Bionic Ears

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

28c3
Berlin, Dec 28th 2011
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Abstract

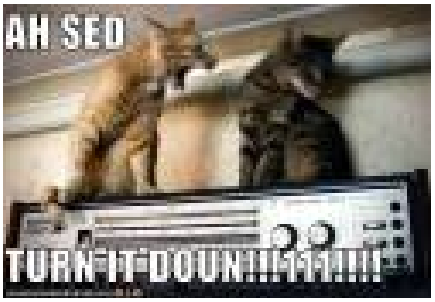
In many social situations being hearing impaired is a serious handicap, not only for elderly people. Today's hearing aids are tiny computers that do a decent job in signal processing. During the last years, the progress in this technology was significant, amongst other things by switching from analog 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



Since I am aware of the fact that my talk will attract people with hearing problems, I provide these slides with quite detailed speaker notes so that it is possible for you to follow the talk.

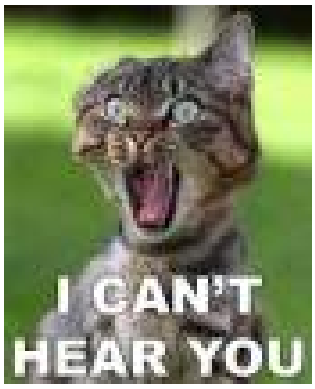
Bear in mind, that these speaker notes, are not exactly what I said, I wrote more or less what I planned to say, but during the talk I spoke rather freely which is why the content might differ here and there.

There will be recordings available soon and I will try to provide subtitles so that you can follow it more closely to what I actually said.

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.



My name is Helga. I work as a software engineer in Munich. I moved there this year, some people might remember me from the CCC Cologne actually.

I am more of a software geek than a hardware hacker. From university, I have a background in signal processing and data mining.

My last job was in the medical engineering branch. It did not have anything to do with hearing aids, but gave me some insight into the certification processes that are necessary there.

Also currently I don't work for a hearing aid company. This project is just a personal pet project of mine. So if you want to sue anyone, sue me in person and not my employer.

I started to care about this topic when I got hearing aids myself 3.5 years ago.

What's this about?

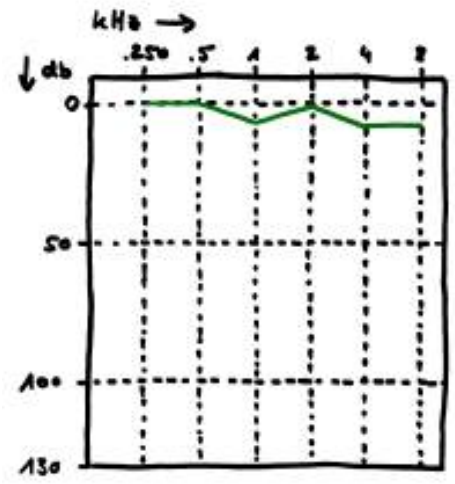
- Audiology
- Getting hearing aids
- Hearing aid models and features
- Peripheral hardware
- Hacking
- Self-tuning
- Conclusions

I will start with some basics in audiology and describe the process of getting hearing aids. Then I will have a look at nowadays hearing aids and what features they provide. In addition to that, there are a couple of peripheral gadgets available that one can connect to hearing aids.

I will talk a bit about the hacking and self-tuning “scene”. Self-tuning means that patients tune their own hearing aids instead of relying on an audiologist.

Audiology

Audiogram



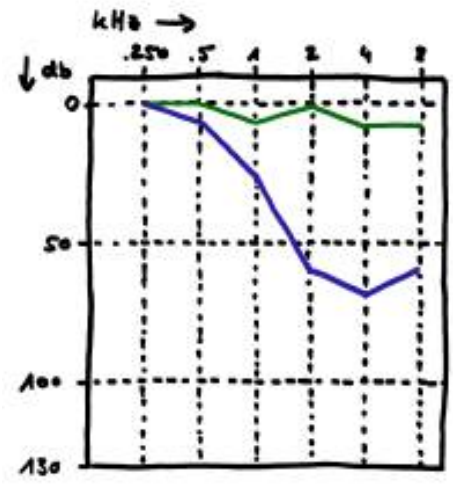
- x-axis: frequency in kHz
- y-axis: volume of signal in db
- healthy person

When you go to a doctor and do a hearing test, they will produce something like that: an audiogram. The x-axis shows the frequency domain in kHz, meaning the range from low frequencies (base sounds) to high frequencies ("ss" and "f" sounds). The y-axis shows the level of volume, starting with very quiet at the top and reaching up to 130 decibel at the bottom.

An audiogram is created by giving a buzzer to the patient and playing different sounds of different frequencies, starting very low and than louder louder. The patient hits the buzzer as soon as he perceives the sound.

That means the curve here is the minimum level of volume that is needed for this person to hear the sound. The green line is a typical line for a normally hearing person.

Audiogram

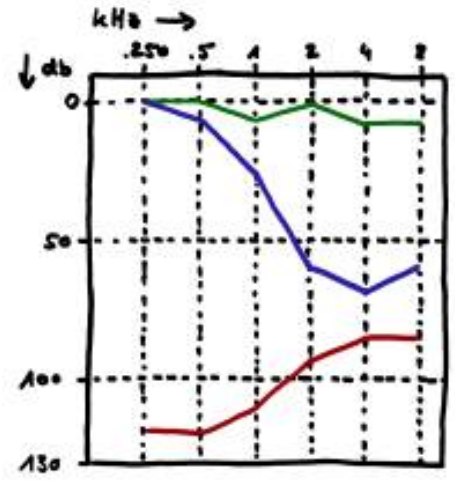


- green: healthy person
- blue: typical hearing impaired

The blue line here shows a typical curve of a hearing impaired person. Usually one still hears the low frequencies quite okay, but not the high frequencies.

Bear in mind that the decibel scale is a logarithmic one. That mean 20db is not double so loud as 10db, but 100 times so loud. 60db are 1000000 times so loud as 10db.

Audiogram

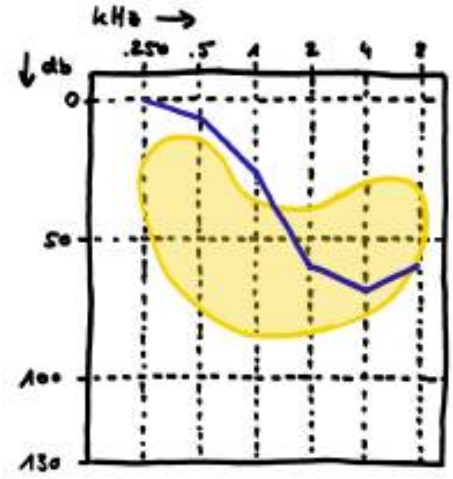


- green: healthy person
- blue: typical hearing impaired
- red: level of discomfort for hearing impaired

Besides the minimum threshold when one starts hearing a sound, another curve is measured. This is the level of discomfort and it is measured by playing the sounds louder and louder until the patient hits the buzzer because it starts making him uncomfortable. This phenomenon is called "recruitment".

Typically, the red curve raises in the areas where the hearing loss is worst. This makes it extremely difficult to tune hearing aids. They cannot simply amplify everything according to the hearing loss, it would reach below the red curve very easily.

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

To get an impression on how understanding speech is affected by a hearing loss, this diagram shows the areas where speech signals usually are. The technical term for it is actually “speech banana” (described by a guy named “Fant”).

It varies of course with the voices of the speakers etc. The vowels range from the left end to the middle of the banana. The consonants, especially the hissing sounds like “s” or “f” are located in the right end of the banana.

If you compare that to the blue curve, hearing loss usually affect the consonants first. You stop hearing them an then every word becomes a guessing game where you fill in the gaps of consonants.

How I Hear (Example)

- Song “Sad Robot” by Pornophonique

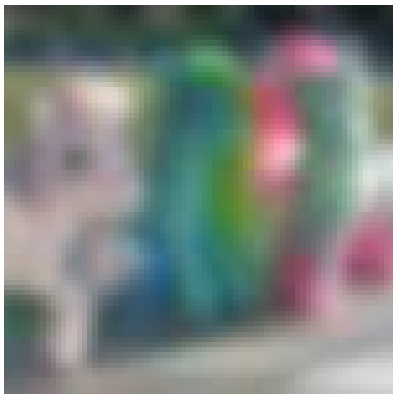
Source of “Sad Robot”: http://www.pornophonique.de
Source of tinnitus sounds: http://www.ata.org/sounds-of-tinnitus

I want to give you an example on how I hear without wearing hearing aids. I took one of my favorite songs and manipulated it in a way that it sounds like I hear it. The original song is called “Sad Robot” by a band called “Pornophonique”. Their music is freely downloadable on their website.

I sampled a tinntius sound over it, additionally to the hearing loss of the high frequencies. There is a website where you can download different tinnitus sounds.

Getting Hearing Aids

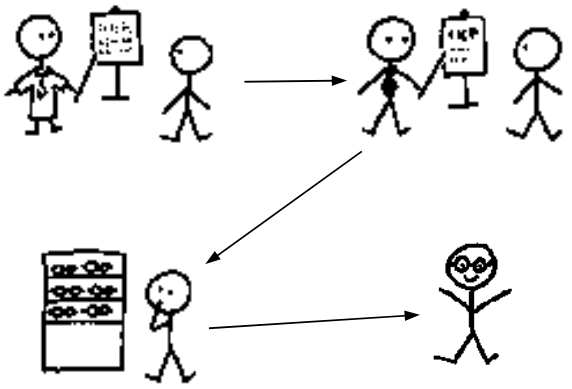
Need Glasses?



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

When describing the process of getting hearing aids, I like to compare it to getting glasses.
One day you realize that you cannot see very well, everything is a little blurry.

Getting Glasses

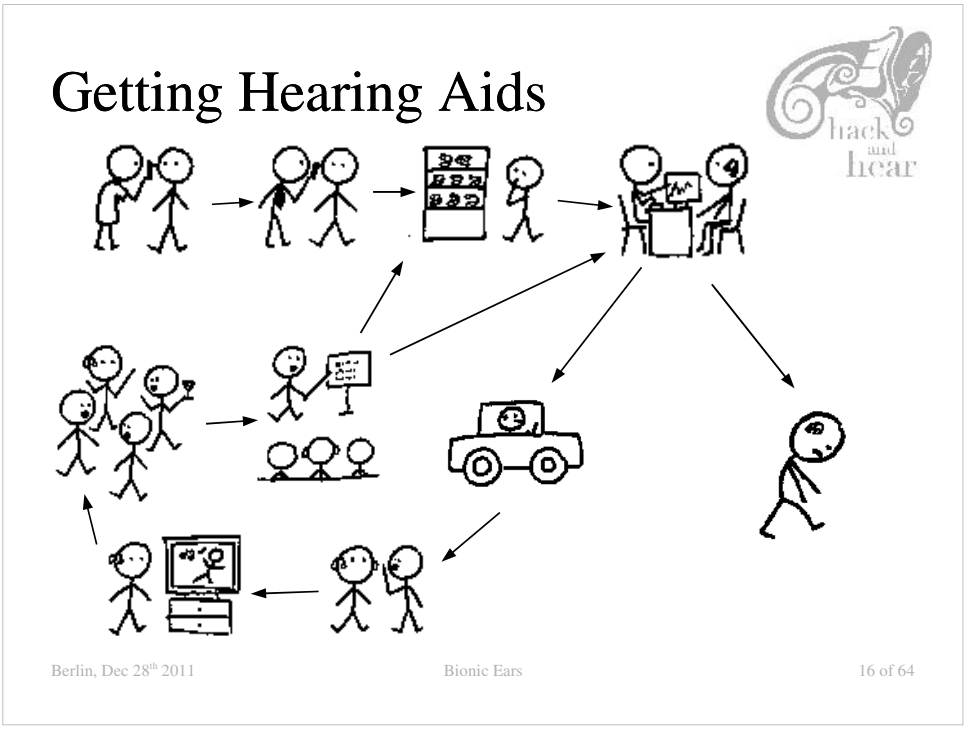


You go to a doctor, he makes some tests with you and sends you to an optometrist to get yourself some glasses.
You go to the optometrists; he makes some more tests with you and determines the parameters for your glasses.
You choose a fancy pair of frames for your glasses from the optometrists shop and order your glasses with the parameters the optometrist determined.
The other day, you pick up your glasses and start being a happy nerd!

Ponies!

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

You are a happy nerd, because you can see …
Ponies!



Getting hearing aids is - unfortunately - not that easy. One day you realize you cannot hear very well anymore. You go to a doctor; he makes some tests with you and sends you to an audiologist to get yourself some hearing aids.

You go to the audiologist and he makes some more tests with you. You choose a hearing aid (or two if necessary) from the audiologists shop. The audiologist tunes the parameters of the hearing aid according to his test result.

But then the fun starts. You start test-wearing the hearing aids for a week or two. During this time, you are supposed to test all common difficult hearing situations. That includes going to gatherings where a lot of people talk to each other, watching a moving, listening to music while driving a car, let someone whisper something into your ear or listen to a talk.

After that testing week, you go back to your audiologist and tell him what bugs you. He either gives you a different hearing aid or tunes the parameters of the one you just tested. And then you iterate and do the testing again. This can take months. It is not uncommon that it takes half a year until you are done with that and even then you will still be not completely happy with them.

Part of the problem is that the tuning is not done under realistic circumstances. The audiologist can only tune what you tell him and he does not have a sample of that particular hearing situation. There is no tuning in realistic circumstances. You don't ride the subway with your audiologists equipment.

Additionally, the brain needs to adjust to the new sensory input it gets. That means the first days (sometimes after every re-tuning) you will have a head-ache and be overwhelmed by the new input. It takes weeks for the brain to adjust to the new situation.

There are also pretty high costs to consider. A device costs 400 - 3000 EUR and the insurance coverage is poor.

Audiologists don't have a good service when it comes to young people's needs. They usually open between 9 to 6 and not on the weekends. As a working person, you will have trouble to schedule all those re-tuning appointments.

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/
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There are (very) roughly 3 types of hearing aids.
In-ear hearing aids are completely located in the ear channel. They are used for relatively light and moderate hearing losses.
Behind-ear hearing aids are the most common type. They are suitable for light to severe hearing losses.
And there are cochlear implants. Those are for very severe hearing losses. Parts of them are implanted in the head and parts of it are connected from the outside.
I will mostly talk about behind-ear hearing aids though.

Visibility of Hearing Aids

Nowadays hearing aids got pretty invisible. Those are pictures of me wearing and not wearing my hearing aids.

You can only see a small wire.

Many people who don't wear hearing aids find it impressive how invisible they are, but when you are hearing-impaired you are not so sure about it. I sometimes wish this handicap was more visible, because when someone talks to you and you have to ask him to repeat it, because you did not understand, that person might think you are stupid, because they did not see that it was an acoustic, rather than a semantic problem.

Size of Hearing Aids

Hearing aids also got pretty small. Those are my hearing aids compared to a 50 euro cent piece. You can also see that most of the space is taken up by the battery compartment.

Hearing Aids

This is a closer look at my hearing aids. Out of curiosity, I took them apart - at least to some (safe) extend. Actually, they are designed in a way that audiologists can change the covers. You can buy them in different colors to match your hair/skin color or your mood.

Unfortunately in the body you don't see that much. There are two microphones and the digital signal processor. Additionally, there is an antenna for the peripheral hardware (I will come to that later).

The speakers are actually in the part which gets put into the ear canal. What you can also see here is that those are open hearing aids. That means around the speakers there are holes that still let in unamplified sound from the outside. This is especially appreciated by audiophile people who like to perceive as much natural sound as possible.

Digital Hearing Aids

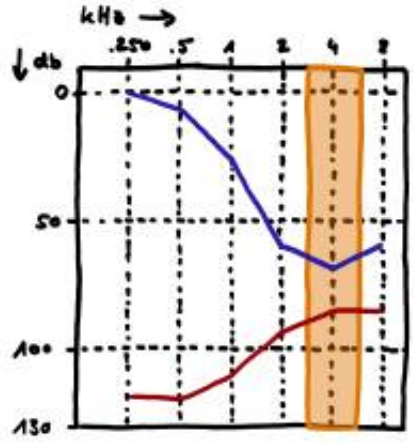
- Standard in first world countries
- Make a lot more features possible
- Real time sound processing
  - analyze signal and react to it instantly

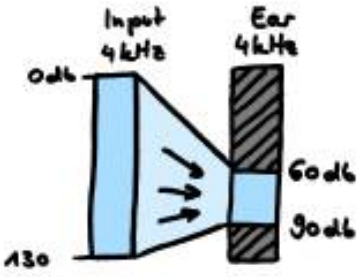
Hearing aids became digital in the last years. By now they are standard in first world countries. With the digital age, the progress they make in development is much faster than it used to be with analog hearing aids. An analog hearing aid of the 90ies was not much worse than a hearing aid of the 70ies.

Nowadays 5 year old digital hearing aids are significantly worse than state-of-the-art hearing aids. Bear in mind that in Germany, you are allowed to get new hearing aids only every 5-6 years.

Some features of hearing aids got only possible because they are digital. In particular, they now have real time sound processing, meaning they analyze the acoustic situation and react to it.

Compression





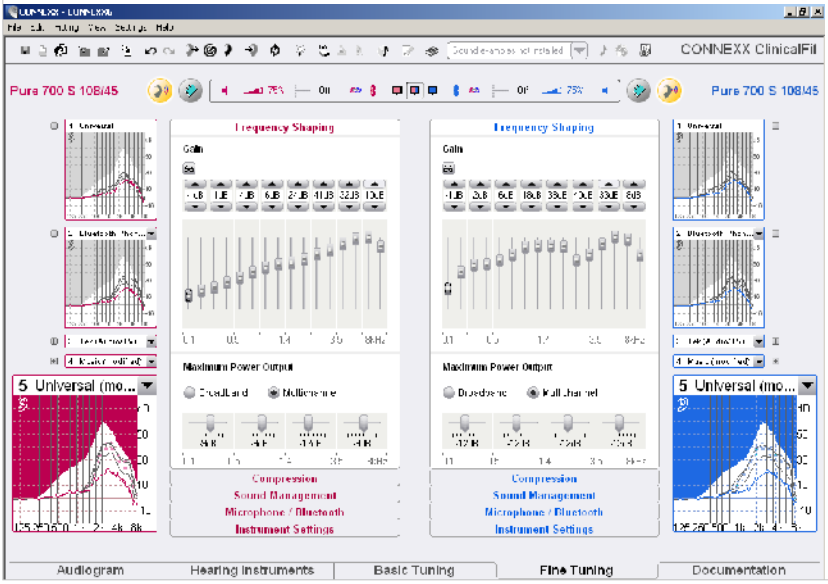
Coming back to the audiogram before, I like to point to a feature called “compression”. Don't mistake that with the term “compression” of mp3 files, that is something (slightly) different.

If you have a look at the audiogram, where the hearing of that person is worst, let's have a closer look at the frequency band around 4khz.

The input sounds of our world range from zero to over 130 decibal. But the range in which it is comfortable to hear for this patient lies only between 60 and 90db.

That means hearing aids should not simply amplify the input signal, they have to compress the range of volume to make it fit into the range the patient is comfortable to hear. This is called compression.

Frequency Shaping

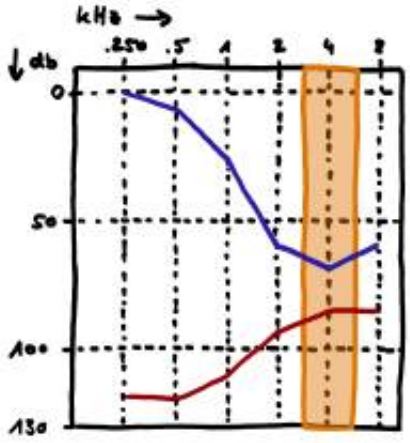


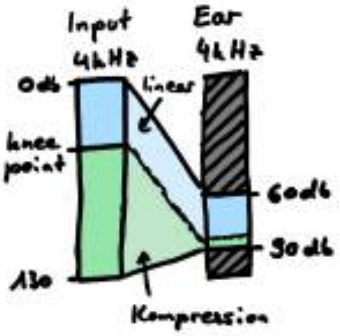
In the hearing-aid tuning software that audiologists use and that happened to end up on my computer, this looks like that.

You have controls for every channel determining how much amplification is needed. So 30db here means “amplify so that it starts at 30db”.

The control “maximum power output” controls the maximum power output of the hearing aids. My hearing aid can create 108db max. If this control shows -12db, it means that 12db are subtracted from the 108db, because it makes me uncomfortable.

Compression





The problem with compression is that it can make the signal sort of fuzzy, which does not really help with understanding speech.

To avoid that, modern hearing aids do not start compressing right away. Instead they amplify the first couple of decibels (sort of) linearly and only after a certain threshold, they start compressing the rest of the domain. The point when compression is started, is called “kneepoint”.

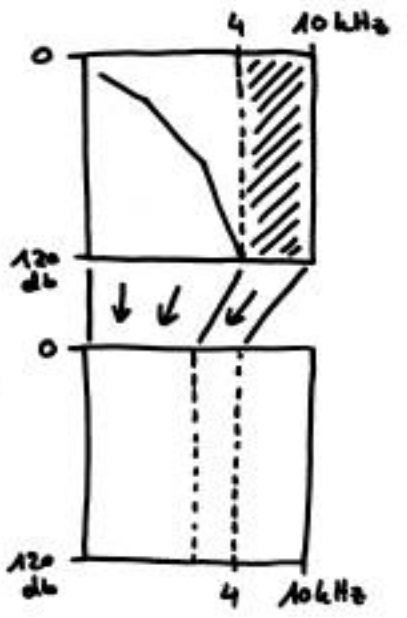
In the hearing aid tuning software this looks like the following. You can specify the kneepoint for every channel.

The second row specifies the compression factor, like 1:4 for example.

The last row specifies the speed in which the hearing aid makes the volume adjustment. “Syll” stands for “syllable” and that means it adjusts the volume in less than the time it takes to pronounce and hear a syllable. “Dual” is the slower variant. That is comparable to how long it takes for a person to adjust the volume manually.

Frequency Compression

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



Compression is a useful features as long as there is something left of the volume range. But some hearing losses affect a complete frequency band. That means that the blue curve pretty much hits the bottom of the audiogram.

In those cases it is useless to compress signals band-wise. Instead the whole frequency domain can be shifted to the frequency domain that is still perceivable by the patient.

This is called “frequency compression” and is a very recent development. Since it overlays one frequency band to another, this works only with “closed” hearing aids, because otherwise you would still hear both, the original and the shifted amplified signal. It is pretty hard for the brain to adjust to that.

Also, there is currently only one brand of hearing aids (Phonak) which offers hearing aids with this feature.

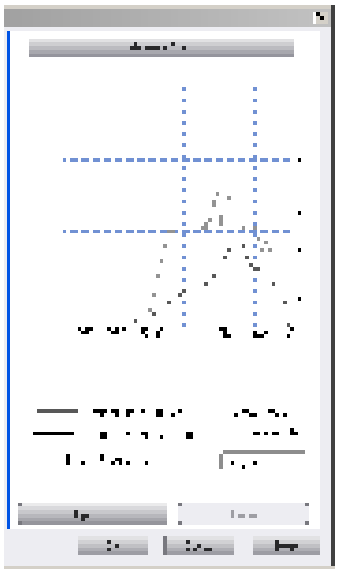
Problem: Feedback Loops

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

Coming to another problem of hearing impairment: feedback loops. Feedback loops are caused when the hearing aid amplifies its own signal. This is in particular a problem of open hearing aids, meaning those which not completely close up the ear channel but also let unamplified signals in. Unfortunately they also let the amplified signal of the hearing aid out. But feedback loops are also (but less) a problem of closed hearing aids.

Feedback loops occur whenever something gets close to the ear. That can be such situations where you wear your hair open or put on a hat. Or you hold a phone against your ear or want to lie down on a sofa. In particularly annoying I find it when people hug me and cause a feedback loop. Especially when they don't know about my hearing condition, they start worry a lot. Not speaking of any other activities where you are close to other people ...

“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

So, what do nowadays hearing aids about feedback loops?

They detect “clear” sinus signals and interpret those as feedback loops. In this case they send an unhearable flag “Oh I detected a feedback loop.”

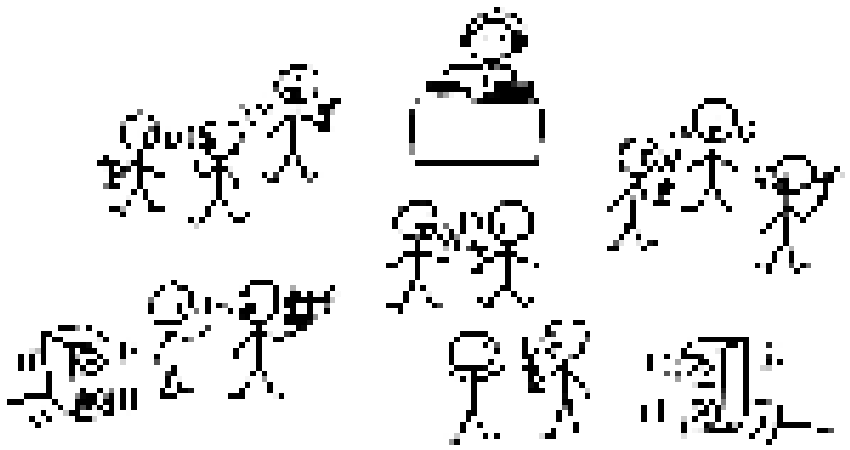
They react to that flag by damping the affected frequencies. This way, they react in real time, usually in a couple of seconds.

The problem with that is: music sometimes contains clear sinus signals. By triggering the damping of frequencies then, your music experience is significantly reduced. Also, the damped frequencies are most often exactly in the area of speech signals, which means whenever you put on a hat and cause feedback loops you are less able to follow a conversation.

Note that analog hearing aids did not have a measure at all against feedback loops.

The screen shot is taken from the hearing aid tuning software showing the feedback loop detection test. This is done while the patient wears the hearing aids. Different signals are played and if they cause a feedback loop the maximum level of output of the hearing aid is reduced. This can pretty much void your carefully tuned parameters.

Cocktail Party Problem



Another typical problem of hearing impairment is the so called “Cocktail Party Problem”. It describes a situation where there is a lot of background noise (for example music) and a lot of people talking to each other. One person is talking to you and you have a hard time understanding him. There are different aspects in this 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

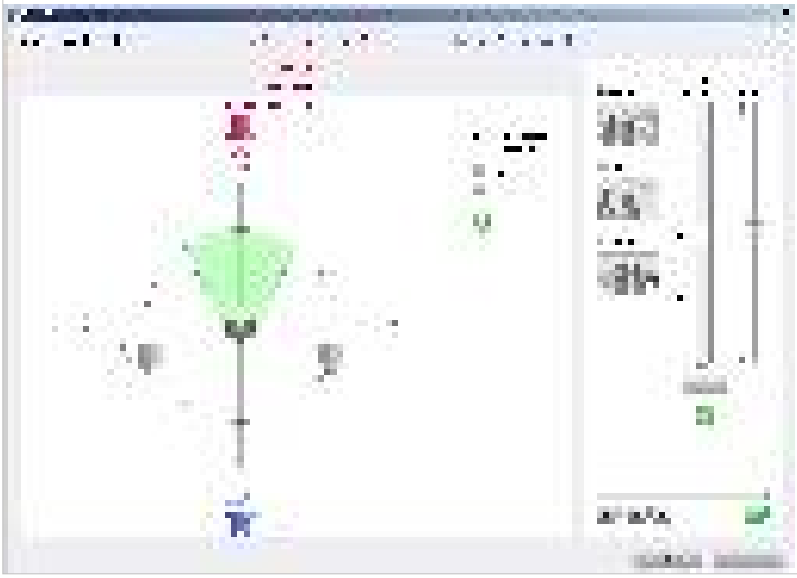
One aspect is the directional hearing. Hearing-impaired people have a hard time making out from which location a sound comes respectively focusing on a particular direction.

The human ear does directional hearing by using both ears and the brain. Addtionally, the pinna (“Ohrmuschel”) does some sort of pre-processing of the signal.

Hearing aids (except for the in-ear ones) don't make use of the pinna, because their microphones are located behind the ears. To simulate directional hearing, each hearing aid is equipped with two microphones. This way they can identify if a signal comes from the front or back. Additionally, hearing aids communicate to each other (if of the same model) so that they identify signal sources from the left or right.

Using these 4 microphones, the algorithms perform a situation recognition and adjust their programs by for example automatically focusing to the front.

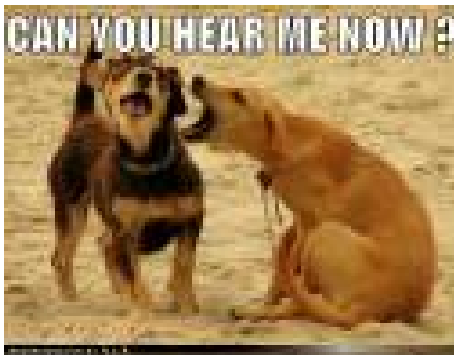
Directional Hearing



This is another screenshot from the hearing aid tuning software. It comes with a real-time monitor where you can test the directional hearing. You can wear your hearing aids while watching that and make some noise in different angles around your ears. It works pretty well in a silent room, but not really on a cocktail party.

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



- Most hearing-impaired people have a problem with the hight frequencies rather than the low ones.
- This makes it particularly hard to distinguish background from foreground noise.
- Low frequencies travel further than high frequencies. That is why you hear the bases of your neighbor's techno party, but not the high frequencies.
- So when something is far away from us, we hear only the bases. When something is close, we get both, high and low frequencies.
- Our brain uses this to determine which signal comes from a source close to us and blends out the background signal.
- Hearing aids are designed mostly focusing on the high frequencies and if tuned well, they amplify those well and enable the brain to filter again.
- Plus they have filters for damping the background noise even more.
- Recognition sometimes fails. Sometimes exactly the person talking to you gets filtered out. Or it works pretty well and you start talking in a low voice and your hearing partner has to ask you to raise your voice.

This is another screenshot from the real time monitor. This time it shows the speech banana (light grey) and where the hearing aid starts amplifying.

It also shows the hearing situation that is recognized by the hearing aids. In this case “music”. I tested this with several different types of music and I must say, if you happen to like death metal, you'll never see “music” here. ;)

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

Berlin, Dec 28th 2011

Humidity is a problem with hearing aids. Most hearing aids are not waterproof. That means: no swimming with friends, no pool parties, no water sports where you have to communicate. Sweat is often a problem, especially for people who do a lot of sports. Also, not audiobooks or music in the bathtub. Plus, you have to be careful when it is heavily raining (like on CCC camps or open air concerts).

Hearing aids have to be dried regularly. If you don't do that you risk trouble with your audiologist and insurance companies if your hearing aids break.

A very recent development are water resistant hearing aids. Phonak offers hearing aids with certification IP67. That means that dust particles cannot enter the hearing aid and you can hold them under water for 30min 1m deep and they won't suffer from irreparable damage. I am not sure what that exactly means, I assume at least that you have to dry them afterwards.

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

Source: http://www.audiologyonline.com/management/uploads/articles/HABootCable.jpg

For hearing aids, there is a market of peripheral hardware. I will present the most common interfaces and what they are used for.

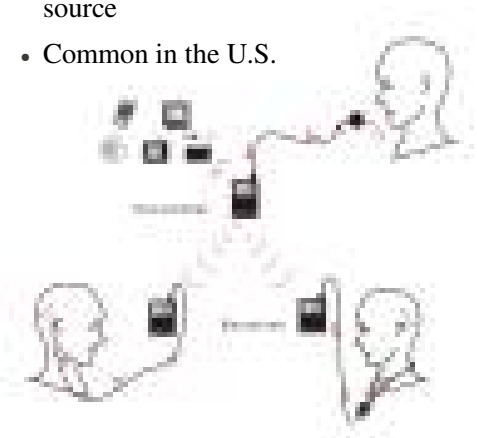
The oldest one is the DAI interface, also called "Euro adapter". It looks like that with three pins. There is a variety of cables available for example to connect it to an mp3 player. This interface is also used to plug in additional adapter to other protocols.

Here you see an example of such a "shoe" that is connected to the hearing aid.

The advantages are that it is a cable, so no interference with other signal. The disadvantage is that it is a cable, so if you connect it to something it could feel like a "leash".

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

Source of picture:
http://www.lovehearing.com/images/FMpic.jpg

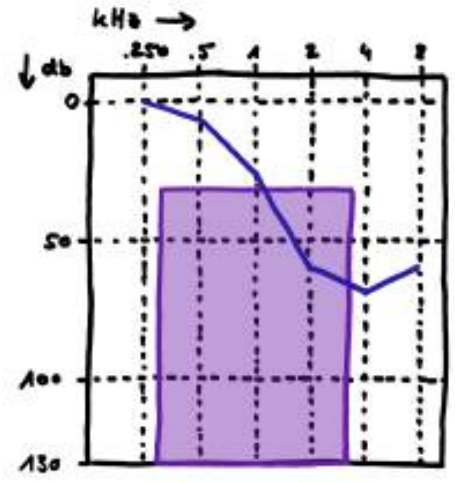
FM systems are wireless systems that use, well, FM. They come in different configurations, but have in common that the receiver is connected to the hearing aids (via an adapter, for example using DAI).

The sender of the FM system is connected to the signal source. There different setups, for example for lecture halls, in cars or for meetings.

I heart different things about the sound quality. It is known to be not bad, but a friend of mine tested it and was not really happy with it.

An audiologist once told me that hearing impaired kids listen to music via FM in class. Teachers called him to asked if they could switch that off because the kids should actually pay attention.

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

An activity that is particularly hard for hearing-impaired people is calling on the phone.

First of all, a lot of hearing-impaired people rely on lip reading as an additional channel of information.

For technical reasons, the frequency range of the phone signal is limited to 300Hz to 3.4khz (blue box in this diagram). If you have a hearing impairment it gets cut even more by your hearing curve.

The background noise does not have this frequency range limitation, which makes it in particular hard to listen to a phone call if you are in a noisy environment.

Additionally, the signal or reception can just be bad for several reasons and you can get feedback loops when holding the phone against your ear.

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, DYI kits available

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

A very old but still common solution to the phone problem is the telecoil or T-coil. It was originally designed for talking on the phone, but is now used for several other applications as well.

The T-coil is a small antenna in the hearing aid (see picture) that receives a signal from an induction loop that is connected to the source. The source can for example be a phone. All phones that claim to be “hearing aid compatible” have an induction loop built in. That includes also quite new phones like the latest Iphone for example.

Induction loops are widely used in Europe and especially Scandinavia. Most public buildings, especially lecture and concert halls are equipped with them.

They have the disadvantage that there is interference with other signals like for example lamps or other wireless signals.

There are DIY kits for building your own induction loop available.

Bluetooth

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

A rather recent solution to the phone problem is to turn your hearing aids into a bluetooth headset. Unfortunately, there are currently no hearing aids on the market that have bluetooth build in, mostly because it consumes too much battery. I am pretty sure this will change in the future. I heart of people living near the Siemens development lap that are testing prototypes with bluetooth already.

There are some solutions using adapters. The connection between the hearing aid and the bluetooth speaking gadget is usually done via DAI, the T-coil or 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

This is an example of such an adapter. I find this particularly interesting, because it combines all interfaces I have talked about so far.

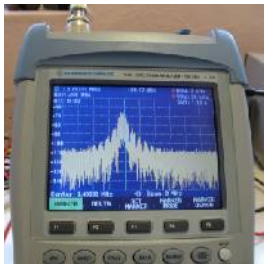
It uses the T-coil to talk to the hearing aids. The induction loop is the loop that you use to hang it around your neck.

It has bluetooth build in. You can add an FM receiver using a DAI plug or you can connect a sound source using the aux-in socket.

It comes with a warning for people who have pace makers. I think this is something that will cause a lot of problems in the future. We will get more and more like Cyborgs and will have to fight compatibility problems all along. I doubt that all hearing aid manufacturers will test their hardware against all available pace makers.

I have a friend who wears this and has a pace maker. He just ignored the warning and luckily he is still alive. But you have to be aware, this might be a very subtle way to kill people in the future.

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 tra TV
- costs: 400 EUR (no insuran
- new version “mini tek”

Bionic Ears

Source: http://hearing.siemens.com/en/04-products/20-minitek/minitek.jsp

Siemens of course provided a solution that ignores all common standards and invented something new, proprietary and totally incompatible device. Their solution for this is called “Siemens Tek”. It is a bluetooth adapter and a remote control at once.

Typical for Siemens, instead of using any of the standard interfaces, they invented their own near field communication protocol to communicate between adapter and hearing aids. I measured the signal, it is around 3.3Mhz.

The same protocol is used for the hearing aids to talk to each other, for example if I switch between the programs on one hearing aid, the other one gets switched as well.

The Tek is compatible to everything that speaks bluetooth (in theory). I tried it with a lot of different devices and I must say, the compatibility really sucks. For mobile phones, you have to try that to make sure the quality is good. Even worse for land line phones.

It comes with an additional transmitter (similar to FM systems) that you can connect to a more distant source (for example TV).

It is quite expensive (400 EUR) and since insurance companies consider it as unnecessary to be able to talk on the phone, they don't pay a single penny of it.

Siemens was so clever to bring a new version of the Tek on the market, called “mini tek”. It has even less features than the old version (no display), but they still charge 400 bucks for it and you don't get a discount if you already bought the old one.

Siemens Tek w Transmitter

This is the setup with the additional transmitter. I use this setup often to watch a movie during long train rides. The battery of this adapter also sucks, sometimes it does not even last the 5 hours that it takes to travel from Munich to Cologne.

The signal quality of the Tek with a well selected source is usually not bad, but it has the disadvantage that whenever you move away from it, there is a “cracking” sound. That means you cannot really use it in a dynamic setting, like when listening to music while jogging. It sort of defeats the purpose if you use a wireless device that can only be used in settings where a cable would do okay, too.

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

Out of curiosity, I took my Tek apart. Well, not surprising you see some proprietary chips, the display and the quite big antenna for the wireless protocol.

Regarding security: the Tek must be coupled with the hearing aids using the hearing aid tuning software. It is sufficient to provide the 7-character serial number there. There must be some kind of authentication. I tried to use my hearing aids with an uncoupled Tek, and it did not work. I actually doubt that the communication is strongly encrypted, because latency is crucial for the audio signal and cannot afford additional load by encryption

I guess it is also possible to hack the bluetooth communication. Of course it comes with the creative bluetooth pin of “0000”.

Not directly related to the Tek, but still: the hearing aids talk to each other. When I switch between the programs on one hearing aid, the program gets switched on the other one as well. The only authentication here is the wireless channel on which they are communicating. It can happened that if you are close to another person wearing the same model of hearing aids, that you cane switch their programs, too. The only fix for that is to let the audiologist switch the channels.

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/

When I started to dig into the “hearing aid” topic, I was hoping that there are people who hack them. Unfortunately, a hacking scene in this area is barely existing. I think this is because the devices are very expensive, the insecurity of losing insurance coverage (if existing anyway) scares people.

There is one forum in the internet “hearingaidhacks.livejournal.com” which goes into the right direction, although the hacks shown there are very cautious. Most of the entries are people asking for technical advice regarding the compatibility of devices with peripheral hardware.

If there is any hacking, it is on the peripheral hardware. I will show two things here.

A hacker named “Gertlex” on flickr hacked a Sony bluetooth headset so it would connect to the DAI interface of his hearing aids. He provided quite nice documentation in his flickr stream.

DYI Bluetooth Adapter

by Gertlex

49 of 64

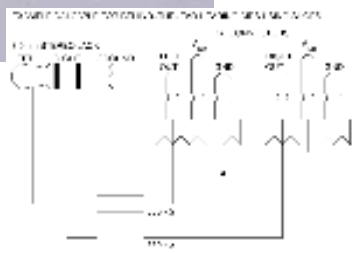
This is the same hack. I'd like to point to the upper right picture. Here, he tested the setup and he was very careful.

He did not use his current hearing aids, but an old one. He did not put it in his ear when testing it and he even used an old mp3 player, because he was afraid of frying that as well.

This is the level of precaution that is necessary when hacking cyborgian devices.

DYI Bluetooth Adapter

by Neil Ferguson



Source: http://gfern.com/btha/btha.html

This is another bluetooth adapter hack. On the right upper picture you see the "ingredients", a bluetooth headset (mono) and DAI cables. He built a bluetooth adapter with it and even provided a nice diagram of the cables.

As I said, the hacking scene with respect to hearing aids is rather small. A related and interesting field is the “self-tuning” or “auto-tuning”. Those are people that are frustrated by the work and the service of audiologists and therefore start tuning their hearing aids themselves.

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

For tuning hearing aids, one needs a special piece of hardware called “hipro”. It exists in a serial and lately also in a bluetooth version.
The software used for tuning is called “Noah” and each hearing aid manufacturer provides its own module for their hearing aids.
Both, hardware and software is only sold to doctors and audiologists. Since it is classified as medical equipment, it is not allowed to sell those on ebay for example.
Nevertheless, there is a self-tuner scene and a black market for the hardware and software. Prices start at a couple of hundred euros for a hipro. Or course, when you self-tune your hearing aids, you have no customer support from the vendors and no warranty for the devices. Especially, you risk frying your hearing even more if you make mistakes.
There is one excetion: in the U. S. there is one company that sells hearing aids and provides a hearing aid tuning software. The hearing aids are in the low budget area and they come pre-tuned according to the audiogram that the patient has to send it. The patient then can download a software and tune that.
Everyone else has to enter the self-tuner scene.

Hipro (Serial Version)

I did some social engineering and somehow a hipro ended up in my hands. Here you can see the setup. The hipro is connected on the serial port to the laptop and the hearing aids are connected to it via a special cable.

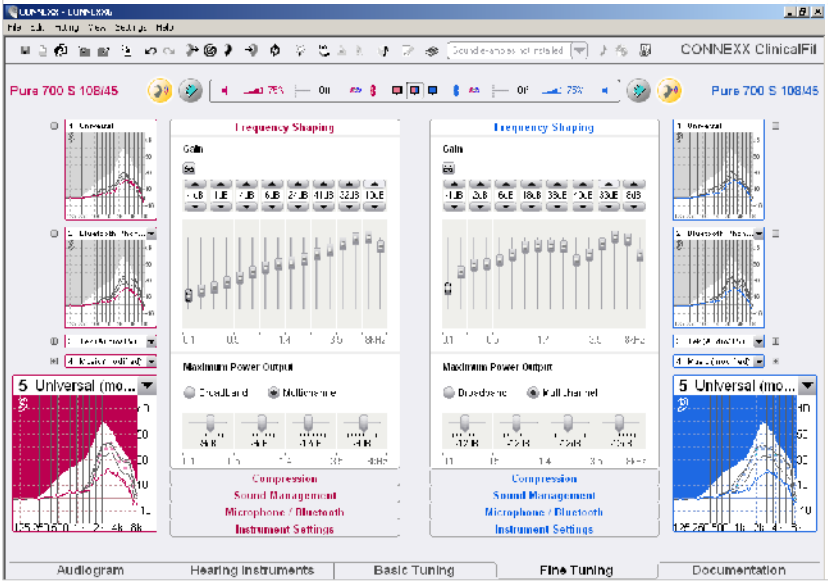
Hipro-HA interface

This is a close-up of the connection between the hearing aids and the hipro. You have to remove the battery and in the battery compartment the end of a flat cable is inserted. The flat cable then connects to the hipro's cable. The flat cable is different for every hearing aid model. So whatever channel you use to get a hipro you have to make sure you get the right cables for your hearing aids as well.

Hipro (Bluetooth Version)

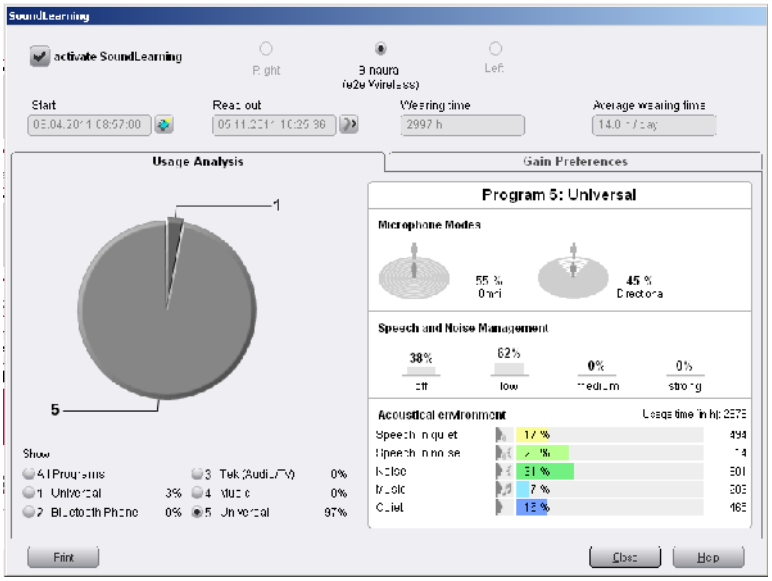
There is also a bluetooth version of the hipro, which also ended up in my hands. The hearing aids are connected to it the same way as for the serial hipro. You can wear the hipro around your neck, not being on the “leash”. Technically with this and a laptop you could go out in the field and do the tuning in the subway or any other realistic environment.

Tuning Software



Another glimpse at the tuning software which I showed throughout the talk.

Big Brother



When I was playing around with the software, I discovered an interesting feature. My hearing aids are actually spying on me. It monitors my usage behavior, for example how many hours I wear them per day, how much time I use different programs. For example I use program “1” only when wearing a hat to avoid feedback loops. It also shows how often the microphones work in the directed mode or not or how much noise management was performed by the hearing aid.

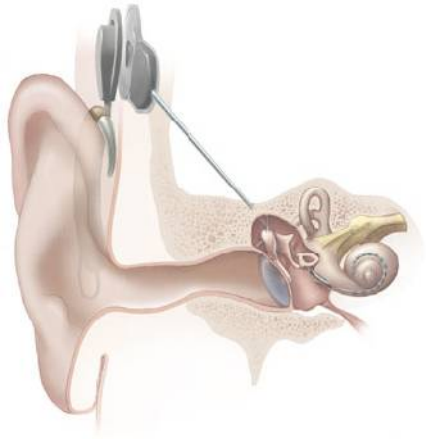
Cochlear Implants

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 are a special type of hearing aids. Here, a part of is implanted in the head and another one is worn outside, behind the ear and attached to the head via a magnet.

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

In my opinion, cochlear implants are the closest thing to the "future". They literally make deaf people hear. During the surgery, the internal part of the implant is implanted and a wire is attached to the hearing nerve.

The surgery destroys any remaining hearing. Therefore, cochlear implants are only applied to people with less than 30% hearing.

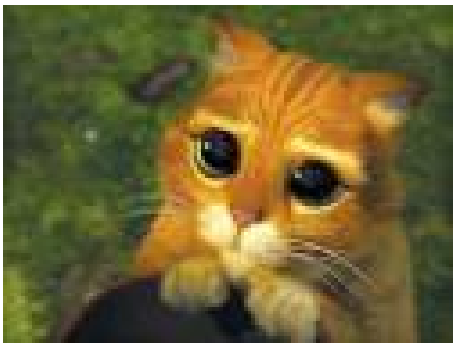
The hearing itself is significantly different. The patient's brain has to adjust to it for quite long time.

The technology in cochlear implants is usually 5 years behind regular hearing aid technology. Of course, also in this area, there are no standards or interoperability between brands. If you have chosen one particular cochlear implant, you are stuck with this company.

I will play an audio sample in my talk of how it is to hear with cochlear implants with different channels.

Conclusions

Want!



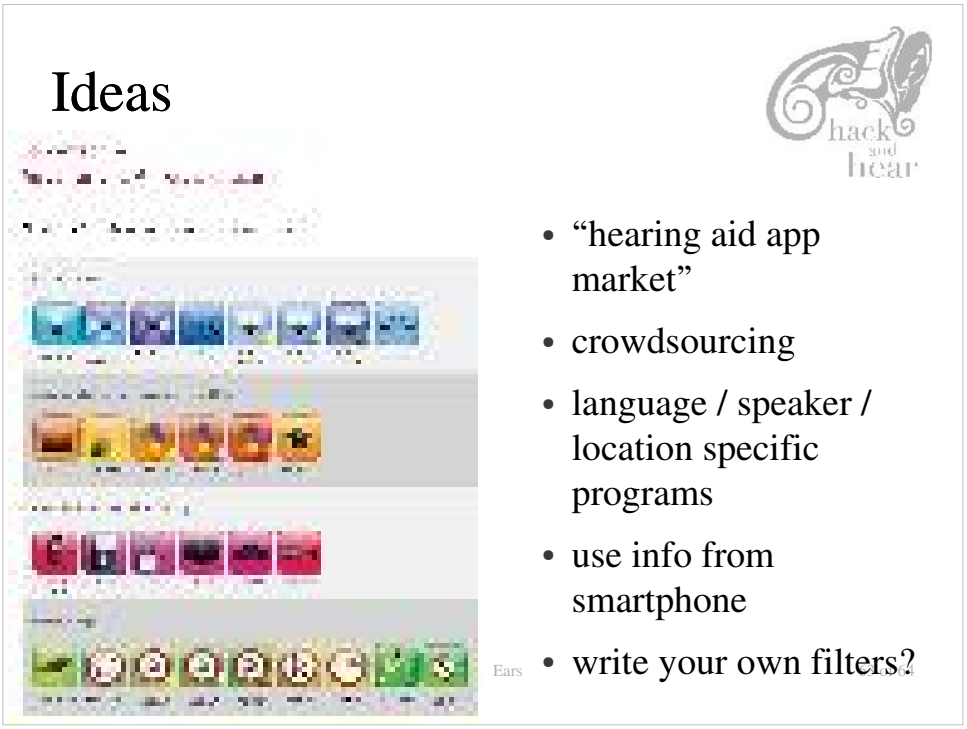
- better service
- consideration of young people's needs
- better signal processing
- (open) standards

Before finishing my talk, I like to summarize by pointing out what I am missing from the hearing aid industry. First of all, I need better service. Audiologists are totally targeting elderly people. That means they have opening hours that you cannot use unless you are unemployed.

Generally, the hearing aid industry totally forgets about young and technophile patients that actually want to use all the gadgets that are out there and of course connect the hearing aids to it.

Better signal processing! Given the size of the devices, the signal processing of nowadays hearing aids is already pretty cool. But unfortunately, reality shows that it is not enough. Especially the cocktail party problem is not solved. Often hearing-impaired people simply avoid gatherings because they cannot understand people there anyway.

It would be really nice if the different vendors would agree on more standards, and make those standards free in particular. It would be really great if you for example could program your own filters for your hearing aid.



My dream is some sort of hearing aid app market where you can download and share your filters. Funnily, at least the hearing aid vendor's marketing has seen this trend in the mobile phone market. This image here is taken from Phonak's marketing material. They talk about “apps” here, but actually those are just “features” of hearing aids. There is not “app market” and you cannot like update or add new apps to your hearing aids.

It would also be cool to have open hardware standards so that you for example could print your own hearing aid with a maker bot.

Additionally, I wish that hearing aids would work better together with existing consumer hardware, for example smart phones. For example my hearing aid has 5 different programs for different hearing situations. To cover my needs, I needed much more, but the hearing aids are too small to accommodate them. An idea would be use load those programs on your smartphone and whenever your Google calendar says that you are now in this meeting room load the programm up in your hearing aids.

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 ...

Thanks for listening!

I also like to thank a couple of people for their support around the creation of my talk!