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Real Time Distortion Product Otoacoustic Emission Using TMS320C6713

Aws Alazawi *, Huda Farooq Jameel *, and Mohammed Sameer Mohsen Alsabah *

Abstract: This study explores the use of distortion product otoacoustic emission (DPOAE) as a hearing screening modality for newborns and adults with hearing impairment. The goal is to improve cochlear response by developing digital filter characteristics to make it consistent for specialists to make accurate diagnoses. To accomplish this, the proposed system consists of a DPOAE ER-10C as stimulation and cochlear response probe, a digital signal processor, an oscilloscope, PC, and audio cables. Real-time distortion product frequency components were extracted using a signal processor of TMS320C6713. To validate the system, a senior medical physicist conducted a study for five hearing-normal participants of men and women aged 38 - 55 years old, at Baghdad Medical City / center for hearing and communication in Iraq. The results showed an ability to extract distortion product components in real-time implementation, with the superiority of shape parameters greater than 0.5. In addition, the quantization of filter coefficients was compared for both floating-point arithmetic and fixed-point arithmetic. Noisy environment-based noise reduction techniques have to be investigated by considering the implementation of robust digital signal processing techniques. Finally, the proposed system would contribute to advancements in hearing screening and treatment for those with hearing impairment.

Keywords: Distortion product otoacoastic emission, digital signal processor TMS320C6713, fixed point digital signal processing, Kaiser filter, real time biomedical signal processing.

1 Introduction

THE A hearing test was used to determine how well a person could hear, and an audiologist usually diagnoses individuals who experience hearing loss. Pure-tone audiometry has been used to define and assess if an individual has hearing problems in the usual frequency range of 0.25 to 8 KHz. Furthermore, individuals with tinnitus and/or auditory processing disorders, which were probable symptoms of cochlear synaptopathy, were frequently tested using high-frequency pure-tone audiometry. Hearing dysfunction significantly influences both newborns' speech progress and adults' life quality. The inner ear in turn transduces sound pressure into an electrical signal, where cochlear function is represented by transduction efficiency. The cochlea function is clinically measured by otoacoustic emissions (OAEs), which are particularly prevalent in humans with low interaction, i.e., babies and the elderly. OAEs were regularly employed in clinical settings to examine cochlear outer hair cell biomechanics, and they may be one of the first tests to detect noise damage, even in the presence of a normal audiogram [1]. In addition, the most recent research was used to measure the newborn hearing screening protocols that explored the actual protocols in terms of the types of frequencies that were used within each protocol [2].

A hearing screening of OAE is considered an objective that has proven to be the method for evaluating the cochlea's performance in terms of spectral analysis. The cochlea's primary purpose was to transform sound waves into electrical impulses, which were then translated into

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* The authors are with the Department of Medical Instrumentation Engineering Techniques, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.
E-mail: aws_basil@mtu.edu., huda_baban@mtu.edu.iq, Mohammed.sh.c@mtu.edu.iq.
Corresponding Author: Aws Alazawi.

frequencies linked to approaching sound by the brain [3]. OAE was a low-level sound generated spontaneously or in reaction to cochlear stimulation, and it was also thought to be a consequence of nonlinear sound processing inside the cochlea [4]. According to cochlea stimuli, OAE was divided into four types: spontaneous OAE (SOAE), transiently evoked OAE (TEOAE), distortion product (DPOAE), and stimulated frequency OAE (SFOAE) [5]. In DPOAE, the cochlea is stimulated by two sinusoids of closely related frequencies, and the response of low-magnitude acoustic emission is then recorded by a low-noise amplifier system [6]. DPOAEs were made up of two components: a nonlinear distortion component and a coherent reflection component. DPOAE components are recovered from discrete frequency recordings using time-domain approaches. On the other hand, DPOAE were found to be sensitive biomarkers of inner dysfunctionality linked to organic solvent exposure. The investigation validated the great sensitivity of DPOAE, which was sensitive to oxidative stress [7]. A comparison of DPOAE suppression to SFOAE suppression from the same ear in normal hearing subjects was introduced [8]. The recovered DPOAE components were compared to recordings made using traditional, continuous primary tones. Suppression of DPOAE and SFOAE was compared using suppression growth rate (SGR), superimposed suppression tuning curves (STCs), and STC-derived metrics, where the findings might help restrict physiology-based models of OAE [9]. Moreover, choosing subjects related to sound perception and neural coding, with the first level of filtering in the cochlea, was proposed. An ability to recognize a particular auditory activity falls into the rule of both processing stages of the cochlea and pitch, where considering the auditory system mechanism improves competence in treating the hearing loss issue in the adultery population [10]. Both cochlear filtering and pitch play important roles in the incapacity to interpret the auditory environment, allowing the review to focus on one auditory item or stream while disregarding others. Increased knowledge of the fundamental mechanics of auditory perception will benefit efforts to address the growing problem of hearing loss in the aging population. Furthermore, to maximize the prediction of hearing status by analyzing DPOAE level and signal-to-noise ratio in a group of babies aged birth to 4 months. An enhancement of sensitivity while balancing specificity by multi-frequency rules employed and an investigation of the possibility of a conductive component to the hearing loss of the sensitive middle ear measured [11]. An objective screening approach incorporating an otoscope, DPOAEs, and tympanometry was also investigated [12]. Also offered was the option of using tele-auditory brainstem response testing as the reference standard, which was available near children's homes. As a result, this was one of the few studies that included a subset of children who passed the screening as well as those who were referred [13]. The sensitivity, specificity, and positive and negative predictive values obtained for the DPOAE screening performed in the community by village health workers are adequate and comparable to findings published in hospital-based analyses. Besides, assessing the utility of high-frequency DPOAEs in minimizing false-positive results associated with traditional DPOAE hearing screening examinations was the proposed [14]. The study entailed assessing OAE amplitudes and noise floors, as well as the OAE pass/fail status, at f_2 frequencies ranging from 2 to 12 KHz for various infant groups, which reduces the cost and overall time required for hearing screening, as well as parental worry and unneeded follow-ups. Alternatively, the bounce phenomenon (BP) was discovered in DPOAEs of gerbils with no signs of noise stress [15]. Shifts in the operating point (OP) and alterations in the transfer function of mechanoelectrical transduction in outer hair cells (OHCs) appear to explain the fundamental causes of BP. Differing oscillation patterns in gerbils and humans are owing to different resting OP positions. As the experimental probe fits primarily higher than the baseline condition, the TEOAE noise amplitudes result in a worse signal-to-noise ratio in general [16]. As a result, if TEOAEs decrease in the context of hearing loss, the impact of probe fitting on TEOAEs may result in more false positives. Furthermore, TEOAEs probe fits are more difficult in newborns and babies, especially when combined with lower ear canal volumes. The recording device influences the accuracy of TEOAE measurements to identify tiny cochlear abnormalities or changes, and additional efforts should be made to enable an objective assessment of the stimulus. In consequence, custom-moulded probe tips minimize probe placement by lowering the variability of chirp frequency sweeps compared to rubber probe tips [17]. The results imply that employing a custom-moulded probe tip for obtaining DPOAE measurements has the benefit of improving probe placement stability across tests at frequencies up to 10 KHz when examined with a chirp-swept-frequency stimulus. Consistent probe positioning may be advantageous for in situ calibration, standardizing DPOAE stimulus levels throughout measurement periods, investigating factors influencing DPOAE repeatability, and collecting repeated DPOAE data across time for specialized applications. In addition, it explains the cause of onset and offset amplitude overshoots in the DPOAE signal measured for intensity pairs in the notches [18]. A simulation with a smooth cochlear model as well as their analytical solution support the theory that destructive interference between individuals causes amplitude notches.

Consequently, DPOAE was an important method for assessing hearing in either pediatric or difficult-to-test groups. Unfortunately, even moderate conductive hearing loss was not uncommon. However, by strategically altering the patient, the physician can significantly enhance DPOAE measurements by adjusting tone levels. Not only could the benefits of DPOAE testing be demonstrated in this manner, but they also tended to a larger number of patients, yet the physician can get information about the health of the auditory system that was not presented by traditional means of DPOAE procedures [19]. DPOAE might be used in screening for middle ear effusion in individuals with a type 'C' tympanogram. A study was conducted to examine the diagnostic utility of DPOAE in conjunction with tympanometry in diagnosing otitis media with effusion in children [20]. However, to improve customized model predictions of auditory function for mixed hearing diseases, such as cochlear synaptopathy in the context of outer-hair-cell loss, and the improvement of future personalized hearing-aid algorithms [21]. DPOAE readings at higher main frequencies were needed to reduce stimulation errors and increase the efficacy of individualized cochlear model simulations. Maps, a statistical approach, was used for identifying changes in DPOAE [22]. These types of studies might be used to check for changes in cochlear function following noise exposure, long-term noise-induced hearing loss, or exposure to ototoxic medicines. The suggested technique addresses past limitations of DPOAE mapping for these applications by allowing for the detection of statistically significant changes in DPOAE amplitude, hence boosting diagnostic capabilities. In addition, they developed a method for analyzing repeated DPOAE amplitude maps in ordinary hearing participants that yields either a single overall score or a descriptive map of reactions over time [23]. The results of the noise exposure after loud music exposure showed significant changes in the audiogram, DP-gram, and map z-scores, but the map scores were a much more robust indicator. For estimates of tuning using DPOAE level ratio functions (LRF) with level and frequency dependency comparable to that reported in cochlear mechanics, a moderate association between behavioral and LRF tuning is proposed [24]. These findings have been used in research for clinical settings that use this tool for assessing cochlear tuning.

Additionally, in a clinical setting, an investigation of the repeatability of DPOAEs recorded with high-frequency (HF) stimuli is proposed. DPOAEs were assessed for 40 patients (17 females and 23 males) with observable behavioral thresholds, and at least two of the high frequencies investigated were 8-16 KHz [25]. A depth-compensated simulator sound pressure level (SPL) calibration approach was used. In addition, a longitudinal repeated-measures methodology was used for the current study sample, which included 91 of the 325 individuals who returned for a repeat screening and diagnostic audiological examination as part of a risk-based newborn hearing screening program [26]. TEOAE screening demonstrated higher specificity than DPOAE screening at both the initial and repeat screenings, regardless of variations in DPOAE pass/refer criteria. However, more study was needed to determine the sensitivity and specificity of OAE screening technologies employing repeated-measures and diagnostic audiological evaluation. A feasible study was introduced to diminish the effect of fine structure and demonstrate the modulating of the frequency of the f_2 basic tone throughout a clinically significant range of stimulation intensities and frequencies without reducing DPOAE amplitude or increasing test time [27]. However, further research was needed to determine the efficacy of this method in newborns and young children, when its therapeutic benefit might be maximized. Moreover, a theoretical investigation of the effect of f_1 suppression on the time for DPOAE amplitude during DPOAE operation was proposed [28]. A series of simulations were performed with the frequency ratio $f_2/f_1 = 1.26$ and various levels of the principal tones (L1 and L2 = 30 – 70 dB SPL) to evaluate the relationship between time dependencies of the DPOAE onset and suppression of the f1 basilar membrane (BM) response. Further, the effect of scattered source areas on the nonlinear distortion component of cubic DPOAE is proposed [29]. This article investigated the probable origins of DPOAE amplitude suppression under certain generation conditions where the level of the f_1 stimulus tone was fixed at 50 dB and the level of the f_2 stimulus tone varied from 30 to 70 dB, or vice versa. Furthermore, a simulation of cochlear distortion products in response to pulsed primary using a hydrodynamic cochlea model of the human cochlea was proposed [30]. Either simulations were run in the temporal domain, recreating acquisition scenarios in which the f_1 or f_2 pulse triggers the DPOAE, where the findings showed differences in short-pulse DPOAE responses with the varying temporal arrangement of the primary tones caused by the nonlinearity of the mechanoelectrical transducer (MET). On the other hand, f_1 is the primary-recommended elicitor for eliciting DPOAEs with a smooth and regular onset. A hypothesized stimulus-frequency otoacoastic emissions (SFOAEs) detect hearing status with high frequencies and perform well in predicting hearing thresholds, at least at 0.5 – 4 KHz, as illustrated using machine-learning algorithms [31]. Machine learning methods used to improve the accuracy of SFOAEs in hearing prediction may play an essential role in future OAE investigations aimed at improving predictive performance. SFOAEs outperform DPOAEs and TEOAEs in terms of predicting hearing thresholds [32]. Other studies considered 65/65 dB SPL and 65/55 dB SPL intensity levels, as well as the 1.18, 1.20, and 1.22 f_2/f_1 ratios, to discover the stimulus parameters for eliciting the greatest and most reliable DPOAEs in adult humans across a wide range of DPOAE applications. Finally, a group of volunteers wore surgical masks, whereas another group used N95 masks; before and after mask use, DPOAE and oxygen saturation were evaluated in both groups [33]. In DPOAE measurements, a comparison of signal-to-noise ratio (SNR) values before and after surgical mask wear indicated a statistically significant difference in the right and left ears. SNR values in DPOAE measurements before and after 8 hours of N95 mask wear indicated statistically significant variations in the right ear at 988, 2963, 4444, and 8000 Hz, as well as in the left ear at 8000 Hz. A prolonged mask-wearing period altered the outer hair cells in the cochlea, resulting in a decrease in DPOAE readings.

After reviewing the introduction and related work, it seems that the focus is on finding the optimal digital filter characteristics to effectively extract the cochlear response that is represented by distortion frequency components. Additionally, efforts are made to reduce noise levels in both the high and low-frequency ranges. To apply the best digital filter characteristics for extracting cochlear response represented by distortion frequency component and also reducing noise levels that exist in the high-frequency and low-frequency ranges. A filter design and analysis tool (FDATool) is considered a tool used specifically for designing the finite impulse response (FIR) Kaiser bandpass filters of centre frequencies 500 Hz, 1 KHz, 2 KHz, 3 KHz. 4 KHz, and 6 KHz, sampling frequency of 16 KHz bandwidth of 100 Hz, 128 coefficients, for floating-point and fixed-point precisions in this work.

The contributions of this research are summarized as follows,

1. A real-time distortion product frequency component is using signal processor TMS320C6713 for cochlea function evolution.
2. Design an FIR bandpass Kaiser Filter for a shape parameter of 0.5, 5, and 10 for frequency components closely spaced.
3. Compared between floating-point arithmetic and fixed-point arithmetic for real-time implementation.

2 Materials and Methods

As mentioned earlier, the study validation of the system conducted for mean age of five hearing-normal participants of men and women considered for 49 years old. The participant left ear with normal hearing (hearing threshold ≤ 20 dB HL) examined by a senior medical physicist at the center for hearing and communication in Baghdad Medical City, Iraq. Where examination included an otoscope, tympanometry, and audiometer as a preparation procedure for experiment conduction. Furthermore, the ear canal should be cleaned from wax and any blockage that probably prevents the conduction of the signals. The procedure of cochlear response estimation is represented by the block diagram shown in Fig. 1.

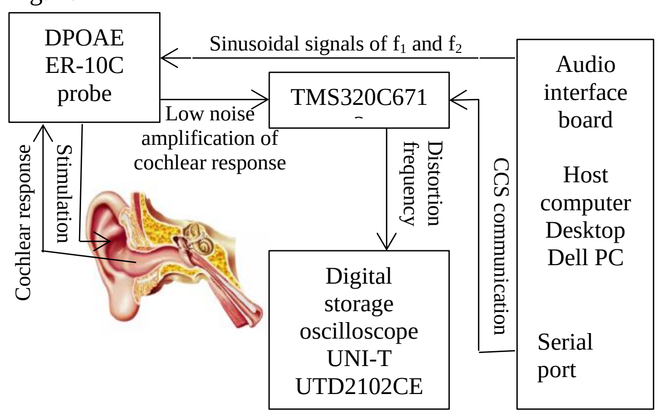

Fig. 1 Block diagram of the procedure.

An experiment set up included a DPOAE probe system of the type ER-10C, a digital signal processor of the type TMS320C6713, a digital storage oscilloscope of the type UNI-T UTD2102CEX operating at 100 MHz and 1 GS/s, a desktop PC of the type Dell, audio cables, and adaptors, as shown in Fig. 2.

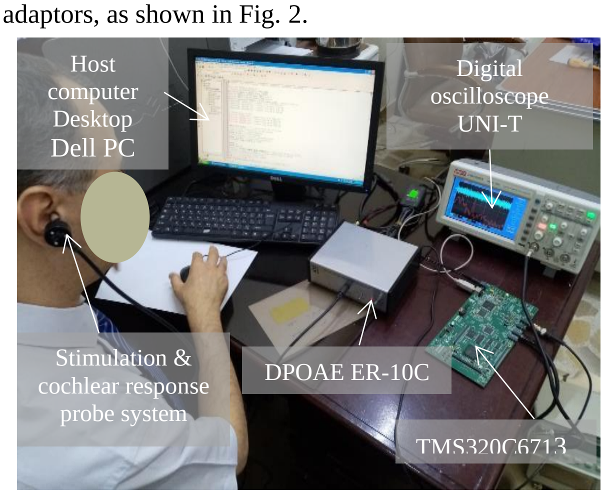

Fig. 2 Experiment set up for real time DPOAE.

The host computer specification required for compatibility with the software of code composer studio (CCS) of digital signal processor (TMS320C6713), where the host computer utilized to generate the stimulus sinusoidal signals of f_1 and f_2 through an audio interface system using MATLAB programming, and to conduct a communication with TMS320C6713 using (CCS) version 3.1. The DPOAE probe system is utilized for cochlear stimulation and cochlear response (40 dB) amplification. The cochlear response is analyzed using the digital signal processor TMS320C6713 for digital band pass filter implementation in real time. Furthermore, communicates with the digital signal processor TMS320C6713 for loading the debugging files and controlling filter parameters of the CCS project through an embedded JTAG emulator. The CCS project is designed with a slide for selecting an appropriate band-pass digital filter characteristic for fd extraction. The stimulation represented by the two following scenarios is

Scenario I:

Stimulation parameters were f_s=44.1 KHz, f_1=4 KHz, f_2=5 KHz, f_2/f_1=1.25. Cochlear response has to be included the following frequency spectra of Dp_1=1 KHz, Dp_2=2 KHz, Dp_3=3 KHz, Dp_4=6 KHz.

Scenario II:

Stimulation parameters were f_s=44.1 KHz, f_1=600 Hz, f_2=696 Hz, f_2/f_1=1.16. Cochlear response has to be included the following frequency spectra of Dp_1=312 Hz, Dp_2=405 Hz, Dp_3=504 Hz, Dp_4=792 Hz.

A consideration of various frequency ratios (f_2/f_1) in scenario-I as f_2/f_1=1.25, while in scenario-II as f_2/f_1=1.16 would be useful to differentiate an efficient bandpass filter characteristic that able to separate closest frequency components (cochlear response).

3 Signal processing algorithm

The scope of the digital filter's applications has significantly increased with the advancement of digital signal processing techniques. The ease of integration, adjustability, good reproducibility, high dependability, reuse, and simplicity of design are some of its advantages over comparable filters. Digital filters' main function is to either reduce the bandwidth of an original signal or recover certain features from it.

In order to develop FIR filters with a narrower transition band, it is typically necessary to reduce the width of the window spectrum's primary lobe. In concentrating the window method's energy to the greatest extent possible on the main lobe, it is also necessary to decrease the fluctuations of the maximal side lobe of the window spectrum. Moreover, the stop band attenuation has to be increased, while the shoulder maximum and ripple has to be decreased. Consequently, the proper window function has to be chosen based on the current situation to generate an optimal FIR filter. Finding the filter coefficients, which regulate filter performance, is a crucial component of digital filter design since they were changed to bring the filter's frequency response closer to the ideal. Thus, FIR filters are recommended over their IIR equivalents in the biomedical field because of their superior capacity to maintain a highly linear phase, which is important to avoid undesirable distortions in the detected signals [34]. Analyze the effectiveness of FIR filter design using conventional and evolutionary approaches. Investigations considered into the suggested evolutionary computation methodologies, specifications, calculation time, designing as well as implementation, suitability for communication devices and biomedical signal processing. A real-time high-frequency discrete-time band pass FIR filter was built in terms of coefficients obtained and applied in the Lab VIEW and FPGA environments [35]. The filter constructed using the Kaiser windowing technique, where FIR filters preferred due to the linear phase of Kaiser window is a particularly flexible and efficient filter, allowing the user to freely select between main lobe size and side lobe attenuation for its specified gravity [36]. Among various filters, Kaiser window shows the remarkable results [37]. To maintain a suitable match in time-frequency approximations, this research suggests an optimization technique on the Kaiser window. Usually, very unpredictable signals are subject to these filters. In Equation (1), the Kaiser window is expressed [38].

$$w(n)\begin{cases}\frac{I_0(\beta)\sqrt{1-\left(\frac{n-\alpha}{\alpha}\right)}}{I_0(\beta)} & 0 \le n \le M \\ 0 & otherwise\end{cases} \tag{1}$$

Where M is the window length, δ = M/2, β is the shape parameter, and I0 is the zero-order modified Bessel function of the first kind. The level of the side lobes α (dB) can be controlled by varying β.

In the design of Kaiser Filter, a range of shape parameter (β) is considered for 0.5, 5, and 10, to improve band pass filter characteristic for efficient band pass filter that would be able to extract useful cochlear features from cochlear response of distortion product.

4 Results

According to the experiment scenario-I, results in Fig. 3 (a) illustrates the frequency spectra include stimulus frequency components of f_1 and f_2 that reflected from the wall of the air canal, in addition to the distortion product frequency components (Dp_1, Dp_2, Dp_3, and Dp_4) as a cochlea response (physiological activity).

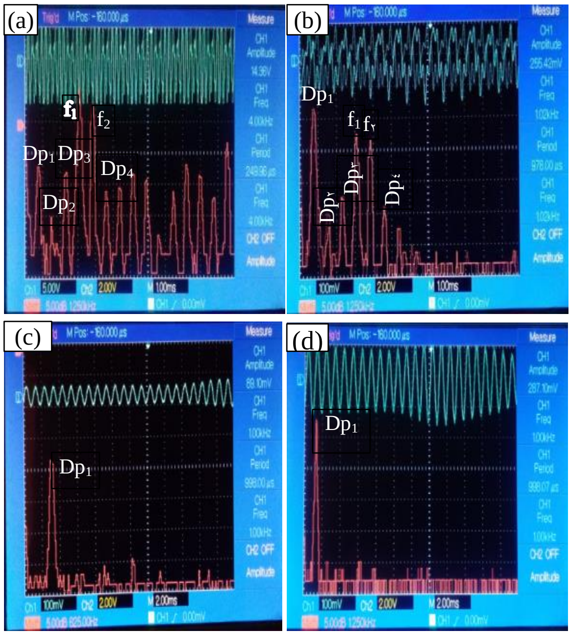

Fig. 3 Cochlear response represented by, (a) distortion product frequency spectra, filter response at 1 KHz center frequency, (b) β of 0.5, (c) β of 5, and (d) β of 10.

Results also illustrated the response of band-pass Kaiser digital filter of center frequency 1 KHz as shown in Fig. 3 (b-d), 2 KHz as shown in Fig. 4 (a-c), 3 KHz as shown in Fig. 5 (a-c), 6 KHz as shown in Fig. 6 (a-c) using β=0.5, 5, and 10 respectively.

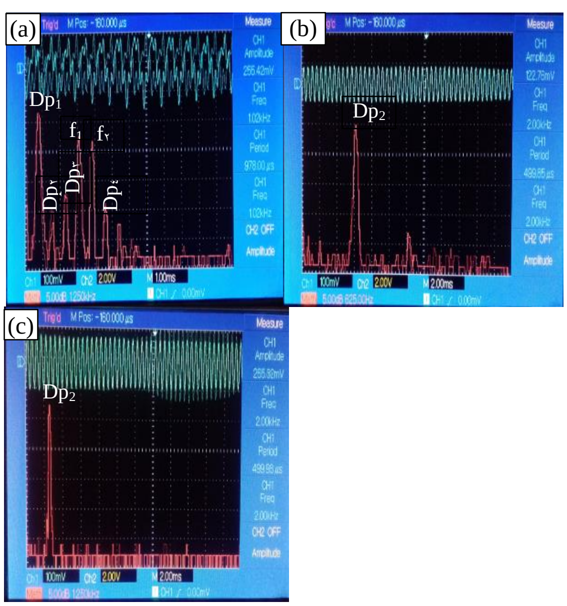

Fig. 4 Cochlear response represented by filter response at 2 KHz center frequency, (a) β of 0.5, (b) β of 5, and (c) β of 10.

While for the experiment scenario-II, results in Fig. 7 (a) illustrates filter response at β of 0.5, β of 5 in Fig. 7 (b). Where Fig. 3 – Fig. 7 captured from oscilloscope monitor using high resolution digital camera.

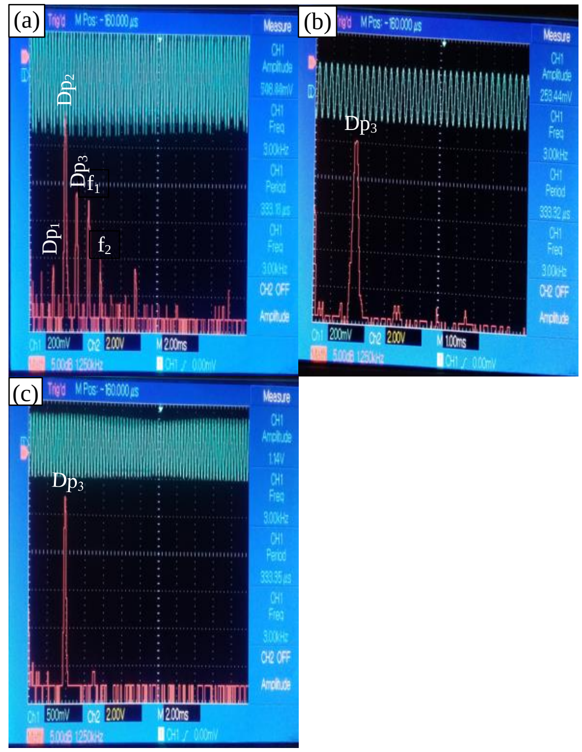

Fig. 5 Cochlear response represented by filter response at 3 KHz center frequency, (a) β of 0.5 (b) β of 5, and (c) β of 10.

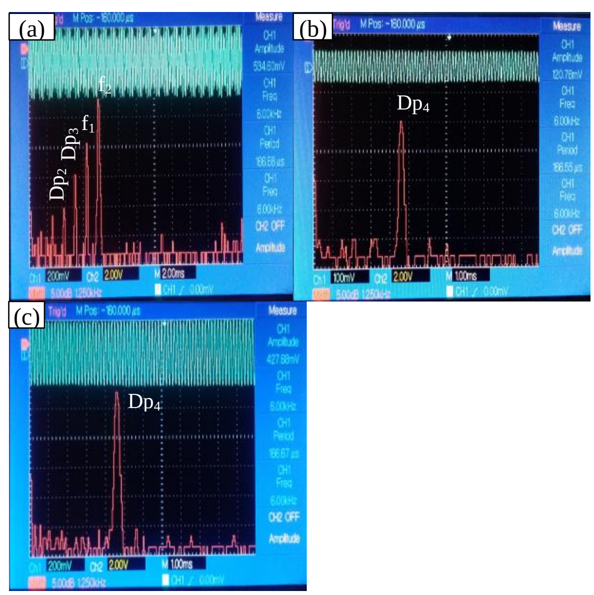

Fig. 6 Cochlear response represented by filter response at 6 KHz center frequency, (a) β of 0.5, (b) β of 5, and (c) β of 10.

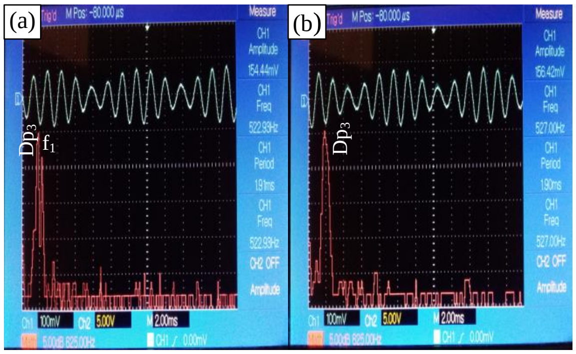

Fig. 7 Cochlear response represented by filter response at 500 Hz center frequency, (a) β of 0.5 and (b) β of 5.

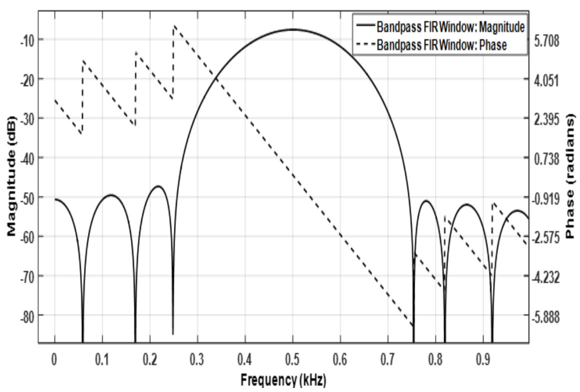

Fig. 8 Frequency spectrum of FIR Kaiser Bandpass filter arithmetic of double precision floating-point.

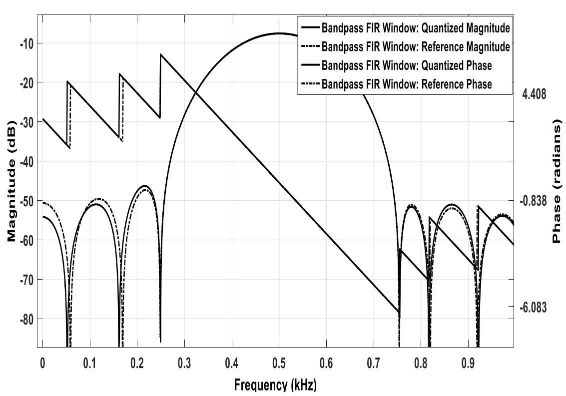

Fig. 9 Frequency spectrum of FIR Kaiser Bandpass filter arithmetic of fixed-point and 8-bit word length.

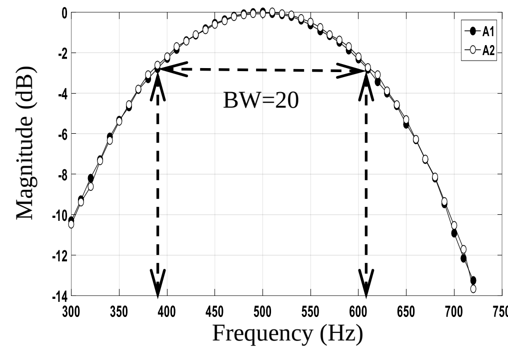

Fig. 10 Magnitude spectrum of FIR Kaiser Bandpass filter arithmetic of floating-point (white circle) and fixed-point (black solid circle).

5 Discussion

The distortion product spectra in Fig. 3 (a) showed the obvious frequency components of stimulus frequencies f_1 of 4 KHz with amplitude spectrum of 30 dB and f_2 of 5 KHz with amplitude spectrum of 22 dB, while cochlear response frequency components of Dp_1 of 1 KHz with amplitude spectrum of 18 dB, Dp_2 of 2 KHz with amplitude spectrum of 10 dB, Dp_3 of 3 KHz with amplitude spectrum of 17 dB, Dp_4 of 6 KHz with amplitude spectrum of 14 dB, and other distortion product components that in turn indicates heathenness of subject cochlear function. An extraction of distortion product frequency component of Dp_1 for filter parameters of β=0.5 in Fig.3 (b) showed multiple frequency components due to non-robust characteristics of filter design, while at β of 5 and 10 in Fig. 3 (c and d) showed only Dp_1 component due to robust characteristic of filter design, particularly for β of 10 where the waveform in time domain measured RMS amplitude and amplitude spectrum higher than at β of 5. The same situation occurred for the extraction of Dp_2 as in Fig. 4 (a-c), Dp_3 as in Fig. 5 (a-c), and Dp_4 as in Fig. 6 (a-c), where filter parameter of β=10 showed higher amplitude.

In addition, the filter response at β of 0.5 in Fig. 7 (a) showed also multiple distortion product components due to non-robust filter characteristics, while at β of 5 in Fig. 7 (b) showed only single component of Dp_3 according to the design characteristics.

In Fig. 8, a simulation characteristic of filter frequency spectra illustrates coincidence between the reference and quantized frequency spectra, while of Fig. 9 illustrates slightly deviation between reference and quantized frequency spectra due to the fact that quantization less influence in FIR than infinite impulse response (IIR) [39].

The magnitude spectrum of Fig. 10 conducted for both floating-point and fixed-point arithmetic, and are highly coincidence within design bandwidth of 200 Hz, while deviation occurred within filter transition region due to the fact that quantization of FIR filter deviates zeros around unite circuit in z-plane, which in turn reduces attenuation at transition band and stop band [40]. On the other hand, the magnitude spectrum of Fig. 10 showed 200 Hz bandwidth that is inconsistent with the designed bandwidth of 100 Hz that would be considered for extracting closely located frequency components of spacing less than 100 Hz.

According to the results of Fig. 10, it has pointed out that filter characteristic of fixed-point can be considered for filter design of greater than 128 coefficients to obtain robust filter characteristics of narrow bandwidth, which is capable to extract frequency components located at frequency spacing of less than 100 Hz occurred when f_2/f_1 of 1.1 and low stimulus frequency (f_1) of less than 600 Hz.

6 Conclusion

The study analyzed the cochlear response by extracting distortion product otoacoustic emission in real-time using a digital signal processor and DPOAE probe system. A bandpass FIR Kaiser Filter with 128 coefficients considered for both floating-point and fixed-point arithmetic. The results showed the ability to extract frequency components of DPOAE for spacing greater than 100 Hz, particularly for filter shape parameters 5 and 10. In the simulation procedure, the magnitude and phase spectra for floating-point arithmetic coincided with reference characteristics, while fixed-point arithmetic showed slight deviation. In a real-time implementation, the magnitude spectrum coincidence observed for both floating-point and fixed-point arithmetic within the bandwidth (-3 dB), but deviation started within the transition band. The study suggests using fixed-point arithmetic of 8-bit numerator word length for robust filter characteristic of coefficients higher than 128 to extract frequency components of spacing less than 100 Hz. Further research is recommended by considering a validation of the experiment scenario at noisy environment that represented by internal noise generated due to patient's physiology and patient's motion, while external noise generated due to daily activity of clinic room, that would be diminished by including adaptive signal processing techniques.

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Aws Alazawi received the B.Sc. degree in Electrical and Electronics Engineering, from MEC, Baghdad-Iraq, in July 1998, the M.Sc. degree in Electrical and Electronics Engineering\Signal Detection, from MEC, Baghdad-Iraq, in August 2003, the Ph.D. degree in Electronics and Electrical Engineering/Biomedical Signal Processing, from Strathclyde University, UK, in Nov. 2015. His research field of interests includes ultrasound elasticity imaging, breast malignant region differentiation-based ultrasound image segmentation, hematological image analysis, cochlear response extraction, skin cancer classification based microscopic image analysis, biomedical sensing system design, and three-dimensional visualization of Covid-19 lungs infection region. Dr. Alazawi is also an author of fifteen research publications, and a member of scientific committee for five conferences. He is currently an academic staff at the department of medical instrumentation engineering techniques/Electrical Engineering Technical College/Middle Technical University. He can be contacted at email: aws_basil@mtu.edu.iq.

Huda Farooq Jameel received her B.Sc. in Medical Instrumentation Techniques Eng. from Middle Technical University, Iraq in 2006. She is with the Department of Medical Instrumentation Engineering Techniques, Electrical Engineering Technical College, Middle Technical University, Baghdad-Iraq, as Technical Engineer. In 2020 she has a master degree Tech. in Medical Instrumentation Engineering Techniques, from Electrical Engineering Technical College, Baghdad-Iraq. She interested in controlling medical device, image processing, and signal processing. She is currently an academic staff at the department of medical instrumentation engineering techniques\Electrical Engineering Technical College/Middle Technical University. She can be contacted at email: huda_baban@mtu.edu.iq.

Mohammed Sameer Mohsen received his B.Sc. in Medical Instrumentation Techniques Eng. From Middle Technical University, Iraq in 2005. He is with the Department of Medical Instrumentation Engineering Techniques, Electrical Engineering Technical College, Middle Technical University, Baghdad-Iraq, as an Assistant teacher. Has MSc degree in Biomedical Engineering Techniques, from Biomedical Engineering College, University polytechnic of Bucharest, Bucharest - Romania in 2018. Interested in studies dealing with medical electronics, Biomechanics, generation of alternative energy without the use of batteries, design of medical devices with low cost and high efficiency, biomedical sensors, applications of microcontrollers, and medical imaging devices and medical image processing. He can be contacted at email: Mohammed.sh.c@mtu.edu.iq.