Correction of Ear Amplitude Characteristic Damages Caused by Natural Aging

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Abstract — **Ways for correction of ear characteristic for persons with damaged hearing caused by natural aging are considered in the paper. Possibilities of application of correction methods during listening of television and radio programs as well as during using mobile phones are analyzed. By corrections of intensity and frequency domain of characteristic of processed sound it can be obtained that persons with damaged hearing have achieved audibility with preserved needed understandability. Adjustments of necessary sound level are based on data of hearing damages for control group of persons with natural damages. Efficiencies of performed corrections are confirmed by measurements in characteristic points on the frequency axis. Obtained results show that in the real time can be provided quality hearing of the sound of dedicated emissions of television and radio where the frequency characteristic for the correction is directly implemented.**

Keywords – hearing damages; correction of ear characteristic; hearing damaging by natural aging; frequency characteristic of ear; quality real time hearing of sound; software corrections

I. Introduction

Amplitude characteristic of ear is different for each person. For higher hearing damages it is needed to perform individual corrections of such characteristic using hearing devices. However, from a set of research results of hearing it is obtained one set of hearing parameters that can be classified by different criteria. One of unavoidable parameters is influence of person age on ear frequency characteristic shape.

Mechanism of hearing sense enables creation of impression of sound picture in the minds of every person and covers recognition and interpretation of sound information. When the sound is considered only as carrier of sound energy then are formed adequate models for prediction. However, the ear is by its nature nonlinear element. Consequently, it has to be combined approach to sound as energy carrier and as signal that includes information aspect. At reproduction of sound it is needed to satisfy sufficient loudness and that at the same time the information be understandable. Because of that it is needed to design optimised correction frequency characteristic for the ear in hearing devices or in interstage between recorded normal sound and corrected recorded sound in systems for correction.

The ear has performance of spectral frequency analyzer that continually in time analyzes every spectral characteristic. As a receiver, the ear has logarithmic characteristic of response on intensity of excitation. The sound pressure level is given by Weber-Fechner law: $SPL \equiv L(dB) = 20 \log p / p_0$, where p is effective value of pressure and p_0 is referent level of sound pressure is $p_0 = 20$ μPa , what corresponds to sound level of 0dB. Boundary of pain corresponds, for f = 1 kHz, to pressure that is 10^6 times greater than the pressure at audibility threshold [1,2,3].

In the range from 20 Hz to 20 kHz along the frequency axis there are about 850 different frequencies that the ear can to differentiate. The frequencies are densely distributed in the range of low frequencies compared to higher frequencies what is a result of the logarithmic dependence of ear characteristic. Lower boundary of sound intensity, co called audibility, is defined by perception threshold of quietest sound components. Audibility range (hearing field) is marked by boundary of audibility and lower and upper boundary frequency.

Relation between subjective sense of sound, in other words characteristics of subjective sense (loudness, height and colour of tone) and its objective characteristics (intensity, frequency and spectral components) is unique but different for every person. At frequency f = 1 kHz the subjective height of sound is equal to the objective height.

The connection between subjective filing of loudness and objective intensity as a function of frequency is given by family of ishophonic lines. Two extreme values in the audible frequency range are the audibility threshold and the pain threshold that are non-linear functions. The boundary of audibility is threshold of stimuli of hearing sense what is different by sound level depending on person age. The audibility threshold can be moved also due to the effects of temporary exposure to high intensity of noise. Besides to the audibility threshold also is important the discomfort threshold when the sound is unpleasant for hearing and that is at the level of around 90dB and approximately is equal at all frequencies.

II. HEARING DAMAGES BY NATURAL AGING AND CORRECTIONS OF DAMAGES

Changes of ear frequency characteristic occur under the influence of person age. That becomes a very important factor that reduces ability to understand speech. Non-linearity of hearing sense sensibility is more precise defined by diagram of ishophonic lines. Ishophonic lines are of non-linear character what create a set of practical problems at adjustment of sound level in systems for sound reproduction. To perform compensation of occurred damage it is necessary that the corrected frequency characteristic has such form of frequency dependence of gain (*Insertion Gain*) that together with open ear canal resonance reaches dB level needed for normal hearing.

Due to changes in key parameters in the ear during the aging process are changed levels of the threshold of hearing for the persons, what is shown in Fig. 1 [4]. For expression of signal value in sound field it is introduced sound pressure level (SPL) = L, given in dB.

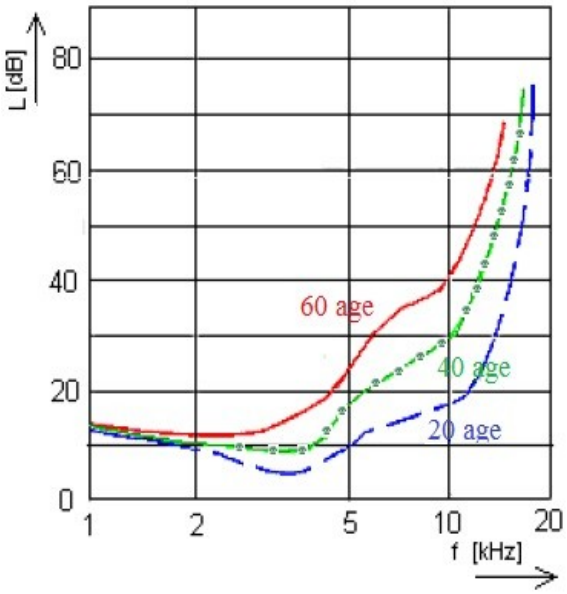

Fig. 1. Amplitude characteristics of sound pressure level as a function of frequency for age as a parameter.

Starting from the fact that the sound is time dependent mechanical deformation in elastic medium, on the basis of average statistic value of a set of experiments, were derived two very important conclusions: the spectral density of speech power is significantly higher in the range of lower frequencies while the higher range of the spectra contributes to the communication understandability.

Because of the narrowed dynamic range of individual characteristic of ear for persons with hearing damage the sound picture is not complete, especially in the range of higher frequencies. Standards of IEC (International Electrotechnical Commission) that include hearing devices are connected with S3 board (Bioacoustics) and Secretariat for standardization of ASA (Acoustical Society of America). According to standardized equivalent scheme of ear given in paper [5] the graph of admittance module $|\underline{Y}|$ [mS] is shown in Fig.2.

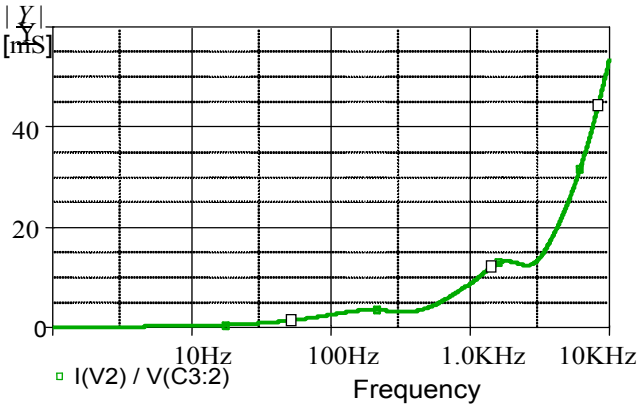

Fig.2. Admittance module of electrical ear model as a function of frequency.

On an analogous way is obtained and shown in Fig.3 the impedance module of the ear according to the same model.

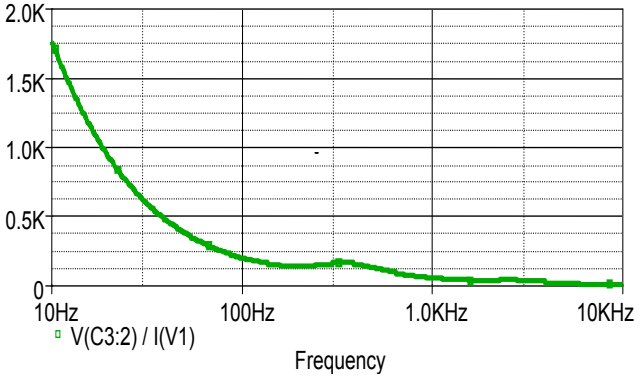

Fig.3. Module of impedance of ear model as a function of frequency.

In calculations of the required levels of amplitude characteristics corrections in frequent domain it is needed to use mathematical models of ear performances.

So, the input admittance $\underline{Y}$ of the ear is described by complex function of dependence of frequency as [5,6]:

$$\underline{Y} = \frac{1}{R_1} + j\omega C_1 + \\ + \frac{j\omega C_2}{1-\omega^2 L_2 C_2 + j\omega C_2 R_2} + \\ + \frac{j\omega C_3}{1-\omega^2 L_3 C_3 + j\omega C_3 R_3}. \quad (1)$$

Resolution of hearing sense by the levels ΔL (minimal hearing increase of sound level) for the periodic tones can be described by linear mathematical model in dependence of sound level n given in dB as [3,6]:

$$\Delta L = \Delta L(0) - n \cdot \frac{\Delta L_{max} - \Delta L_{min}}{n_{max} - n_{min}} [dB], \quad (2)$$

Lower level of audibility depends on frequency and can be modelled by polynomial that is given by [6]:

$$L(f) = \sum_{i=1}^{n} \prod_{k \neq i} \frac{(f - f_k)}{(f_i - f_k)} \cdot L_i, \quad (3)$$

Perception $\Delta L[\mathrm{dB}]$ of loudness as a function of duration time $t[\mathrm{ms}]$ is linear decreasing from the time moment t_1 ($t_1 \leq 10\,\mathrm{ms}$) up to double value of the time constant of the ear that has value $\tau_o = 100$ ms :

$$\Delta L(t) = \Delta L(t_1) - \frac{\Delta L(t_1)}{2\tau_o - t_1} \cdot (t - t_1). \quad (4)$$

These models have been used for determination of needed characteristics corrections for persons with damaged hearing caused by aging.

For persons with hearing damages the conditions are diagnosed by audiometric determination of hearing field boundary in a function of the frequency and sound pressure intensity.

Research of specificities and level of damage of frequency characteristic shows that the conductive loss of hearing is very often. Clinical picture due to mutual interactions differs in terms of process duration, seriousness of symptoms and pathological-anatomical changes, as well as functional damages of conductive segment.

Important are measurements of basic values [6,7,8]:

AC - Air conduction as a function of frequency,
BC - Bone conduction as a function of frequency.

A special emphasis is given to frequency analysis and signal gain. For processing of audio signal are used several available softwares. It is suitable to use Sony Sound Forge, Audacity®. In Fig.4 shown is time waveform of a normal sound signal while in Fig.5 is shown time waveform of signal with intensity that hear person with damaged hearing.

After the correction the person hears sound what the waveform is approximately the same as the initial signal given in Fig.4.

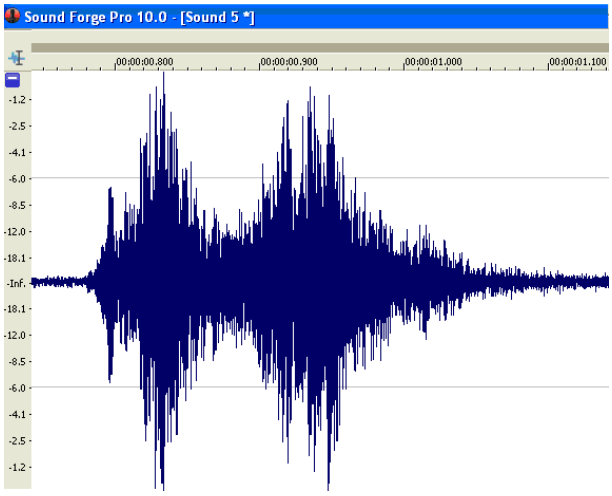

Fig.4. Time waveform of initial signal.

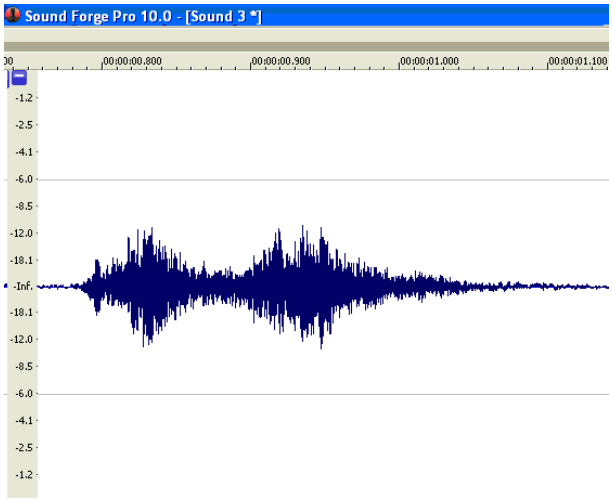

Fig.5. Time waveform of uncorrected signal.

III. EXPERIMENTAL RESULTS

For processing of audio signals in use are a number of professional softwares. For experiments here was used software package Sony Sound Forge pro 10-1, Audacity® 1.3. The quality of settings for recording depends of choice of sampling rate. The sampling rate for good quality of music signal is equal to 44100 Hz while for sampling of telephone-quality speech signal is sufficient value of 8000 Hz [5-7]. Correction of gain of sound file (*.wav) enables changing of signal level in the domain from -N dB to +N dB.

In the audiology laboratory are performed recordings of audiograms for persons with hearing damages (Table 1). Based on measurements it have been determined that for persons in age from 40 years to 70 years are appearing hearing

damages especially in the range of higher frequencies [6,7,8]. The measurements of examined persons sample were covered the range from the moderate damage up to the deep hearing loss. In Table 1 are given sound pressure levels L [dB] for persons with different age (in index are shown years of age of persons. All the results are also shown in graphic form in Fig.6.

TABLE 1. MEASUREMENT RESULTS FOR AGED PERSONS

f [kHz]	1	2	3	4	5	6	8
L_{40} [dB]	8	6	5	6	10	18	27
L_{50} [dB]	9	8	12	16	23	28	38
L_{60} [dB]	14	14	17	28	34	40	50
L_{70} [dB]	18	17	30	40	45	55	80

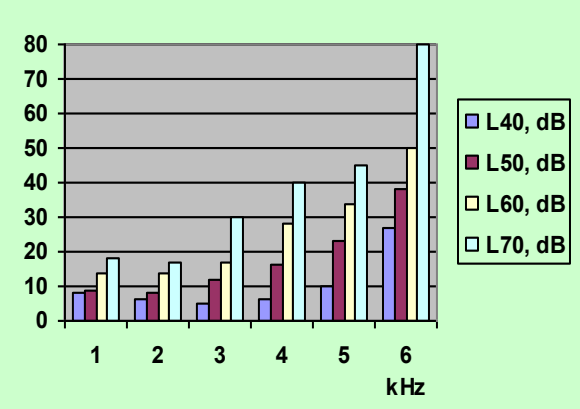

Fig.6. Measurement results of audibility threshold for persons from 40 to 70 years of age.

Settings and adjustments of audibility threshold in the software package Sony Sound Forge for person with 60 years of age are shown in Fig.7 [9].

In order to enable listening of radio programs or sound from television it is needed to perform correction in the gain of emitted signal. It is suitable and recommended to create a special emissions and programs for older persons with over of specified number of years.

Also, the same procedure for settings and adjustments of needed signal gain was in experiments applied on mobile phones, too. The needed corrected frequency characteristic is shown in Fig.8. The shown experiment was performed by using Mix Zing Player that is used on smart mobile phone with Android operation system [10,11]. For gain of signal it is sufficient that the target curve differ for 10 dB because it gives satisfactory hearing with the necessary understandability.

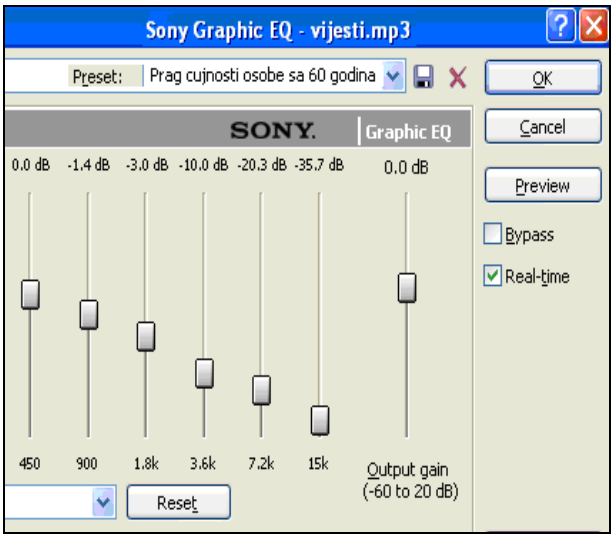

Fig.7. Audibility threshold settings for person with 60 years of age using Sony Sound Forge.

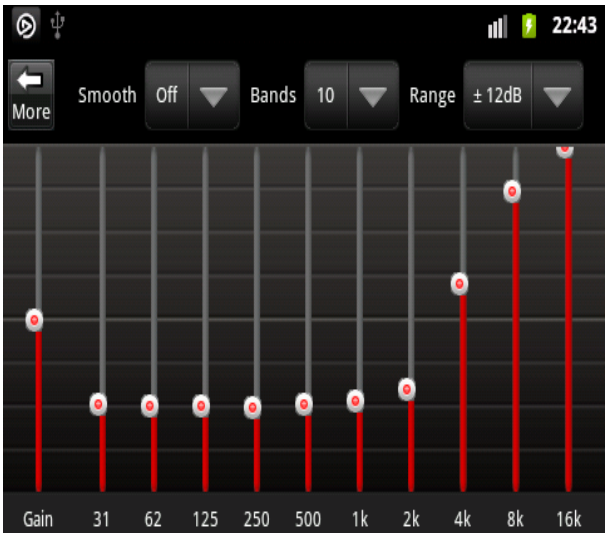

Fig.8. Correction for mobile phones by using Mix Zing Player.

Spectral characteristic of signal for persons with 20 years, 40 years and 60 years of age is shown in Fig.9.

The graphical results of performed corrections of frequency characteristic for persons with damaged hearing caused by known reasons of aging are shown in Fig.10. Here is shown set and adjusted values of correction gain at frequency of 15 kHz although contribution of this component has no important impact in hearing for analyzed persons.

Spectral form of signal after performed gain correction is shown in Fig.11. Sufficient range for needed quality of hearing includes frequencies up to 8 kHz.

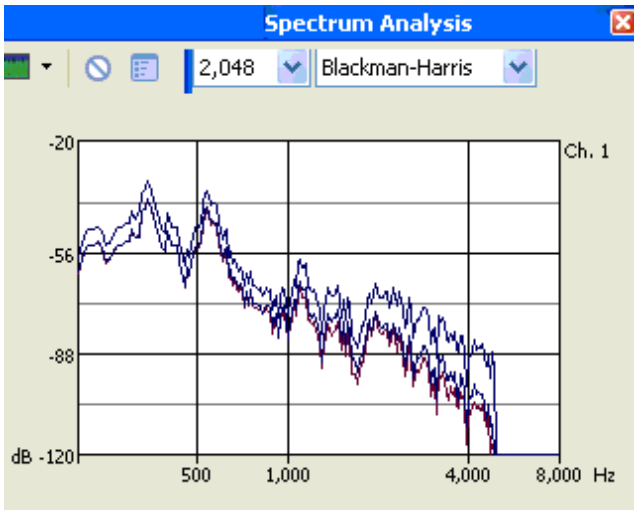

Fig.9. Spectral form of signal processed according to hearing characteristic of persons with 20, 40 and 60 years of age.

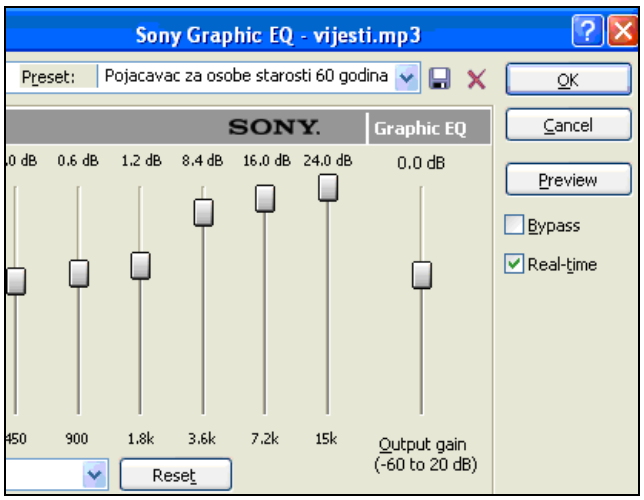

Fig.10. Gain correction in range of higher frequencies for older persons.

IV. CONCLUSIONS

In the paper are considered and presented the ways to determine correction characteristic by which the person with damaged hearing by natural aging could hear sound materials in their personal environment without using hearing device. Some of obtained results of measurements and experiments are shown and presented in graphical form.

In order to enable listening of radio programs, sound on television and sound materials from mobile phones it is needed to make corrections of gain of the listened audio signal. It is recommended to create special radio and television programs for older persons and correct audio signals in mobile phones for such persons.

During creation of special television and radio programs for older persons the settings of needed corrections of gain by equalizers in the studio should be adjusted according to averaged values of hearing damages.

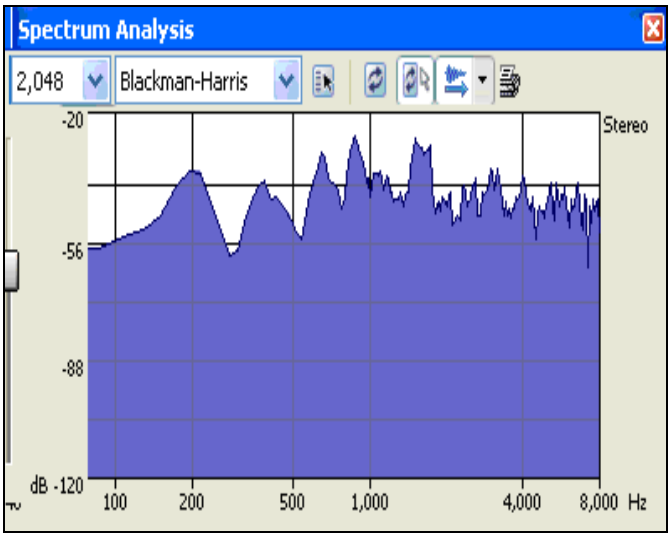

Fig.11. Signal spectrum after performed gain correction.

Then such persons in their home ambient would be able to avoid usage of electronic amplifiers such as are the hearing devices. In this way would be achieved greater comfort of such persons

For quality hearing it is needed sufficient level of sound signal and broader frequency range. But, for analyzed persons with hearing damages caused by natural aging the limit frequency does not reach 8kHz and is easier to set needed frequency characteristic of the emitted signal. So, it can be obtained that the persons with hearing damage caused by natural aging have achieved audibility with preserved needed understandability without using the hearing devices. Obtained results show that also in the real time can be provided quality hearing of the sound of dedicated emissions of television and radio where the frequent characteristic for the correction is directly implemented.

REFERENCES

[1] M. Valente, "Hearing Aids: Standards, Options And Limitations", Edition 2, Thieme, 2002., *www.thieme.com*
[2] S. T. Jovičić, "Voice communication – phisiology, psichoacoustics and perception" , Nauka, Beograd, Serbia, 1999. (in Serbian)
[3] M. Mijić, "Electroacoustics", Faculty of Electrical Engineering, Belgrade, Serbia, 2007. (in Serbian).
[4] "Hearing Loss, a Growing Problem that Affect Quality of Life", National Academy of an Aging Society, no. 2, Washington, 1999.
[5] "IEC Publication 318", Courtesy of International Electrotechnical Commission.
[6] F. Softić, Z. Bundalo, Ž. Blagojević. A. Stjepanović, " Listening of Sound Files Using Mobile Phones without Hearing Aid Devices for Persons with Damaged Hearing", Proceedings of International Scientific Conference ERK2011, Portoroz, Slovenia, 2011, pp 83-86.
[7] Medical Electronics, Sonomed - Siemens, Laboratory for ORL, Banja Luka, 2009.
[8]https//www.google.ba/search?q=hearing+age&hl=bs&client=firefoxa&hs=ZQl&rls=org.mozilla:en-US:official&channel=np&prmd=imvnsa&tbm=isch&tbo=u&source=univ&sa=X&ei=y6FoUNOgNsndsgbz5oH4Ag&ved=0CF8QsAQ&biw=1137&bih=963
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