Effect of some factors and variables on the frequency - time distribution of the otoacoustic emissions

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The hearing process of the ear consists of two parts, the first part is related to the ear and its anatomy and the second part is related to the sound and its properties. Therefore, it is expected that there are a number of factors and variables, including those related to the ear, including sound related to the audio process. In this study, the effect of two of these factors on the otoacoustic emission is studied in general and in particular the frequency map. The relationship between frequency and quality factor is examined by changing the stimulus level.

Keywords: Hear process; Frequency map; Stimulus level; Sound.

1. INTRODUCTION

Due to high request of effective and accurate sensors, research is ongoing for new elements and methods to design and build biosensors that are based on capacitive electrodes. Common capacitive structures such as parallel plate and interdigitated electrodes (IDEs) are used widely in the literature, the first is distinguished by unpretentious design in terms of modeling [1], whereas, the second is more favored due to its effectiveness in acquiring stable and fixed temperature for the dielectric [2].

Four different electrodes models discussed thoroughly in the literature can be used as some capacitive sensors; interdigitated electrodes, spiral electrodes, meandered electrodes and serpentine electrodes. IDEs are considered for sensing; the signals have been detected by sensing materials. Analytical equations for the capacitance between electrodes fingers have been developed, which proposed a general model that can be used for any dimension and finger width as well as any number of layers with different permittivity and thickness [3]. The geometry of interdigitated schottky-barrier has been enhanced thus, the quantum efficiency and response time are analyzed and the optimum spacing for interdigitated photodetector has been identified [4]. The process of IDEs manufacturing consists of different steps of exposure, photoresist coating and etching processes using special instruments [5-10]. Therefore, many attempts have been done for simplifying the fabrication process by introducing some new and different ones such as inkjet-printing [11-13], screen printing [14],
micro fabrication [15] and stamp method [16]. IDEs have been explored extensively and used widely in many applications such as humidity sensing [17], gas sensing [18], bacteria sensing [19], pressure sensing [20], DNA sensing [21], pH sensing [22] and immunosensor [23]. The hearing process is very important to human communication in individuals [1]. Our auditory ability is due to the complex automated transmission that takes place within the inner ear that turns the waves caused by pressure into signals transmitted through the auditory nerve to the brain. Takes mechanical energy and produces electrical energy [2]. The inner ear contains an amplification system that leads to the generation of sounds within the cochlea and is transformed into the ear canal through the middle ear. These sounds are known as otoacoustic emissions (OAEs). OAE are acoustic signals generated from within the inner ear, which can be recorded in the ear canal using a sensitive microphone [3-4]. OAE are a consequence of the nonlinear and active pre-processing of sound in the cochlea [3]. OAE was first demonstrated by (David Kemp in 1978) [5]. Otoacoustic emissions have since been shown to arise through a number of different cellular and mechanical causes within the inner ear [6-7]. Studies have shown that OAEs disappear after the inner ear has been damaged, so OAEs are often used in the laboratory and clinic as a measure of inner ear health [3]. OAEs have been used to explore the differences in the auditory system between sexes, with a number of studies suggesting that females have larger OAEs than males [8-9]. There are several evidences to suggest that the outer hair cells in the human ear are enhanced by the sensitivity of the cochlea and frequency selectivity [10]. The mechanical process resulting from the transmission of sound through the ear to the movement of the tympanic membrane causes the transfer of the wave in the cochlea fluids along the basilar membrane. Therefore, the outer hair cells on the basilar membrane are part of this. This active process is emitted from an incoming signal to the auditory nerve and the incoming signal travels back to the outer ear canal through the middle ear where it can be detected [11]. Each part of the basilar membrane has a maximum sensitivity to the frequency closer to the characteristic oval window with higher frequencies, so the high frequency responses will have the shortest time to move back to the outer ear canal.

Otoacoustic emissions are measured by a probe placed in the ear canal containing microphone that records sound in the external ear canal. TEOAE is brief acoustic stimulus with a wide frequency spectrum respond to a large part of the basilar membrane, the acoustic stimulus is used with the spectrum at a range of (1000-4000 Hz) [11]. At high frequencies, spectroscopy of the TEOAE response can reveal cochlear damage due to noise or toxic drugs of the ear [12-13-14].

2. EXPERIMENTAL

We study here the otoacoustic emission of the ear using the nonlinear model by controlling two variables, the stimulus level and the quality factor, noting the effect of the factors on the distribution of frequency - time by studying a set of frequencies.

As in Adnan Al-Maamury (2018) [19], Adnan Al-Maamury (2015) [15] and Moleti et al. (2009) [17], we refer the nonlinear model is mathematically described as follows:

\[
\frac{\partial^2 P(x, 0, t)}{\partial X^2} = \frac{2\rho}{H} \xi(x, t)
\]  

(1)
\[
\ddot{\xi}(x,t) + \gamma_{bm}\dot{\xi}(x,t) + \omega_{bm}^2\xi(x,t) = \frac{P(x,0,t)}{\sigma_{bm}}
\]  \hspace{1cm} (2)

In the above equations, the fluid density is denoted as \(\rho\), the BM surface density is \(\sigma_{bm}\), BM transverse displacement at the longitudinal position is \(x\) and time is \(t\), and it is assumed that a cochlear duct of rectangular constant cross section of length \(L\) and half-height \(H\).

The dynamics of a passive oscillator driven by differential pressure is described by Equation (2).

The relation between longitudinal position \((x)\), angular frequency and passive damping constant of the tonotopically resonant are set by Greenwood (1990) [18] as in Talmadge et al. (1998) [16].

\[
\omega_{bm}(x) = \omega_0 e^{-k_{ax} + \omega_1}
\]  \hspace{1cm} (3)

\[
\gamma_{bm}(x) = \gamma_0 e^{-k_{rx}} + \gamma_1
\]  \hspace{1cm} (4)

The quality factor is denoted as \(Q(x)\) and the local passive quality factor is defined as:

\[
Q(x) = \frac{\omega_{bm}(x)}{\gamma_{bm}(x)}
\]  \hspace{1cm} (5)

3. RESULTS AND DISCUSSION

There are some factors and variables have a clear effect on the hearing mechanism of these factors, anatomy of the ear and nature, age and other related to the sound such as the stimulus level of the sound and the quality factor.

In this study, otoacoustic measurements of the ear were taken with two variables, namely the stimulus level and the quality factor to study the relationship between the auditory process represented by frequency-time distribution and the factors expected to affect the auditory process. This relationship was studied by a set of different frequencies (0.8227, 1.304, 2.067, 3.271, 4.134 and 5.197) KHz. The results of the research that obtained of the otoacoustic emissions are presented in the form of steps and according to the selected frequencies, as follows:

First step: the frequency (0.8227 KHz)

In this case, the otoacoustic emission is studied for a different set of quality factors (2, 4, 6, 8, 10, 14, 16, 18 and 20). Different stimulus levels (30, 40, 50, 60, 70, 80 and 90) dB are used for each value of the quality factor.

According to this method, arithmetic sets show the frequency-time distribution, this distribution shows the relationship between frequency and time and according to the method,
it will be clear that there are some differences in time due to the effect of changing the stimulus level and the quality factor.

Figure (1) shows all the information for frequency 0.8227 KHz where it contains seven different curves each curve showing the relationship between time and quality factor. It refers to a single stimulus level, so the number of curves equals the number of stimulus levels used in the computations. It is generally concerned with frequency 0.8227 KHz and all its information. It shows the frequency-time distribution and shows the relationship between time and the quality factor. It also gives information for the frequency-time relationship by changing the quality factor and the stimulus level.

Second step: the frequency (1.304 KHz)
In this case and the following cases, the same technique is used in the first step to study the otoacoustic emission. The same values of the coefficient of quality and intensity levels are used in calculations.

According the results, the frequency-time distribution shows the relationship between frequency and time and according to the method, it will be clear that there are some differences in time due to the effect of changing the stimulus level and the quality factor.

Figure (2) shows all the information for frequency 1.304 KHz where it contains seven different curves each curve showing the relationship between time and quality factor. It is generally concerned with frequency 1.304 KHz and all its information. It shows the frequency-time distribution and shows the relationship between time and the quality factor, and gives information for the frequency-time relationship by changing the quality factor and the stimulus level.
Third step: the frequency (2.067 KHz) In this case, Figure (3) shows all the information for frequency (2.067) KHz where it contains seven different curves each curve showing the relationship between time and quality factor. Each curve in the figure refers to a single stimulus level, so the number of curves equals the number of stimulus levels used in the computations. It is generally concerned with frequency (2.067) KHz and all its information. It shows the frequency-time distribution and shows the relationship between time and the quality factor. It also gives information for the frequency-time relationship by changing the quality factor and the stimulus level.

Fourth step: the frequency (3.271 KHz)
In this case, Figure (4) shows all the information for frequency (3.271 KHz) where it contains seven different curves each curve showing the relationship between time and quality factor. Each curve in the figure refers to a single stimulus level, so the number of curves equals the number of stimulus levels used in the computations. It is generally concerned with frequency (3.271 KHz) and all its information. It shows the frequency-time distribution and shows the relationship between time and the quality factor. It also gives information for the frequency-time relationship by changing the quality factor and the stimulus level.

Figure (4) shows the relationship between the frequency 3.271 KHz and other parameters

Fifth step: the frequency (4.134 KHz)
In this case, the same technique is used to study the otoacoustic emission. According to this method, arithmetic sets show the frequency-time distribution, this distribution shows the relationship between frequency and time and according to the method, it will be clear that there are some differences in time due to the effect of changing the stimulus level and the quality factor.

Figure (5) shows all the information for frequency (4.134 KHz) where it contains seven different curves each curve showing the relationship between time and quality factor. Each curve refers to a single stimulus level, so the number of curves equals the number of stimulus levels used in the computations. It shows the frequency-time distribution and shows the relationship between time and the quality factor. It also gives information for the frequency-time relationship by changing the quality factor and the stimulus level.
Sixth step: the frequency (5.197 KHz)
The last case does not differ from all previous cases in terms of calculations, taking into account the use of two parameters, the stimulus level and the quality factor. In the otoacoustic emissions calculations, the stimulus level is changed according to the values (30, 40, 50, 60, 70, 80 and 90) dB, at the same time, the value of the quality factor (Q) is changed according to the values (2, 4, 6, 8, 10, 12, 14, 16, 18 and 20).

According to this method, arithmetic sets show the frequency-time distribution, this distribution shows the relationship between frequency and time and according to the method, it will be clear that there are some differences in time due to the effect of changing the stimulus level and the quality factor.

Figure (6) shows all the information for frequency (5.197 KHz) where it contains seven different curves each curve showing the relationship between time and quality factor. Each curve in Fig. 6 refers to a single stimulus level, so the number of curves equals the number of stimulus levels used in the computations. Finally, good information is available on the relationship between frequency, stimulus levels, quality factor and time for all cases.
4. CONCLUSIONS

It is concluded that the quality factor and stimulus levels have a clear vary effect on the otoacoustic emission. The behavior of the quality factor and its effect on the otoacoustic emissions is based on the low and high values and the effect is clear to the low values, this result is consistent with previous studies [19-20]. In general, we believe that there are some variables have an effect on the auditory process as an example of these influential factors and variables roughness, As roughness has an effect on other transactions and variables [21]. As for the effect of the stimulus level, the behavior of the stimulus levels divided into two groups according to their effect on the otoacoustic emission, the first group is the low stimulus levels such as 30 dB and 40 dB and the second group is high stimulus levels such as 80 dB and 90 dB. For low frequencies such as 0.822 KHz, it is observed that the effect of the stimulus levels is clear, as the low levels such as 30 dB are different from the high levels in terms of the time value of the otoacoustic emission as the change in time is greater. The high stimulus levels such as 90 dB, the time of the otoacoustic emission ranges from 8 ms to 11ms for the quality factor values 2 to 20. While the time of the otoacoustic emission of the low levels ranges from 10 ms to 16 ms for the values 8 to 20 for the quality factor and similar to the high levels of values 2 to 8 for the quality factor, this situation is shared by a range of frequencies such as frequency 0.8227 KHz. As for frequencies 1.304 KHz the effect exists but is different from the previous group, the stimulus levels effect is different for the quality factor values less than 8, while the values greater than 8 have almost the same effect. The frequency 2.067 KHz is a characteristic frequency in terms of the behavior of the stimulus levels and their effect on the otoacoustic emission for all values of the quality factor. Through the results of all frequencies. For frequencies 4.134 KHz and 5.197 KHz, the change of time is from 9ms to 12ms for all levels and for almost all the values of the quality factor. According to the results
obtained in this study, it is concluded that levels are classified into two categories, the first category is the low stimulus levels and the second category is the high stimulus levels. The quality factor in terms of its values is classified into two categories: the first category is the low values and the second category is the high values. The frequencies are classified into three categories: Class I is the low frequencies; Class II is the intermediate frequencies and Class III the high frequencies. Where the frequency 2.067 KHz is the best frequency in terms of systematic results.

References