window titled 'Real Time Display'. At the top, it shows '5 Universal (modified)' and two radio buttons for 'Pure 700 S 108/45'. Below this are sections for 'Audibility' and 'Noise Reduction'. The main area features an 'Adaptive Directional Microphone' diagram with a green beam pointing up (0°) and a blue beam pointing down (180°). To the right of the diagram is a toggle for 'Adaptive Signal Processing' which is currently 'On'. On the far right, there are three scene icons: 'Sidewalk', 'Café', and 'Kitchen'. Below these is a vertical scale for 'dB SPL Mic. Input' ranging from 35 to 95, and a 'Volume' slider. A 'Calibrate' button and an information icon are also present. At the bottom, there are playback controls (play, pause, stop, refresh) and 'Help' and 'Close' buttons.

Fore- and Background



- Low frequencies travel further than high ones
- Brain uses this to extract foreground signal and source location
- HAs amplify high frequencies
- HAs filter background signal



Realtime Monitor



Humidity



- Most hearing aids are not waterproof
- No swimming with friends
- No pool parties
- No (social) water sports
- No sweating
- No audiobooks in the bathtub
- No heavy rain
- Drying material necessary
- very recent development: water and dust resistancy
- example: Phonak HAs claim certification of IP67
- no damage due to dust
- 30 min, 1 meter under water: no irreparable damage



M H2O



Naída S CRT



Nios S H2O

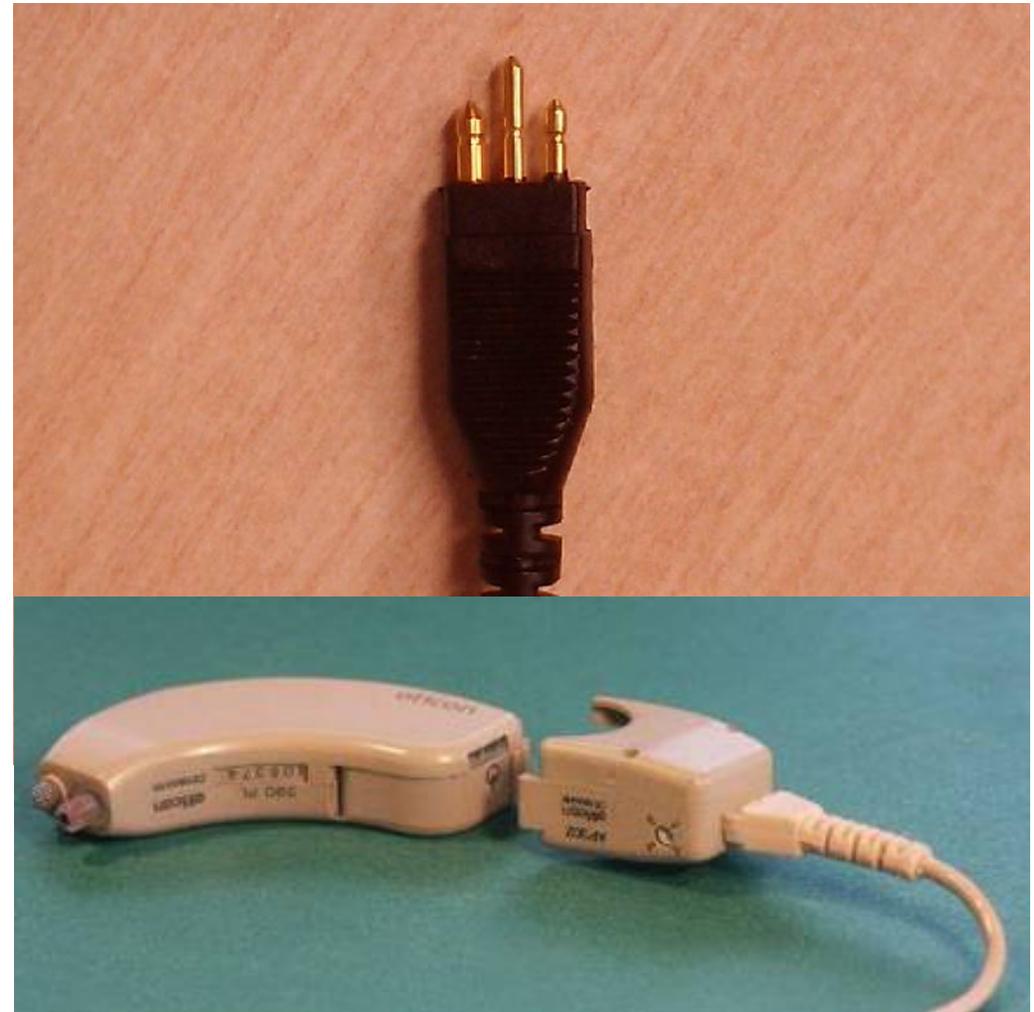


Peripheral Hardware

DAI interface



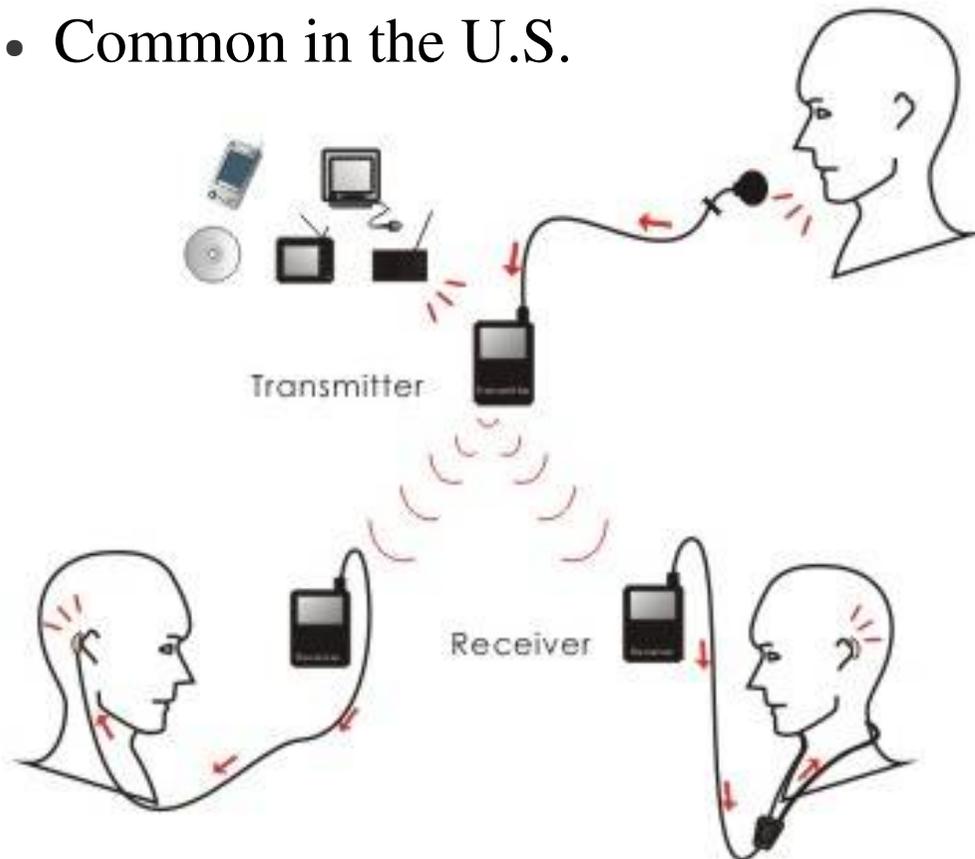
- “direct audio input”
- also called “Euro Adapter”
- cables for all kinds of devices
- Pro:
 - no interference with wireless devices
 - variety of cables available
 - used for FM / Bluetooth adapters
- Con:
 - it's a cable
 - too big for really small hearing aids



FM systems

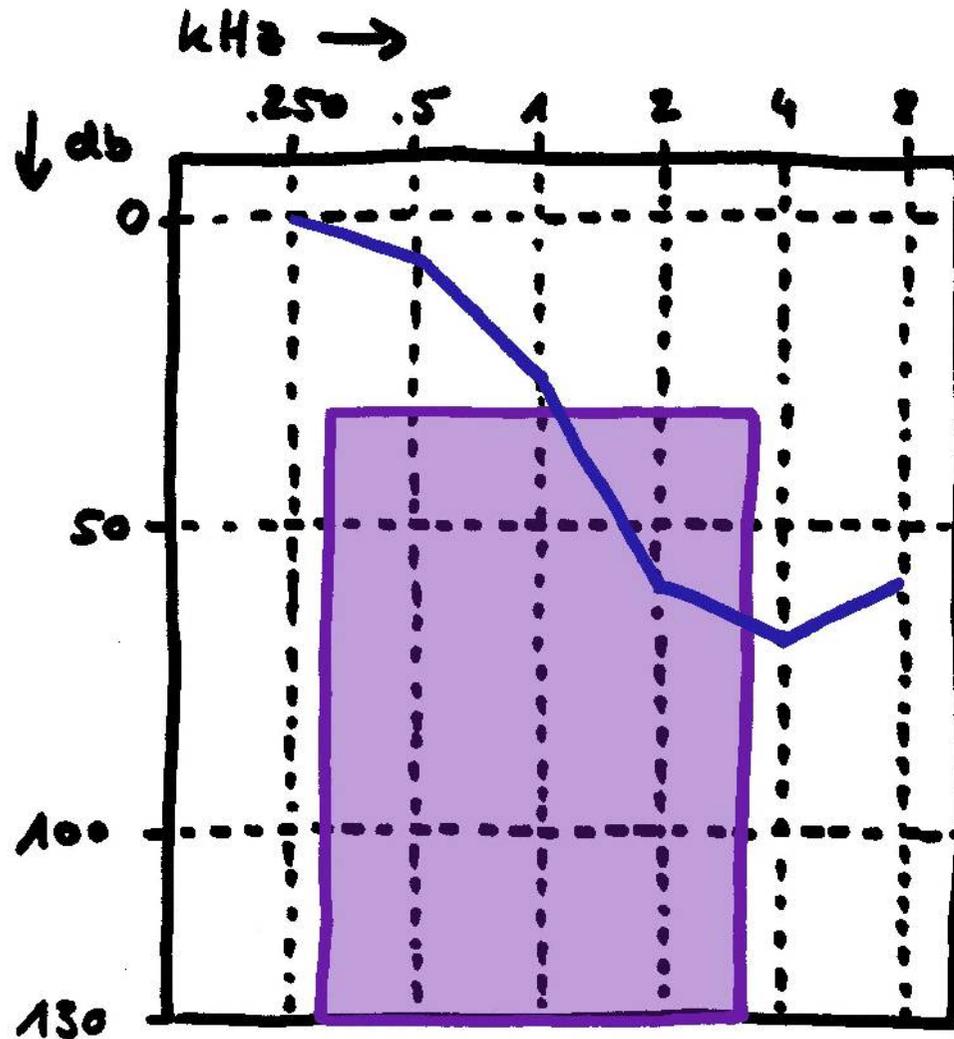


- FM receiver in hearing aids
- FM transmitter connected to source
- Common in the U.S.



- Pro:
 - lots of hardware available
 - different setups
 - (some) standards
- Cons:
 - Interference
 - sound quality
 - incompatibility between systems

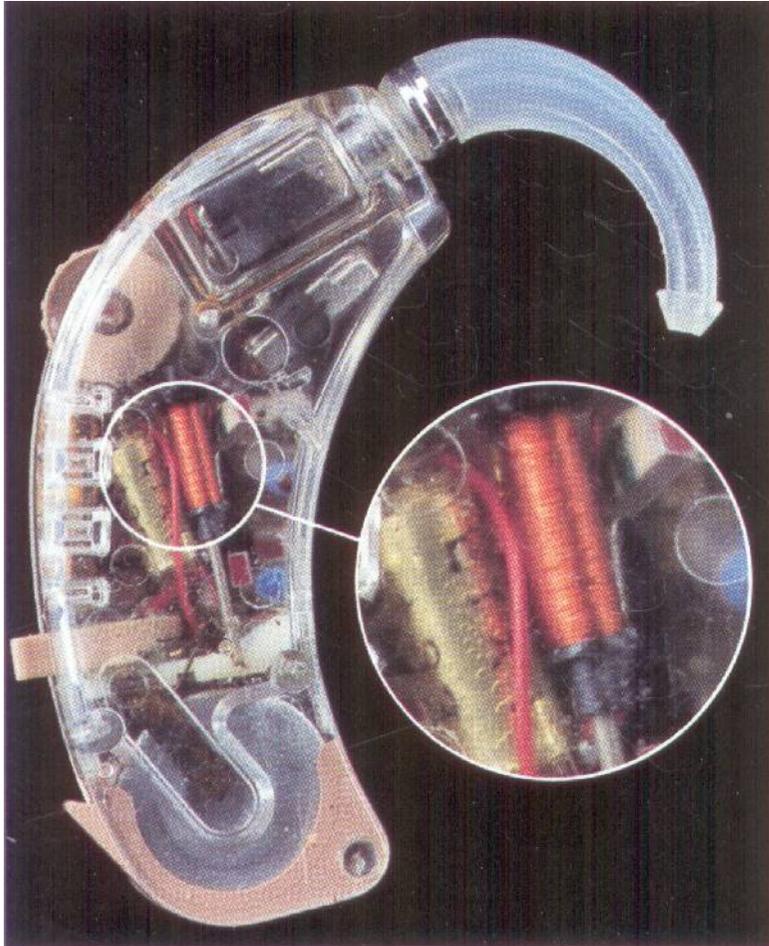
Calling on the Phone



- lip reading
- frequency range of phone signal: 300Hz - 3400Hz
- background noise: full range
- signal is altered and unnatural
- missing base
- bad reception
- hearing only in one ear
- feedback loops

Source: <http://de.wikipedia.org/wiki/Telefonnetz>

Telecoil and Audio Induction Loop



- telecoil / T-coil in hearing aids
- audio induction loops connected to source
- phone, room installation, cars, adapters
- technology rather old
- widely used in Europe
- cons: interference, sound level differences when moving head, high initial costs
- pros: microphones are automatically switched off, standard in even for new phones, some hearing aids use both ears, DIY kits available

Source: http://en.wikipedia.org/wiki/Audio_induction_loop

Bluetooth



- no hearing aids available with Bluetooth (yet)
- too much battery consumption
- adapters via telecoil, DAI, proprietary protocols



Phonak ICOM

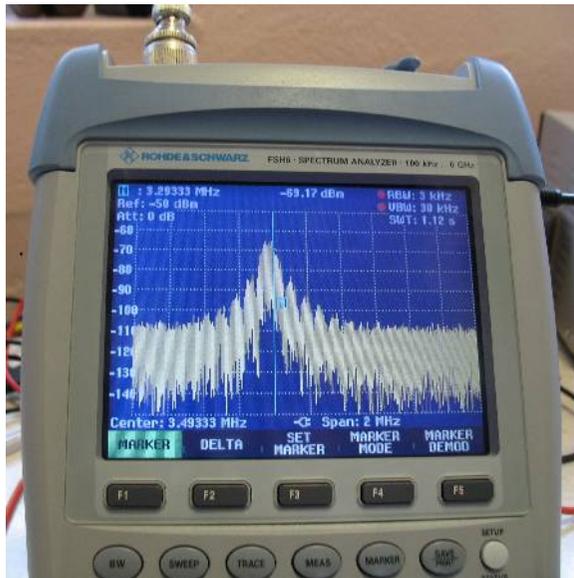


- example of a wireless adapter
- uses telecoil to talk to hearing aids
- interfaces: DAI, aux-in and bluetooth
- FM systems via DAI
- warning regarding pace makers



Source: http://www.remorina.com/clients/eBay/images/icom/iCom_02.jpg

Siemens Tek



- adapter + remote control
- proprietary NFC protocol between adapter and hearing aids
- signal around 3.3Mhz
- compatible with any bluetooth speaking source (in theory)
- mobile phones, land line phones, computers
- comes with an additional transmitter for TV
- costs: 400 EUR (no insurance)
- new version “mini tek”



Bionic Ears

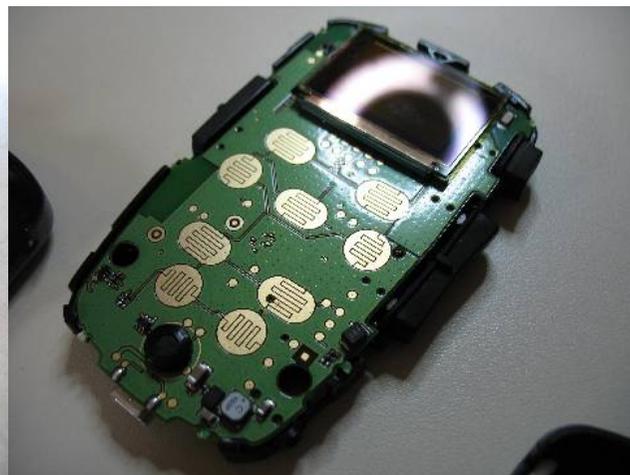
Siemens Tek w Transmitter



Siemens Tek Inside



- coupled with hearing aids using hearing aid tuning software
- identifies with 7-character serial number
- latency is crucial (encryption?)
- bluetooth pin “0000”
- ear-2-ear communication unauthenticated



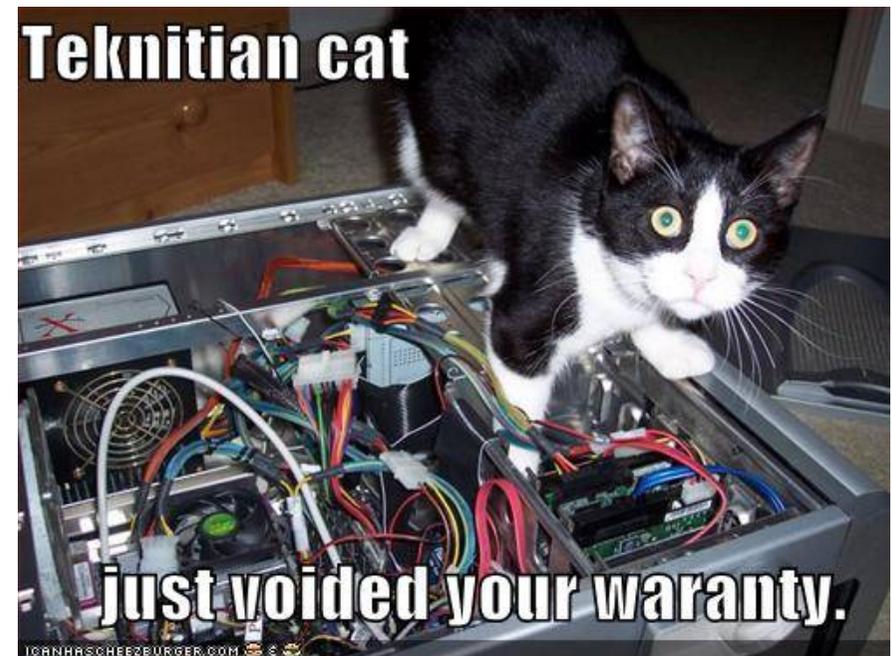


Hacking

Hacking “Scene”



- barely existing
- devices too expensive
- mostly: compatibility issues, asking for technical advice
- a little hacking on peripheral hardware



<http://hearingaidhacks.livejournal.com/>

DYI Bluetooth Adapter

by Gertlex



Bluetooth Headphones Hack

[Thumbnails](#) [Detail](#) [Comments](#)

Slideshow



Share



In this album... you see my dissection of various electronics, followed by a not quite complete glimpse of the steps I took in modifying these headphones to have two audio jacks. These audio jacks are used for DAI cables that plug into my hearing aids.

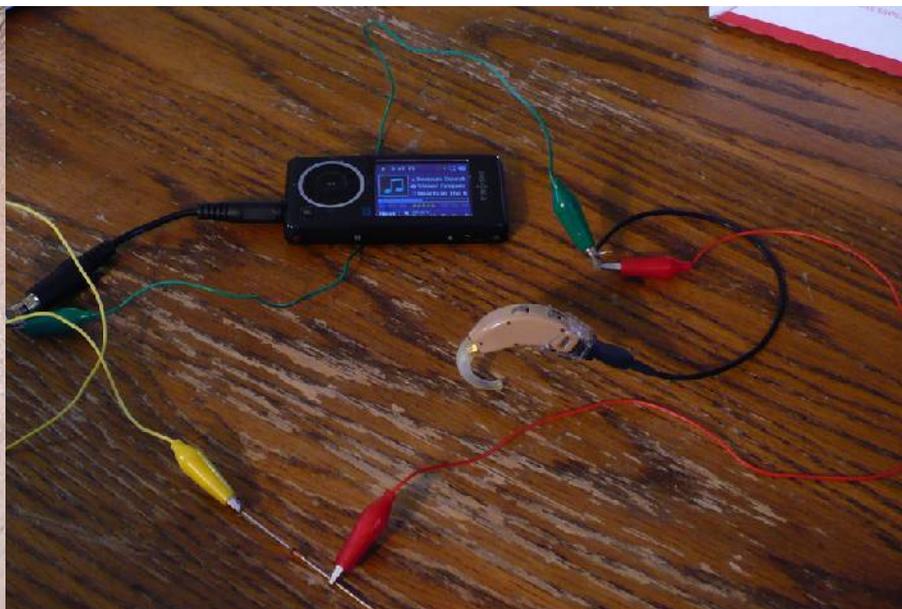
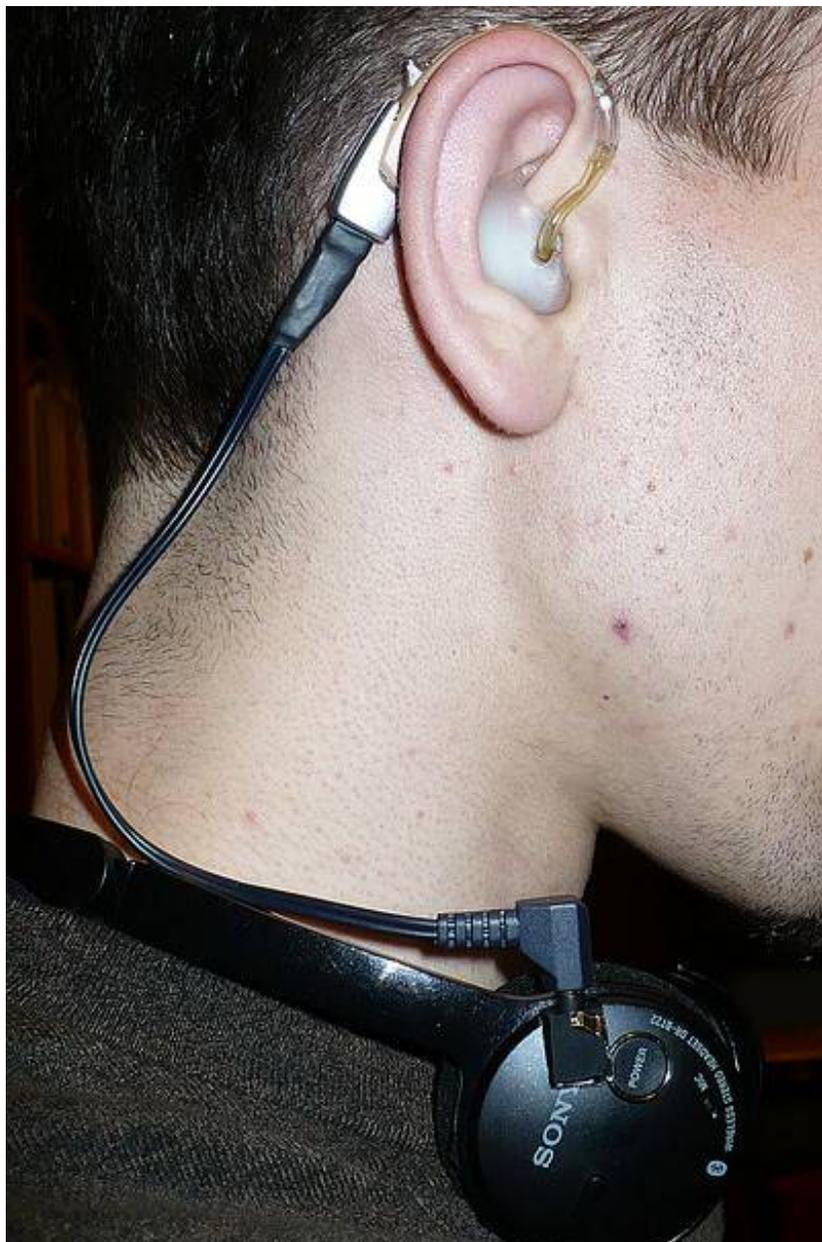
50 photos | 359 views

Items are from between 09 Dec 2007 & 01 Jan 2008.



DYI Bluetooth Adapter

by Gertlex

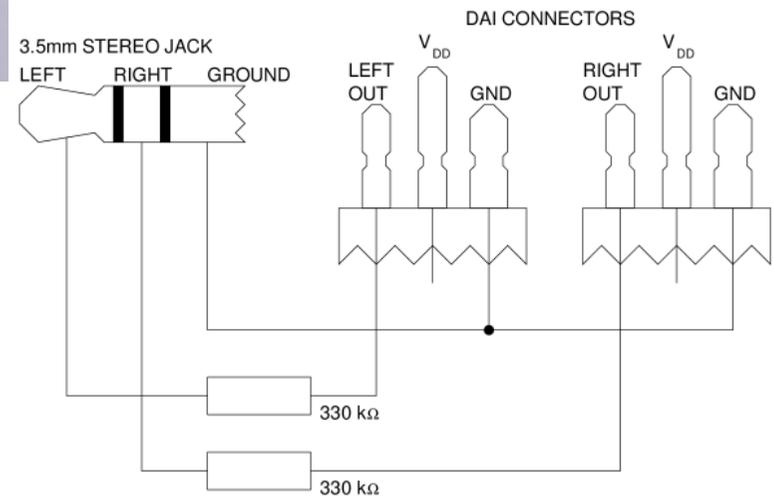


DYI Bluetooth Adapter

by Neil Ferguson



EXAMPLE DAI CABLE FOR BEHIND-THE-EAR HEARING AIDS USING SHOES





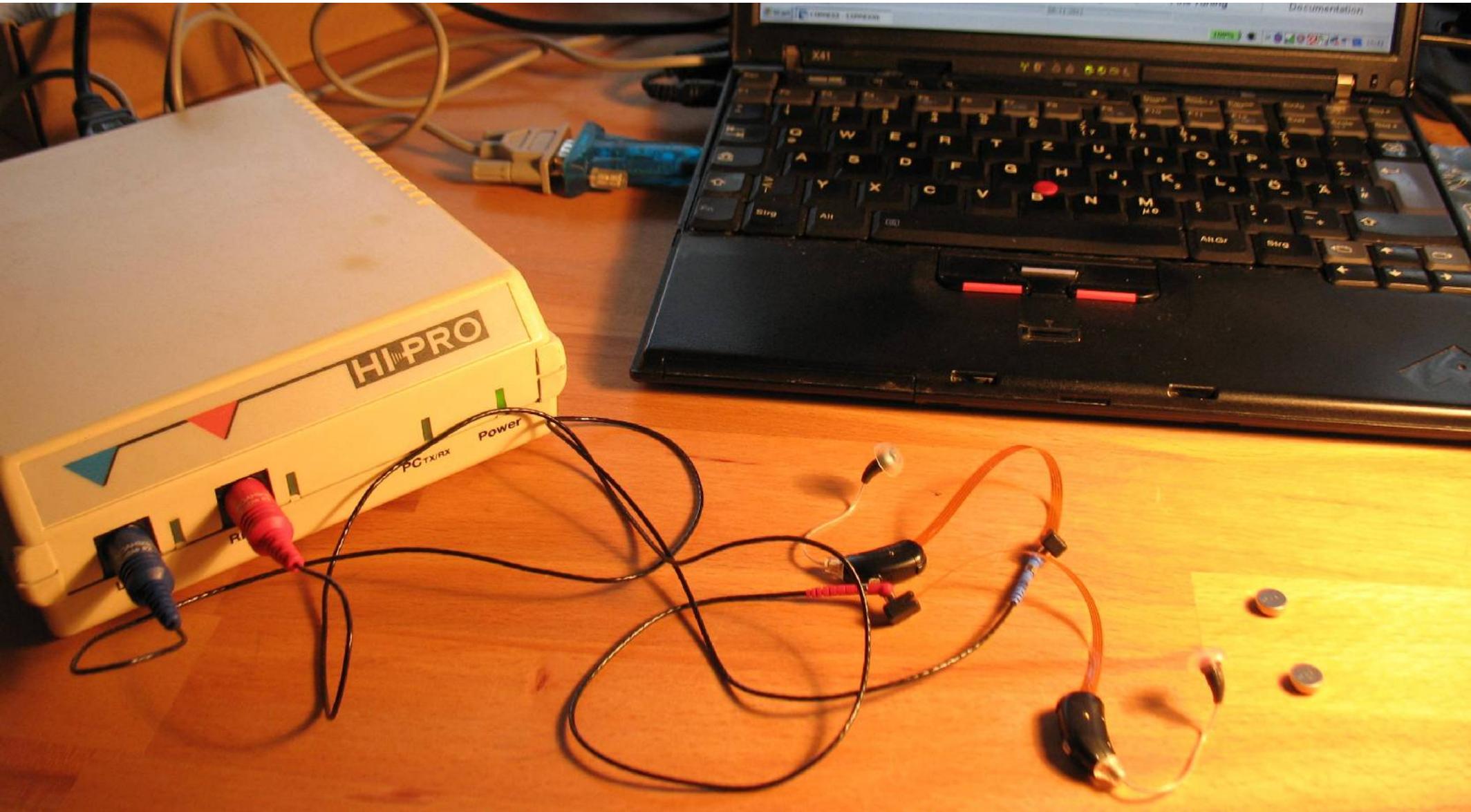
Self-Tuning

Tuning

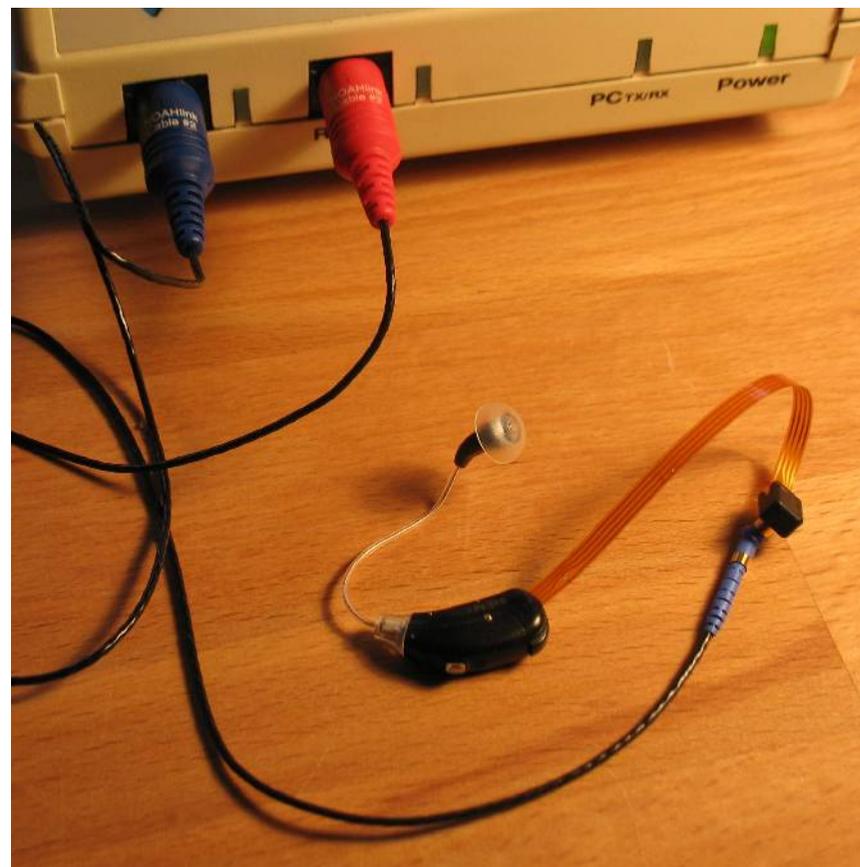
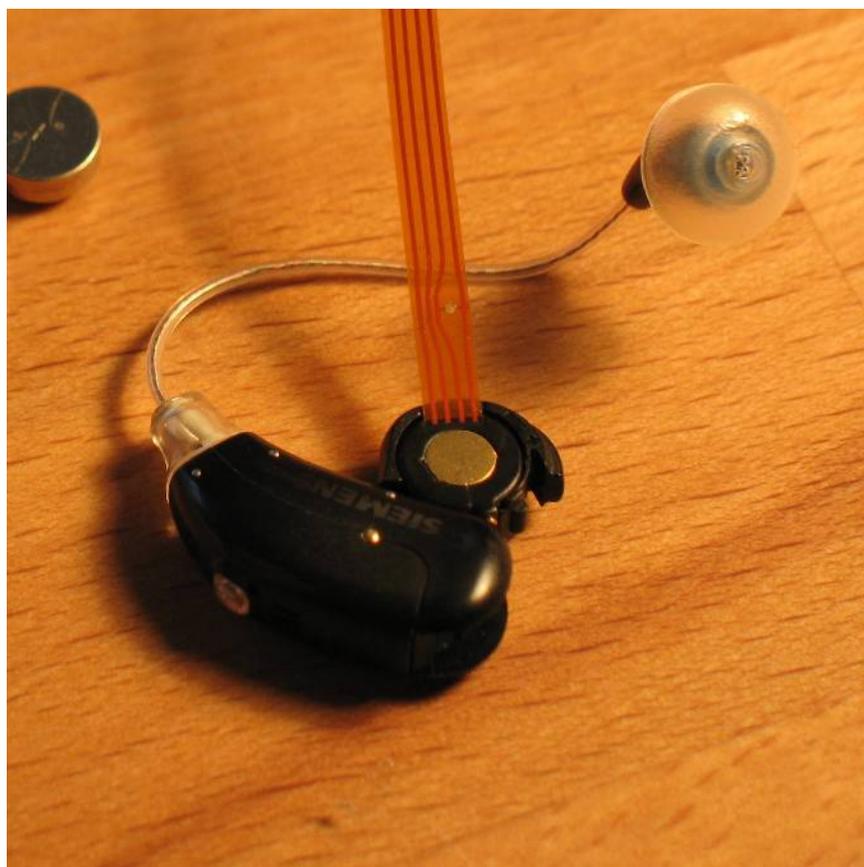


- special hardware: hipro (serial/usb/bluetooth)
- software: noah + modules for each brand
- sold only to doctors and audiologists
- medical equipment (no ebay etc.)
- there is a self-tuner “scene”
- no customer support, no warranty
- exception: americahears.com

Hipro (Serial Version)



Hipro-HA interface



Hipro (Bluetooth Version)



Tuning Software



CONNEXX - CONNEXX6

File Edit Fitting View Settings Help

Sound examples not installed

CONNEXX ClinicalFit

Pure 700 S 108/45

75% Off 75%

Pure 700 S 108/45

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-9dB -9dB -12dB -9dB

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Compression

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Audiogram Hearing Instruments Basic Tuning **Fine Tuning** Documentation

Big Brother



SoundLearning

activate SoundLearning

Right
 Binaural (e2e Wireless)
 Left

Start: 08.04.2011 08:57:00
 Read out: 05.11.2011 16:25:36
 Wearing time: 2997 h
 Average wearing time: 14.0 h / day

Usage Analysis

Show

- All Programs
- 1 Universal 3%
- 2 Bluetooth Phone 0%
- 3 Tek (Audio/TV) 0%
- 4 Music 0%
- 5 Universal 97%

Gain Preferences

Program 5: Universal

Microphone Modes

55 %
Omni

45 %
Directional

Speech and Noise Management

38%

off

62%

low

0%

medium

0%

strong

Acoustical environment Usage time (in h): 2878

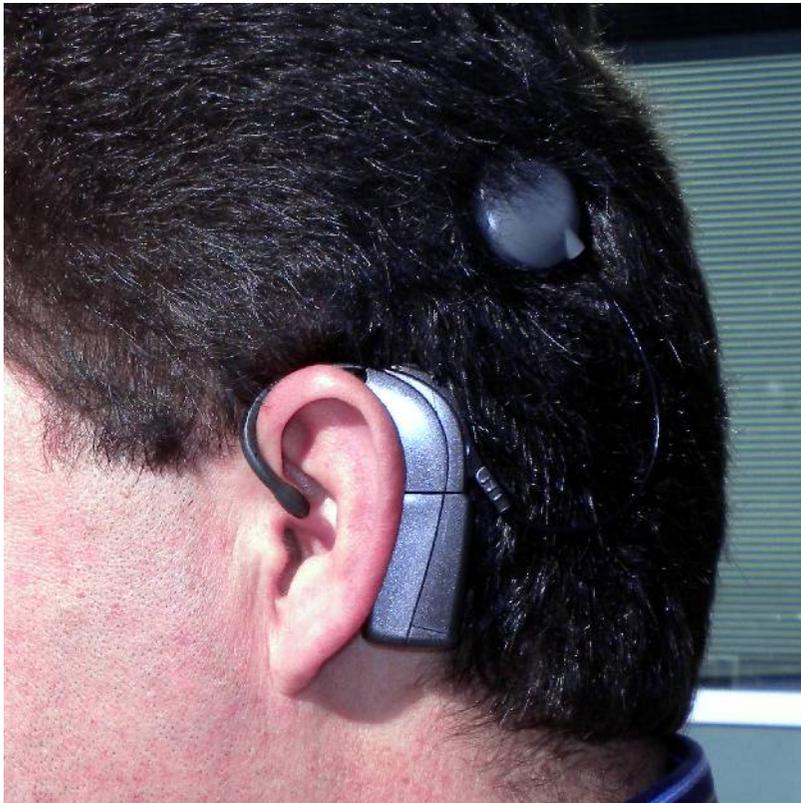
Speech in quiet	17 %	494
Speech in noise	28 %	814
Noise	31 %	901
Music	7 %	203
Quiet	16 %	465

Print Close Help



Cochlear Implants

Cochlear Implants



Source of images:

<http://www.flickr.com/photos/yaccesslab/5431069155/>

http://www.flickr.com/photos/oaspetele_de_piatra/4581664897/sizes/o/in/photostream/

Cochlear Implants



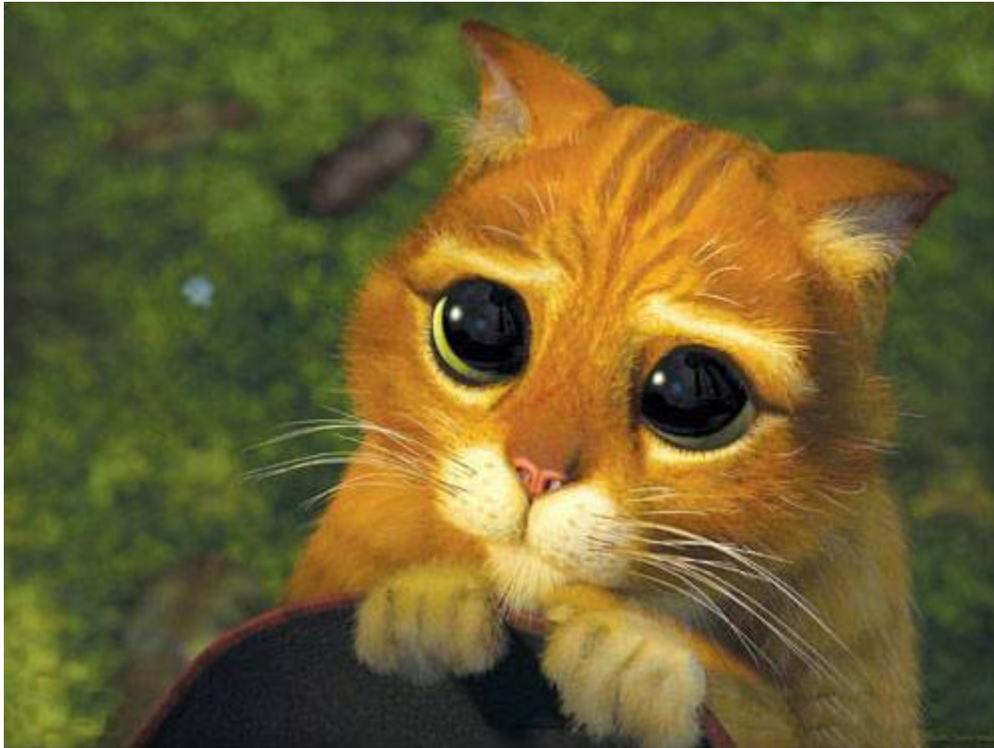
- makes deaf people hear
- surgical insertion of device
- destroys any remaining hearing
- surgery might affect other nerves
- signal is different:
brain has to adjust
- technology usually 5 years
behind
- no standards, no interoperability
between brands





Conclusions

Want!



- better service
- consideration of young people's needs
- better signal processing
- (open) standards

Ideas



So einfach – Apps für alle Anforderungen

Wir haben die Audéo S Apps in vier Hauptbereiche zusammengefasst.

Binaurale Apps

StereoZoom auto ZoomControl ZoomControl DuoPhone UltraZoom Premium UltraZoom Advanced UltraZoom Standard QuickSync

Apps für adaptive Intelligenz und Interaktion

FlexControl FlexVolume SoundFlow Premium SoundFlow Advanced SoundFlow Standard SelfLearning

Apps für Steuerung und Anbindung

Phonak PilotOne myPilot iCom Phonak TVLink Click'nTalk Dynamic FM

Signatur-Apps

SoundRecover WhistleBlock NoiseBlock Premium NoiseBlock Advanced NoiseBlock Standard EchoBlock WindBlock SoundRelax Real Ear Sound

- “hearing aid app market”
- crowdsourcing
- language / speaker / location specific programs
- use info from smartphone
- write your own filters?

Ears

63/64

Thanks!

- Questions?
- Slides and speaker notes on hackandhear.com
- Give Feedback, please!

Credits:



- Heike Pott
heike-pott.de
- LupusE, Nicolas
- Habo, Jump
- Kevin, the Chaoswelle guys
- ThinkPad, Heiko
- and all I forgot to mention ...