DIGITAL HEARING AIDS: THE COCHLEAR APPROACH

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Abstract

One may encounter numerous forms of hearing losses in daily life. From conductive to sensorineural form of it, there has been a strong surge to develop compensating means which could stand sufficient, both on the performance and the economic scale. From the seventeenth century itself, hearing aids had made their presence felt as a gift for the impaired, but the aspect of their bulkiness, high cost and relatively lower flexibility and poor efficiency overshadowed them. Over the decades, digital domain's utilization for hearing aid's operation has curbed the mentioned drawbacks significantly. The present paper deals with the details of how a digitized counterpart scores over the obsolete ones and also how measures can be incorporated to effectively utilize the frequency spectrum in order to curb the hearing impairment density across the globe. Several simulations were carried out over a cochlear prosthesis simulator and results on a comparative basis were tabulated too. The authors have also concluded that this adaptive digitization in the implementation of cochlear hearing-aids possesses good future potential.

Keywords—ADC, ALD, Decibel, DFR, Digital domain, Digital Signal Processing, DNR, DSE, FPGA/ASIC block, Sensorineural, Speech Enhancement, SNR.

1. Introduction

From 10,000 BC to 1700 AD was an era where human ears remained relatively pristine to external factors that could prove fatal to human health. Nothing could hamper one's ability to hear unless he got eaten by a carnivorous animal and instances of this sort. Following two centuries, saw ear trumpets being used by some hard of hearing people, which also didn't mark the indispensable need for hearing aids. Even the 19th century popularized silent (captioned) movies which enabled the hard of hearing clan to easily interpret whatever was being conveyed. But in this century itself, the first electronic hearing aid was patented. To anybody's surprise in the present time, it was bulky enough to utilize a chair as its root-mechanism. Talking pictures were promoted and captions were banned throughout. This was a boon for the entertainment sector but a bane for the human-health's perspective.1950s brought the telecoils (coiled structures to revive reception) and 1960s the Behind the Ear (BTE) Hearing Aids [1][2]. Since then, in the form of In the Ear (ITE) Hearing Aids, Amplified Phones, Assistive Listening System, invention of Cued Speech, technology took off and never looked back since then. But the major milestone was achieved with the introduction of Cochlear Implants [1][2]. At the outset, the log-domain analog cochlear implants were brought to light, but have seen constant tremendous shrinking, becoming in-the-ear and in-the-canal devices and almost invisible over time with the shift in utilization of the digital domain. A few of those reasons and modifications have hereby been discussed.

2. The Present Scenario

A. Classification

The hearing loss as known to the society today can be classified into two major categories—conductive and sensorineural [3]. Conductive hearing loss (CHL) occurs due to mechanical problems that appear in the outer or middle ear. Following which, the ear ossicles may fail in directing sound vibrations properly. Or, the eardrum may cease to vibrate normally in response to the incoming sound. Persistent fluid in the middle ear is also a contributor to this form of hearing loss. Sensorineural form of hearing loss (SNHL) appears as a result of troubles with the inner ear. It mostly observed when the nerve endings in the ear that conduct sound in the ear are damaged, diseased, work unexpectedly, or have worn out. Mixed Hearing Loss is another classification, when the malfunctioning lies in all: outer, middle and inner ear's neural path. An example of a mixed hearing loss may be the temporary appearance of glue in the ear in a child who has a sensorineural hearing loss caused by meningitis. The sensorineural loss is more prominent in our society today [4]. Deafness, profound hearing loss, is now a global problem which in turn is a consequence of these forms of hearing losses.

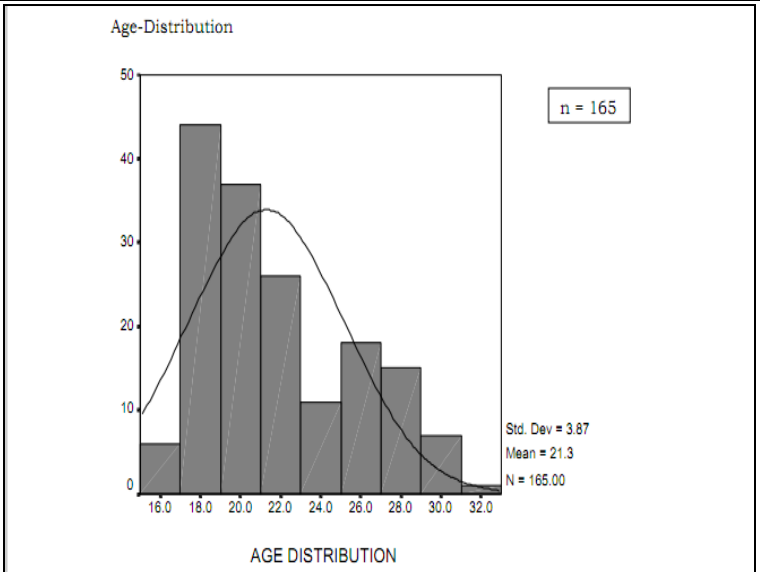
However, the causes of, attitudes toward, and management options for deafness (extreme state of hearing loss) differ considerably from region to region. A study seeks to identify the present causes of profound sensorineural hearing loss in Indian society particularly [4], which in our environment is almost synonymous to a life sentence of silence and isolation.

Out of the total 165 respondents in that study, 58% were male and the rest were female. 34% respondents possessed their own cell-phones, mp3 players and other entertainment medias for more than two years while 64% had purchased it recent times. The statistics only seem to worsen in the rural sector. Age-wise distribution observed is as given in Figure 1 [5]:-

With these statistics swelling every year, hearing impairment has been of prime concern for the society and so is the need for devices that could aid the disabled in reviving hearing.

B. Diagnosis and Cure

If a person is exposed to loud noises at work or listen loud music, then it can cause severe and irreversible damage to his ear and in turn to his hearing ability. It can be prevented by wearing earplugs during working hours. Moderate exposure cases lead to wax blockage in human ears which can be curbed with mustard oil, baby oil etc. If hearing loss has occurred due to ageing (presbycusis), then it can be cured by means of a hearing aid. Doctor's consent and medicine are indispensable in either of the cases.



The bi-modal distribution of age reflects that there is a slight skew towards the 15-19 year old age bracket.

Figure 1 Age and the usage: The age-wise distribution as per the statistics gathered after carrying out a number of surveys.

C. The three big questions facing the youth

1) How can I tell if the volume on my iPod or MP3 player is loud enough to cause hearing damage?

One can make use of three simple measures to see if the volume on the personal music player is set too high: If you are playing something over it and can’t hear somebody talking to you at a normal voice level from a distance of three feet or less, it’s certainly too loud; if a person next to you can hear the music emanating from your headsets (music device), it is indeed too loud; and if you have to scream out to hear yourself while talking and listening to music, it is way too loud.

2) What’s worse? Ear buds or over-the-ear headphones?

It is advised that ear buds could bring in more of a potential threat to listeners because they sit closer to the ear out as effectively as traditional headphones. Ear buds, that don’t block out noise well may cause the user to turn the volume up, which could lead to hearing loss over a period of time. However, experts believe that listening to music beyond optimum levels and that too for hours, presents a risk, no matter what type and quality of headphone is worn.

3) How long does it take for my hearing to get damaged from listening to a personal music player?

Listening to a music player at moderate levels likely will not pose problems. But higher volume levels bring forth the cons. One might face increased risk of permanent hearing loss if music is listened for 45 minutes or more per day that itself is so loud that someone at an arm's length must scream to be heard. Listening to music for five minutes a day, loud enough that a person must shout into your ear to be heard, will pose dire consequences [7].

D. Frequency spectrum utilization: a proposal by the European Union [8]

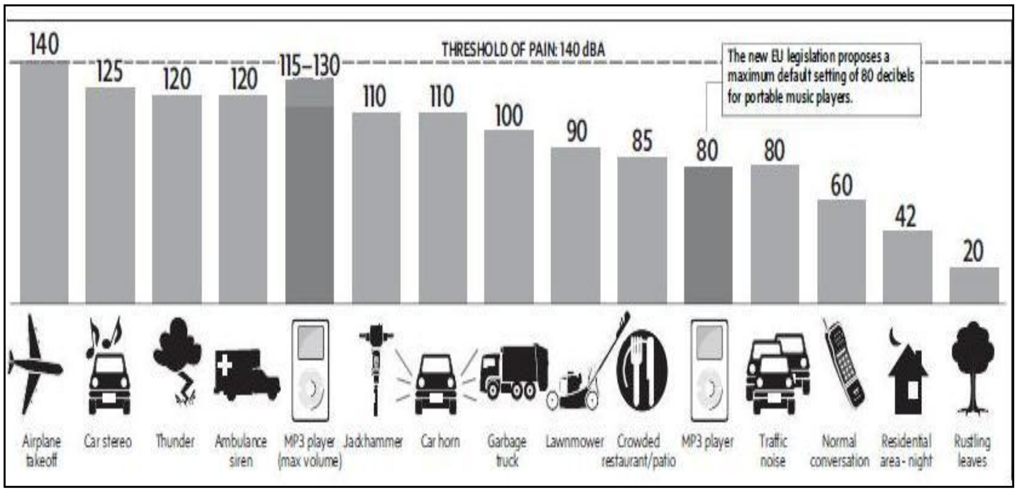


Fig. 2. Comparative chart: Decibel levels and the threshold level of pain in ear- a relative representation as has been put forward by the European union.

If we carry out the relative study of these proposed levels with the frequency thresholds, it is observed that chronic exposure to sound levels of greater than 20 decibels and ranging up to 50 decibels is sufficient to cause mild hearing loss in humans. An increment of 20 decibels each will lead to moderate and severe hearing losses respectively. Levels greater than 90 decibels contribute to profound hearing impairment.

3. Digital domain: Why is it the ground today?

Plethora of features and evolution bound digital signal processing schemes available in current digital hearing aids, which do possess distinguished advantages over those seen in analog counterparts. Potential digital domain advantages are [9]:

Gain Processing, associated with modifiable gain-processing methods is the potential for enhanced audibility of sounds vibrations of one's interest without unnecessary discomfort resulting from higher decibel levels. Moreover, Digital Feedback Reduction (DFR), the most popular feedback reduction schemes keep a check for the availability of feedback, while the person is putting on the hearing aid. Moderate feedback is then decreased or entirely removed with the use of a cancellation system or notch filtering [10].
Digital Noise Reduction (DNR) is another scheme in digital signal processing which is implemented to decrease gain, usually at the lower frequency ranges, when noise signals are picked up. While directional microphones can curb the levels of background jitter regardless of what its temporal content is, they are limited in operation from behind or from the sides of the listener. Additionally, Digital Speech Enhancement (DSE) systems intend to enhance the relative

strength of some selected parts of the speech. The form of DSE processing being utilized today identifies and boosts speech signals based either on temporal, or more recently, spectral content. DSE in hearing aids is a relatively new concept, and its effectiveness is relatively pristine.
Directional Microphones and DSP support directional hearing to improvise the effective SNR provided to the user and is quite popular. Although, it has been observed that combining DSP technology with directional microphones, do add to the overall enhancement to a certain extent. In certain cases, DSP is used in calibration of microphone devices, manipulate the shape of the signal's directional pattern, auto-switching between directional and omnidirectional modes of operation, and curb additional circuitry which adds to inclusion of noise signals [9][10].

"Current digital hearing aids are certainly exciting, and the future possibilities are endless. Before long, digital hearing aids will replace their analog counterparts altogether."

- Todd A. Ricketts (Asst. professor- dept of hearing and speech sciences, Vanderbilt University and director of the Dan Maddox Hearing Aid Research Laboratory.)

A. The basic digital hearing-aid: Block diagram approach.

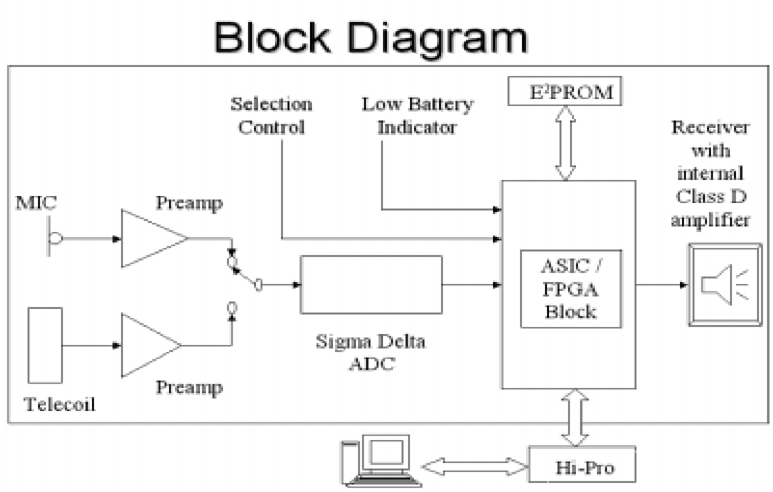


Fig. 3.Aid model: Block diagram for the basic programmable hearing aid model.

The block diagram of a generalized digital hearing aid is as shown above. The design stands programmable where in, the output of microphone is amplified and fed to FPGA/ASIC block. This block manipulates the received digital data and generates a digital output. The microphone device captures the the speech signals converts them to electrical variations. Tele-coil has been employed to sense the magnetic field produced by the hearing aid compatible telephones and Assistive Listening Devices (ALD) and transform them into electrical vibrations. They serve as an auxiliary input and utilized to curb higher background noise levels. The pre-amplifier, as the name suggests, amplifies the signal. An ADC converter is required to convert the analog signals to digital form. Following this, processing is done in the digital form only. Making use of over-sampling technique along with an apt noise-shaping circuit, sigma delta ADC increases the effective resolution of the signal. The FPGA block gets the data and accumulates it. It alters the digital signal and forwards it to the an amplified receiver, which converts the electrical variations to speech. For the purpose, usually Class D amplifiers are utilized. HI-PRO consists of a level converter and an appropriate algorithm implied for providing serial communication between computer systems and Hearing Aid devices.

B. A cost effective model proposal

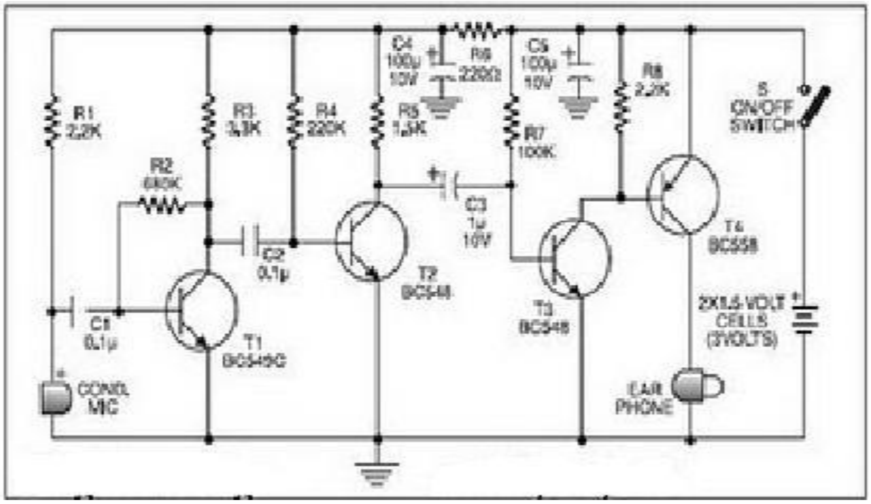


Fig. 4 An alternative circuit: The circuit diagram to the low cost model of hearing aid and could prove in handy if improved upon further.

Hearing aids available in the market today are quite costly. They range from several thousand rupees to even more, in the Indian scenario. A relatively cost effective hearing aid circuit that utilizes only four BJTs and a few passive components like capacitors and resistors, earphone, microphone and on-off switch. Enabling or closing the switch S to 'ON' position, the microphone depicted would receive the speech signals, which is further boosted by BJTs T1 and T2. Further, the amplified version of the signal is fed to the coupling capacitor C3 to the base of BJT T3. It is then boosted by a pnp transistor T4 to drive a low impedance earphone. Capacitors C4 and C5 in the circuit are meant for decoupling the power supply. This simple circuit can be assembled over general-purpose PCB with ease. It has been tested to operate properly at a 3V DC input [11]. For this, one may use two small 1.5V cells commercially available. The switch S can be kept open when the circuit is not in use. In order to enhance the microphone sensitivity, place it inside a small tubular structure.
This circuit would cost around Rs 65 going by the standard commercial prices of electronic devices.

4. How Cochlear Devices Are A Savior ?

A. Basic operation

The hair cells in the inner ear are responsible for transmitting the neurons which interact with the nervous system and results in hearing. If these hair cells are damaged then it results in hearing loss and this can happen because of congential disorders, menire's disease or by many other causes. So to make up for this hearing loss we can electrically generating the auditory neurons. Here cochlear aids come into picture.

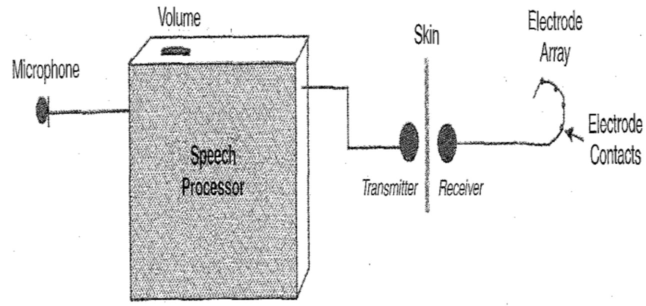


Figure. 5. Fundamentally speaking: Basic cochlear device operation model.

The above figure shows the operation which consists of a microphone that receives sounds which are converted to electrical signal by a speech processor which are then transferred to electrodes, a part of the cochlear aid. Hence cochlear aid can be of two types:-single channel implant consisting of one electrode and multichannel implant consisting of several electrodes. Multichannel implant is better because in that different electrodes can correspond to the different frequency present in the received sound. Thus cochlear hearing aid generates the required neurons which are interpreted by the brain as sound whose loudness depends upon the stimulus current [12].

B. Factors which influence the operation

The cochlear implants work differently as per:
1. Position of the electrodes and the relative spacing between them affects the stimulation process. Implants differ in a way that in some electrodes are extra-cochlear and in others they are intra-cochlear.
2. The type of Simulation may be-analog or pulse form. In the former one analog waveform is presented to the electrode while in the latter pulses are presented to the electrodes which are extracted from the waveform itself. Analog simulation involves a disadvantage of increasing the interactions among the channels (electrodes).
3. The transmission link decides how the wave is propagated from the processor to the electrodes. There are two ways:-
(a) Through a transcutaneous connection-It transfers the stimuli through RF link which involves using a transmitter and a receiver which is placed in the ear.
(b) Through a percutaneous connection which transfers the stimuli through plug circuits.
4. Signal processing techniques aimed at preserving waveform information, some at preserving envelope information and some at preserving formants.

For someone to put on a cochlear device, it is a must that
there should be a profound hearing loss of 90db or more and hearing loss should be in both ears[12].

C. After the implantation of the device

After a cochlear hearing aid is implanted, person undergoes some tests so that evaluation of its hearing abilities can be made. They are evaluated against monosyllabic, vowel, consonants,

sentence tests. Monosyllabic tests are the most difficult and they basically help to evaluate the performance of the aid while sentence tests are the easiest ones because in those tests a person can guess the remaining words in the test by his mental ability.
Beyond this, the functionality and performance of an implant holder depends on several factors. These include duration of deafness prior to implantation, age of onset of deafness, duration of cochlear implant use, electrode placement, signal processing strategy etc.

5. Experimental Approach To Cochlear Design

The authors utilized a simulator, namely Tigercis to observe the influence of several parameters on a digital hearing aid design in this very domain.
In majority of cochlear implant speech processors, the voice signals are bandpassed into different frequency ranges, the envelope in each range will be detected by rectification and means of a lowpass filte. The amplitude thus obtained will be converted to electric current by a pre-defined algorithm. The electric current will be delivered to implanted cochlear electrode. Tools like Noise vocoder or sinewave vocoder provide important tool to understand the effects of speech processor parameters on speech performance in normal-hearing listeners. In them, the voice signals are bandpassed into different ranges. The parameters which can be adjusted include the number of frequency channels, gain in decibels, corner frequencies, slope of filters, carrier type and a wide range of pre-defined processors. Sounds can be tested as per one's own choice by simply browsing to the required destination of storage. This simulator helped in simulating and observing the behavior of a live cochlear hearing device to the closest proximity possible. Grades in the range A-F were provided to the observed simulations. The same has been computed on a two point scale of fidelity points, where A=12 points, B=10 points and so on further.

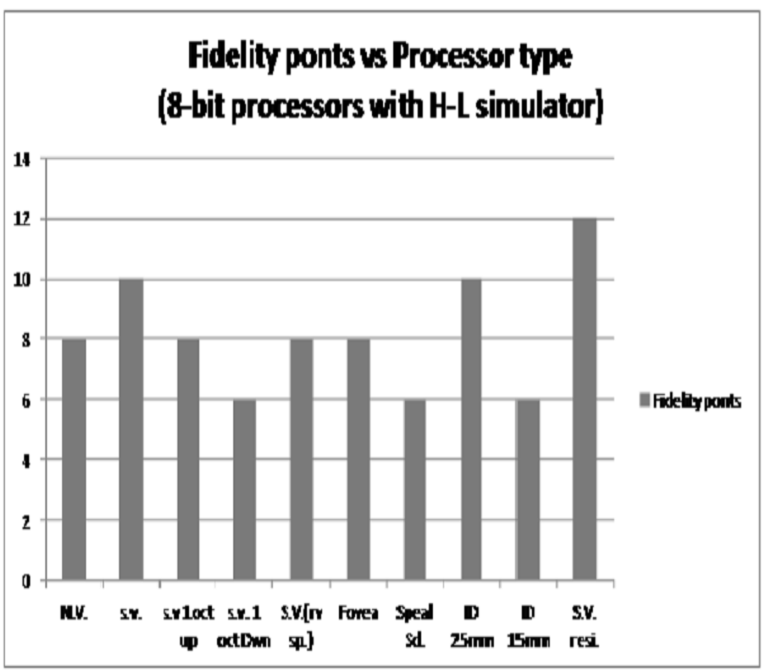


Figure 6. Chart1: Variation in fidelity of output sounds observed with different processors when H-L simulator was used.

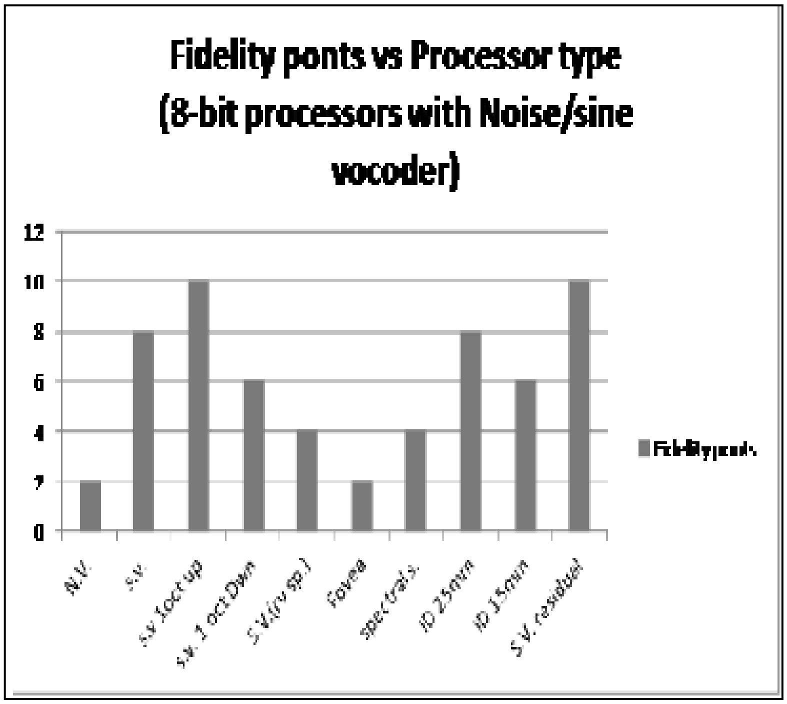


Figure 7 Chart2: Variation in fidelity of output sounds observed with different processors when Noise/sine vocoders were used.

The results obtained from this comparative study have been incorporated as conclusions to the experiment.

6. Conclusion

With numerous forms of hearing impairment appearing in human beings at some stage of life or the other, there is an indispensable need for hearing aids. Statistically, youth are the worst hit of all categories of people. Demand is for smaller, cheaper, robust and user-friendly too. Digital hearing aids provide all this and score much above their analog counterparts. One cost effective model has also been illustrated. H-L simulator provided with better fidelity of audible simulated output as compared to the equivalent processor counterpart with S.V/N.V processors. The noise vocoders infested along with white noise as a carrier in all the cases added large amount of dimness to the original sound. This was never the case with HL simulator options. Increasing the channels, gain in decibels added to the improved fidelity. The opposite hampered it, for both the types of simulators/vocoders.

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