Study the Effect of the Different Stimulation Levels for TEOAEs by the Non-Linear Models

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ABSTRACT

In this work, we study the effect of different stimulation levels on TEOAEs in the hearing process using non-linear models for the stimulus levels (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120) dB. We found that the latency as a function to stimulation level, by the results of TEOAEs we get from the different stimulus levels in the relationship of time-frequency. Therefore, relationship of time-frequency is very important in comparison results the different stimulus level with the previous studies and also useful in the study of hearing process in humans. At the analysis of relationship of time-frequency we get a lot of the results that show the characteristics for TEOAEs. From these results obtained in study the effect of different stimulus levels for TEOAEs in the relationship of time-frequency are the energy distribution and waveform behavior of TEOAEs. Energy distribution of TEOAEs shows the pool (concentration) energy in a number of spots (points) and the energy distribution varies from one stimulus level to another. Effect of waveform behavior TEOAEs by different stimulus levels, so latency is as a function to the frequency and the stimulation level.
Keywords: Non-Linear Model, Stimulation Levels, TEOAEs Latency, and TEOAEs Frequency.

1. INTRODUCTION

After 20 years on the discovery Kemp 1978, otoacoustic emissions (OAEs) have become widely used in the field of diagnostic and clinical examination [1, 2, 3, 4, and5] for the detection of early hearing loss, And so by many researchers note a relationship between the hearing deterioration and several OAE parameters [6]. Demonstrated when the absence of transient evoked otoacoustic emissions (TEOAEs) in the ears leads to the audiometrically weakness frequency range, for hearing threshold levels more than 20 dB [6, 7, and 8], this within clinical roles other potential, and which ones newborn screening [9]. So used OAE test target as the hearing threshold is limited by the complexity of their generation mechanisms [9].

Until now, the generation OAEs mechanism does not fully create. According to Shira and Guinan 1999 [10], two reasonable mechanisms have been proposed for the generation TEOAEs in the cochlea are: 1) non-linear intermodulation distortion (IMD) because of non-linear characteristics of the basement membrane (BM) [9, 11, and 12], 2) linear reflection from cochlear regions extended toward the base [11, 13]. The two components are characterized through latencies and curves different (short-latency, curves more accurate for non-linear distortion and long-latency, curves least accurate for linear reflection) [9, 14], so can of excellence between them by analyzing resulting the responses TEOAEs from the different stimulation levels of technique latency-frequency analysis.

Experimental studies provided plenty of evidence on the existence of: 1) A long latency-transient evoked otoacoustic emission (LL-TEOAE) component [11, 15, 16, and 17], and this properties supports the generation of TEAOEs by coherent linear reflection generation from the tonotopic region. 2) Short latency-transient evoked otoacoustic emission (SL-TEOAE) component, which growing much faster with increasing stimulus level [11, 12, and 13], and this properties supports the generation of TEAOEs by non-linear intermodulation distortion (IMD). Recently, experimental and theoretical studies of modern [10, 11, 18, and 19] suggest that TEOAEs produces from linear reflection mechanism and not from non-linear distortion (It is mostly created by place-fixed linear reflection).

Latency is the time required for the transmission of the sound wave along the cochlear membrane from the base to the tonotopic site (As tonotopic sites are distributed along the basilar membrane of the cochlea according to the Greenwood frequency mapping) and back to the basement membrane of the new (the time of the distance traveled by the sound wave within the cochlea), with a very small contribution comes from the transmission wave in the outer and middle ear [6]. Through the latency-frequency analysis techniques, we get the information about the transmission of the sound wave along the basement membrane, and this information can be defined latency as a function of frequency [6]. The evaluation of the relationship between latency, frequency, and the stimulation level of TEOAEs by: 1) tone bursts [6, 16, 20, and 21]. 2) Clicks [6, 15, 16, 22, 23, 24, and 25]. 3) latency-frequency analysis techniques (according to recent studies). Experimentally, you can prediction in LL, SL- TEOAEs on the basis of transmission non-linear cochlear models (a set of mathematical algorithms).

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In this study, we use the time domain numerical solutions of non-linear differential equations of the model, showing many of the response to stimuli impulsive typical response characteristics TEOAE. We can get on the latency of transient evoked OAEs (TEOAEs) is a function of both the frequency of the emission and the stimulus level [6].

2. THE METHODS

The model used in this study is simple passive 1-D transmission line cochlear model [11, 26], nonlinear, with a term of antidamping nonlinear [9]. In this model, the main equations are described as follows:

$$\frac{\partial^2 p(x,0,t)}{\partial X^2} = \frac{2\rho}{H} \ddot{\xi}(x,t) , \qquad \qquad ..... (1)$$

$$\ddot{\xi}(x,t) + \gamma_{bm}\dot{\xi}(x,t) + \omega_{bm}^2 \xi(x,t) = \frac{p(x,0,t)}{\sigma_{bm}} , \qquad ..... (2)$$

Where:
X is the longitudinal coordinate along the BM [m].
t is the time [ms].
p is the differential fluid pressure on the BM [mPa].
ρ the density of the fluid [kg/m3].
$\xi(x,t)$ the BM transverse displacement at the longitudinal position X and time t [nm].
γ_{bm} dissipation constant of the local BM [ms-1].
ω_{bm} the resonance frequency of the local BM [ms-1].
σ_{bm} the BM of the surface density [kg/m3].
In the box model assume that the cross-section of the channel cochlear be fixed, its length L and half-height H [11]. Has been the introduction of the cochlear roughness (cochlear resistance) ε is the represented a small random fluctuation of the local resonance frequency, which is responsible for coherent linear reflection [27], controlled by the dimensionless parameter [11] $\Delta\omega_{bm}^2/\omega_{bm}^2$, so that in Eq. (6), we replace $\omega_{bm}^2 \rightarrow \omega_{bm}^2(1 + \varepsilon_r), r$ is a random number, normally distributed, with contrast equal to unity.
Eq. (2) is describes each cochlear position x, the dynamics of a passive oscillator resulting from differential fluid pressure only. Active terms, either commensurate with p or with n, which will be added later to equation schematize is the additional forces on the BM associated with the OHC mechanism [11]. The relation between longitudinal position x, angular frequency and passive damping constant are set by the Greenwood (1990) maps, as in [28].

$$\omega_{bm}(x) = \omega_0 e^{-\mathcal{K}_\omega t} + \omega_1,$$

$$\gamma_{bm}(x) = \gamma_0 e^{-\mathcal{K}_\gamma t} + \gamma_1 \qquad (3)$$

Although the scaling symmetry does not include real cochlea fully, because we have not introduced scale-invariance breaking terms in the model to preserve some useful properties of scaling-symmetric models, which makes it easy evaluate of the simulation results [11].
The first of the N elements of the discretized model includes the middle ear and oval window dynamics [26, 29]. Oval window applies boundary condition

$$\frac{\partial p}{\partial x} \bigg|_{x=0} = 2\rho\ddot{\xi}_{ow} \qquad (4)$$

Where:
$\ddot{\xi}_{ow}$ is the acceleration of the stapes.
The dynamical equation for the first element is

$$\ddot{\xi}_{ow}(t) + \gamma_{ow}\dot{\xi}_{ow}(t) + \omega_{ow}^2\xi_{ow}(t) = \frac{p(0,t) + G_{me}p_{dr}(t)}{\sigma_{ow}} \qquad (5)$$

Where:
γ_{ow} is the middle ear damping constant.
ω_{ow} is the frequency.
σ_{ow} is the effective oval window density.
p_{dr} is the standard pressure in the ear canal (the ear drum).
G_{me} is the middle ear mechanical gain of the ossicles.
Through [26, 30] can learn more details about the model into the state-space formalism, and [31] can knowledge analysis of the numerical method using for simulations.
In antidamping models, the additional pressure on the BM results through the OHC proportional to the BM transverse velocity. Through the introduction of additional force as a the non-linear function of the model we get

$$p_{add} = \sigma_{bm}\Gamma_{nl}(\dot{\xi})\dot{\xi} ,$$

$$\Gamma_{nl}(\dot{\xi}) = (\gamma_{bm} - \Gamma_a)\left(1 - \tanh\left(\frac{\xi^2}{\xi_{sat}^2}\right)\right), \qquad (6)$$

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Where:

$\dot{\xi}^2$ is a Gaussian average of the square of the BM velocity over a length scale of order one-tenth of octave.

$\dot{\xi}^2_{sat}$ is the transverse velocity scale around which the abovementioned transition between the two asymptotic linear regimes occurs [26].

The "effective damping function" becomes

$$\Gamma_{eff}(\dot{\xi}) = \gamma_{bm} - (\gamma_{bm} - \Gamma_a)\left(1 - \tanh\left(\frac{\xi^2}{\xi^2_{sat}}\right)\right) \qquad (7)$$

So Eq. (2) becomes

$$\ddot{\xi}(x,t) + \Gamma_{eff}(\dot{\xi})\dot{\xi}(x,t) + \omega^2_{bm}(1 + \varepsilon_r)\xi(x,t) = \frac{p(x,0,t)}{\sigma_{hm}} \qquad (8)$$

The effective damping be the velocity almost constant in the lower levels $(\Gamma_{eff} = \Gamma_a)$ and high $(\Gamma_{eff} = \gamma_{bm})$; and increases quadratically with BM velocity in the low to intermediate level range, create cubic distortion products [11]. Which is define:

$$\alpha(\dot{\xi}) = \alpha_0\left(1 - \tanh\left(\frac{\xi^2}{\xi^2_{sat}}\right)\right), \qquad (9)$$
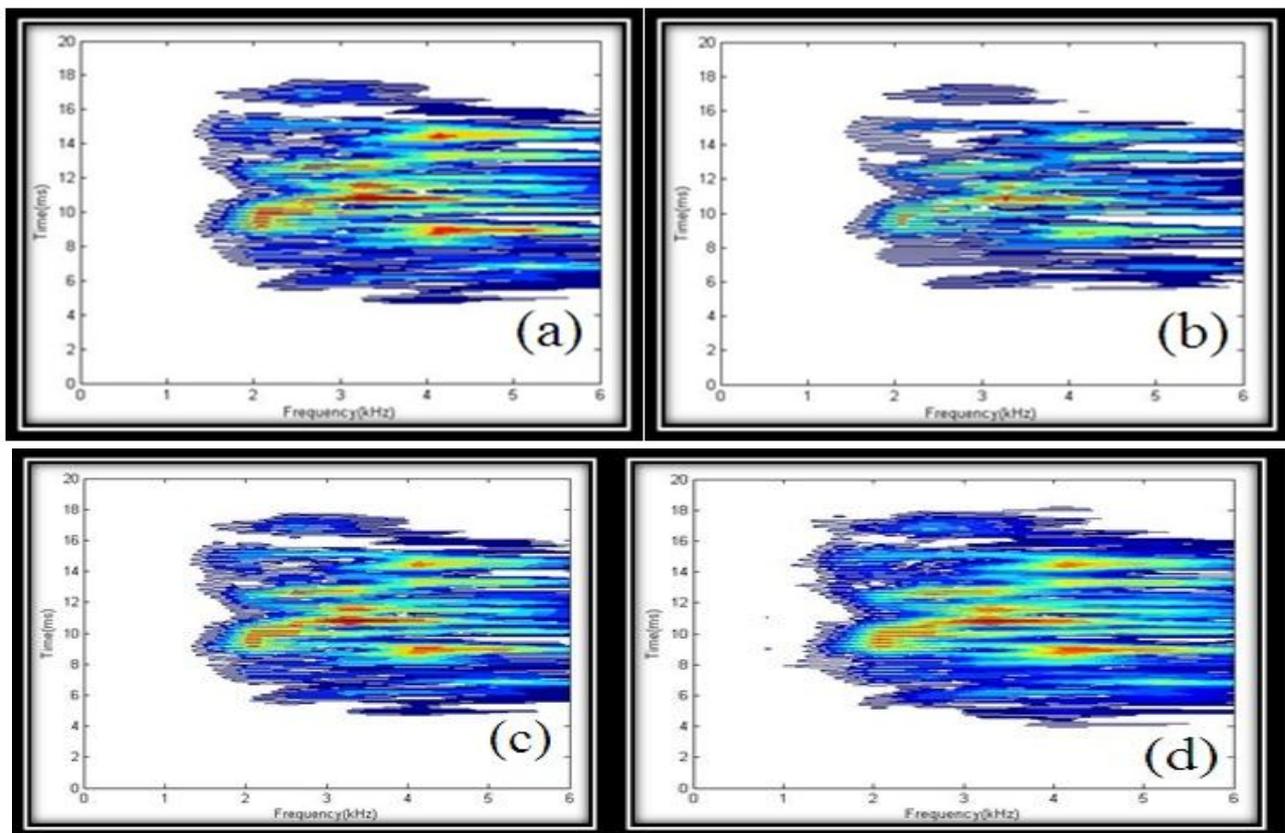
So that

$$\alpha_0 = \frac{(\gamma_{bm} - \Gamma_a)}{\gamma_{hm}} \quad . \qquad (10)$$

In this model, the two parameters γ_{bm} and Γ_a are working on determine the form of the nonlinear response of the cochlear amplifier. The active nonlinear anti-damping term of the second line of Eq. (6) is little different from that used in [30], where Γ_{nl} is a nonlinear function of the BM transverse displacement. Stimulation process occurs in this model using parameter N=1000, Roughness=0.001, Nonlin term=7..*10^{-2}, tmax (ms) =20, Nt =1024, TEOAEs=click 0.05 ms - 10 kHz.

3. RESULTS AND DISCATION

In this study, we use the values of the different stimulation levels (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120) dB for the same frequency, to get the effect of the different stimulation levels for energy distribution and waveform behavior of TEOAEs, accordance to the relationship latency-frequency by use a non-linear model. We get the following results:

3.1 The results of the different stimulation levels on energy distribution of TEOAEs:

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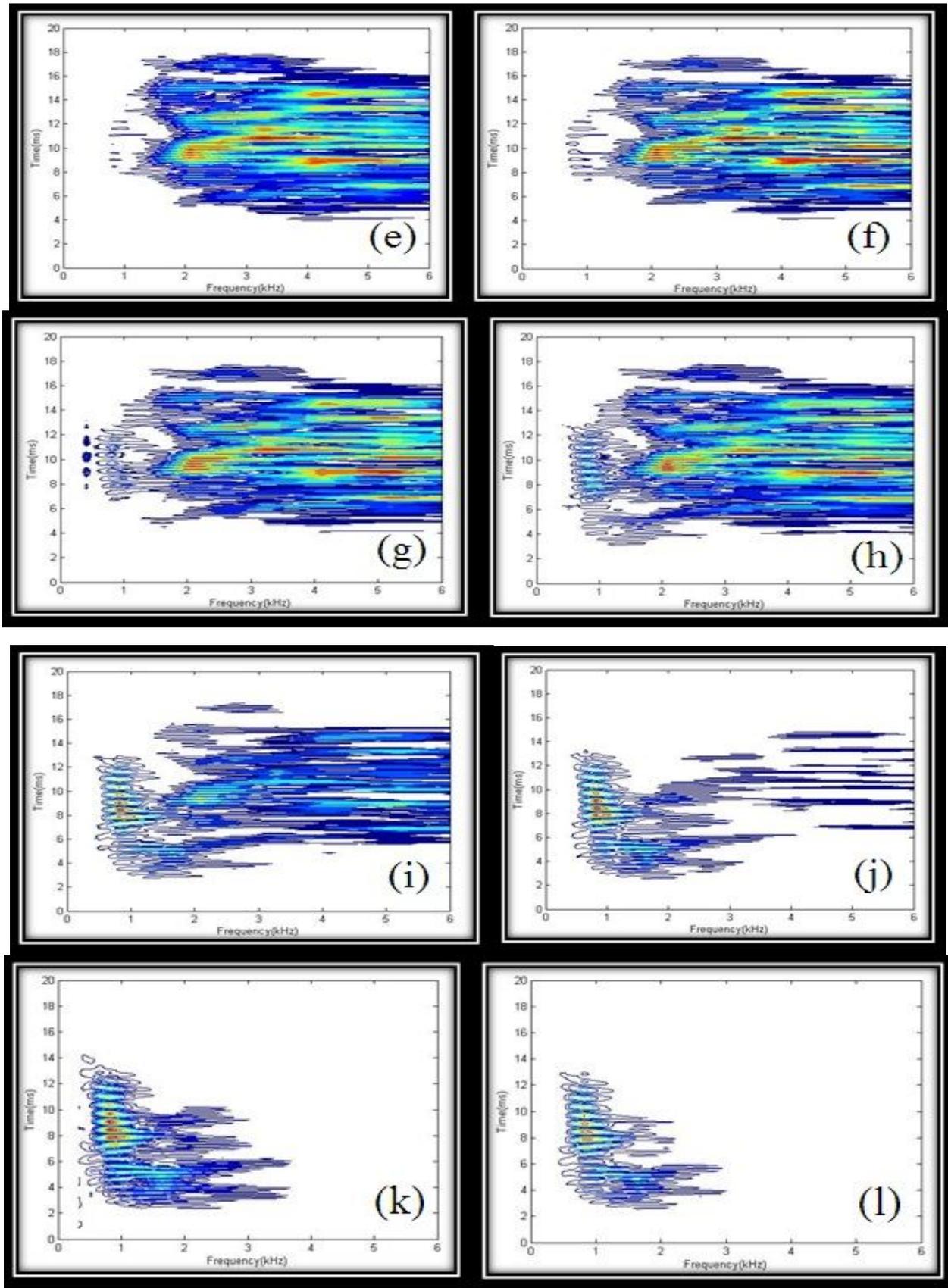
Figure 1 shows the energy distribution TEOAEs in the different stimulation levels, (a) stimulus level 10 dB, (b) stimulus level 20 dB, (c) stimulus lev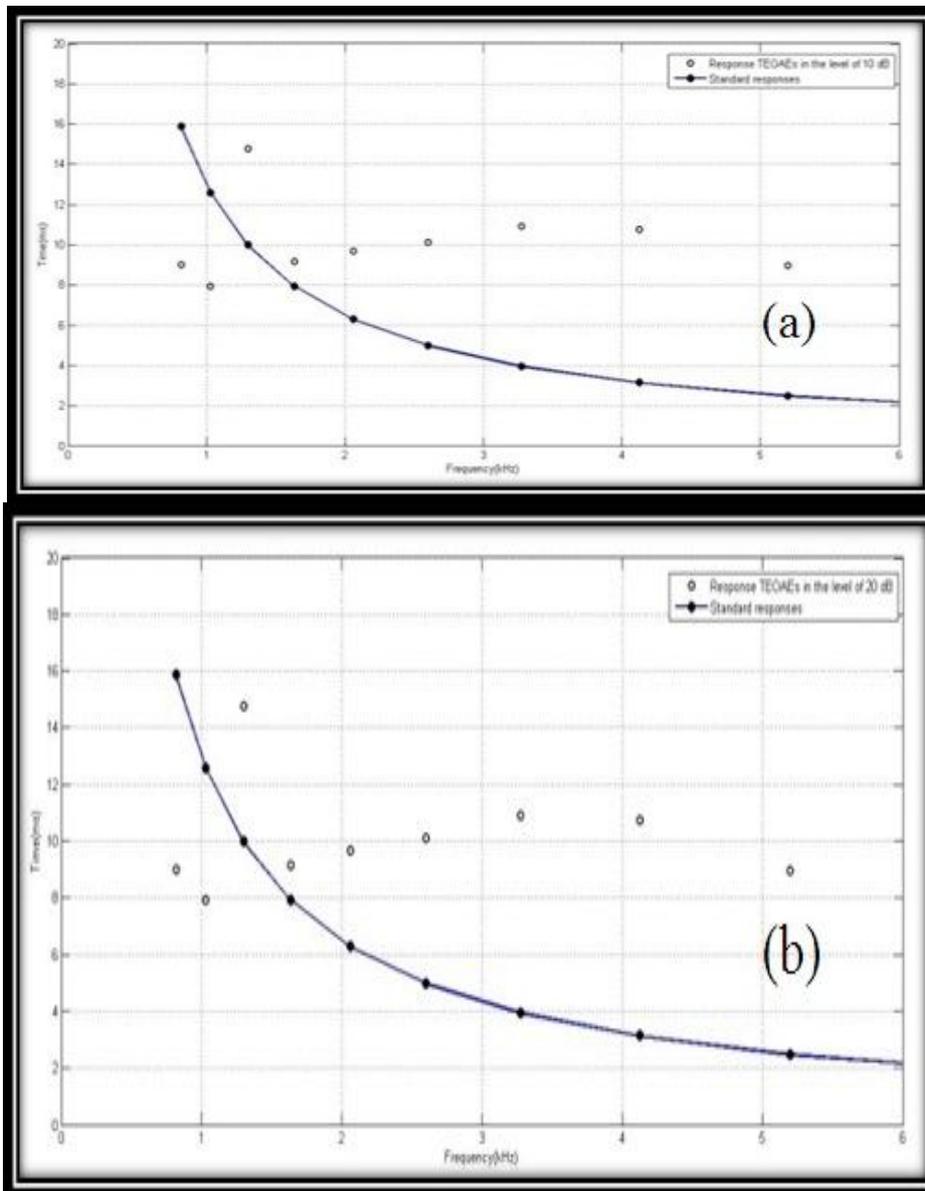el 30 dB, (d) stimulus level 40 dB, (e) stimulus level 50 dB, (f) stimulus level 60 dB, (g) stimulus level 70 dB, (h) stimulus level 80 dB, (i) stimulus level 90 dB, (j) stimulus level 100 dB, (k) stimulus level 110 dB, and (l) stimulus level 120 dB.

Figure (1) which is obtained, show emission responses from the inner ear (cochlea) and that result from the effect of different stimulation levels. The figure (a), (b), (C), (d), (e), (f), (g), (h), (i), (j), (k), and (l) is represents the values of the stimulus levels (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120) dB, respectively, which have the energy distribution TEOAEs is concentrated in a set of points (spots).
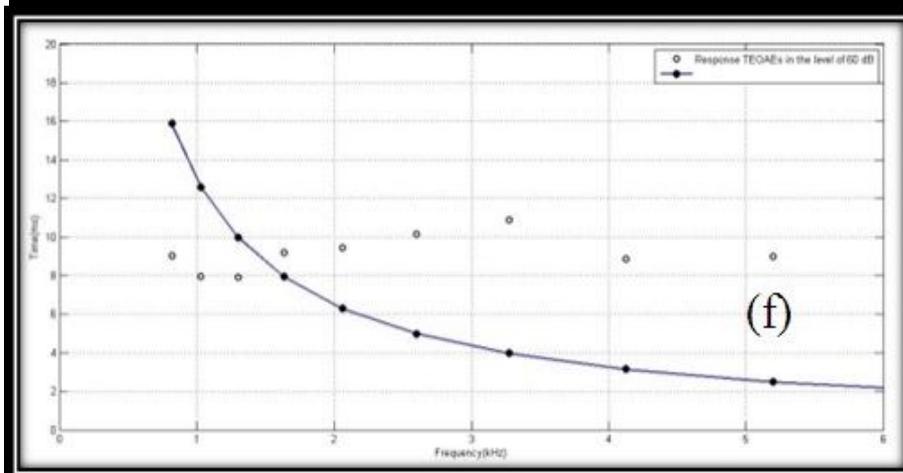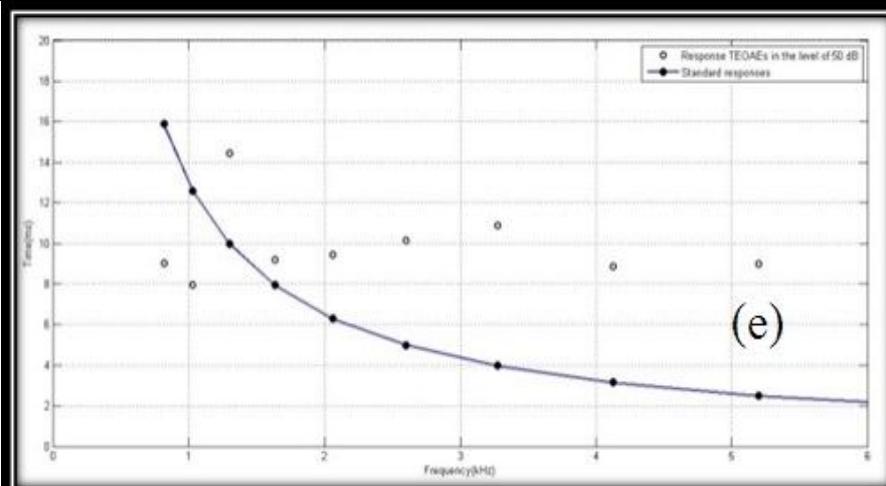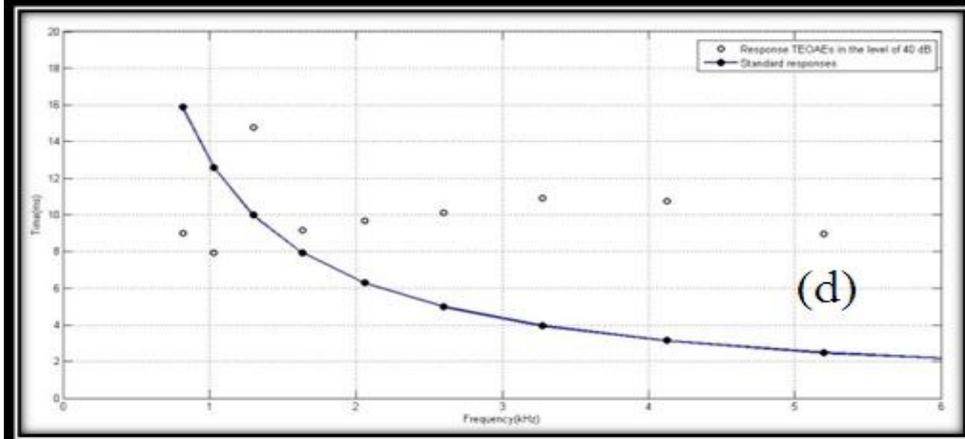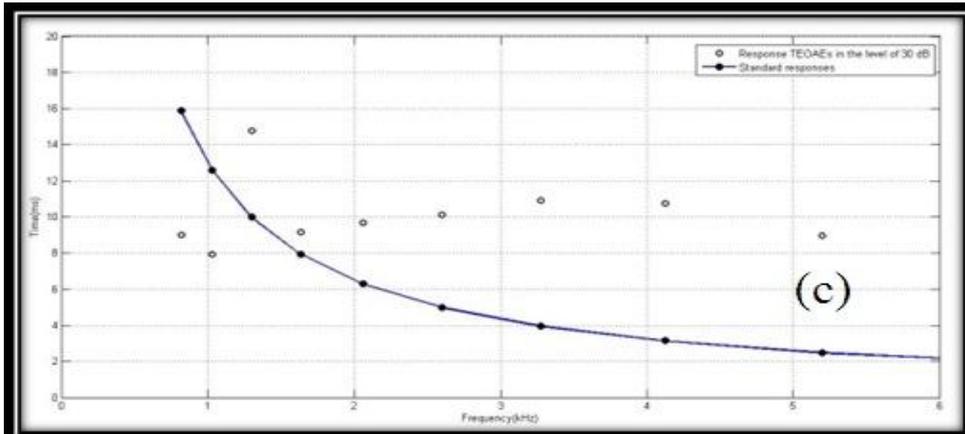
The figure (a), (b), (C), (d), and (e)is represents low-stimulus levels (10, 20, 30, 40, and 50) dB, respectively, which have the energy distribution TEOAEs is concentrated in the number of spots, located within the package of frequencies ranging from 2.2 kHz to 4.2 kHz approx, amount of latency is from 8.5 ms even up to about 14.5 ms, and these spots are very clear in these levels.
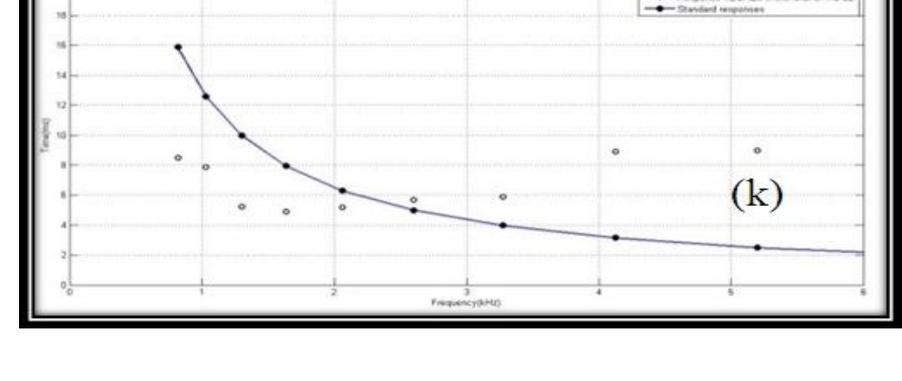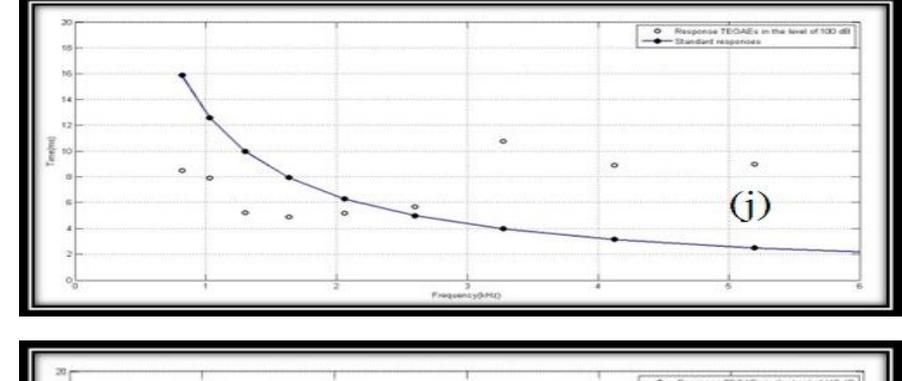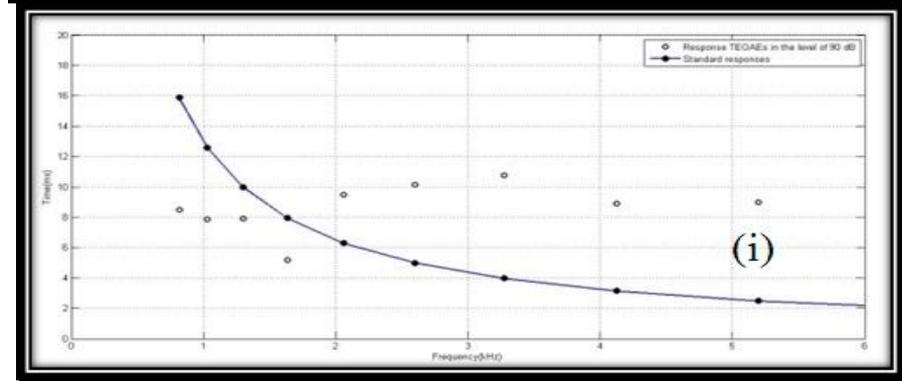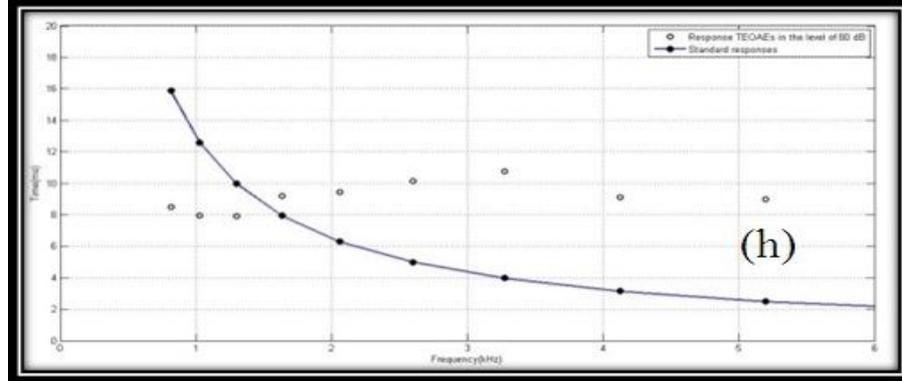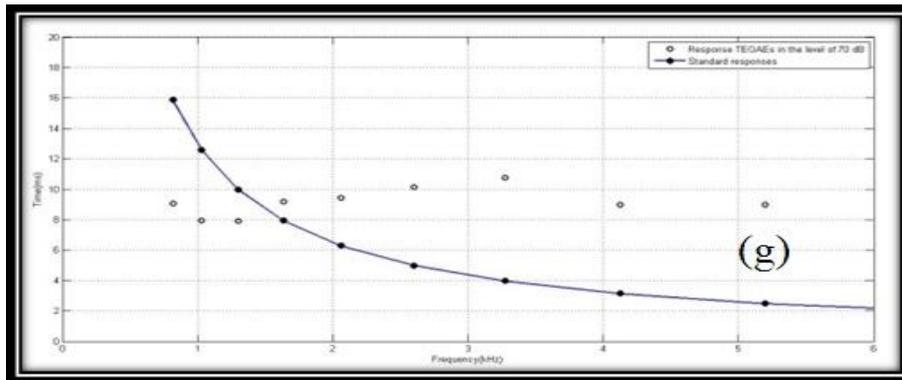
The figure (f), (g), (h), and (i)is represents medium-stimulus levels (60, 70, 80, and 90) dB, respectively, which have the energy distribution TEOAEs is concentrated in the slightly larger number of spots, located within the package of frequencies ranging from 2.2 kHz to 5.3 kHz approx, amount of latency is from 7 ms even up to about 14.5 ms, and these spots are less clear from the low-stimulation levels.

The figure (j), (k), and (l) is represents high-stimulus levels (100, 100, and 120) dB, respectively, which have the energy distribution TEOAEs is concentrated in a very little number compared with points other stimulation levels, located within one frequency almost equal to 0.9 kHz,amount of latency is from 7 ms even up to about 11 ms. In these levels, we note fading energy of TEOAEs and their decline in the low-frequency region, and gathering these spots within one frequency with the same repetition through repeated reflection. These figures are consistent with previous studies [1, 6, 10, and 11].

3.2 The results of the different stimulation levels on waveform behavior of TEOAEs:

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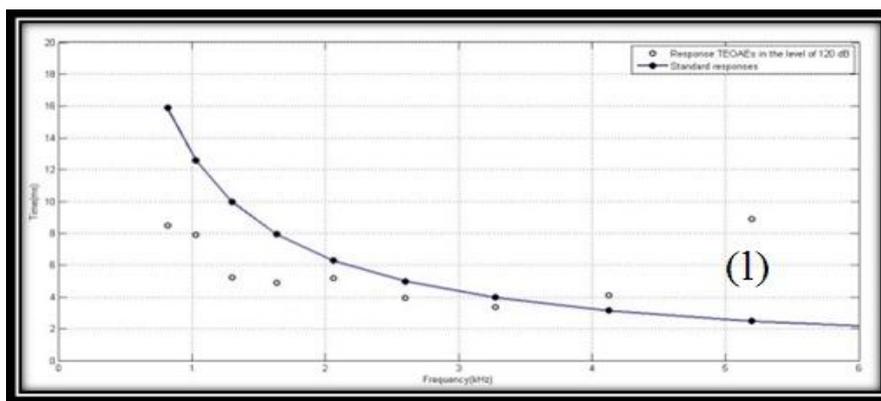**Volume 4, Issue 11, November 2015** **ISSN 2319 - 4847**

Figure (2) shows the waveform behavior TEOAEs in the different stimulation levels, (a) stimulus level 10 dB, (b) stimulus level 20 dB, (c) stimulus level 30 dB, (d) stimulus level 40 dB, (e) stimulus level 50 dB, (f) stimulus level 60 dB, (g) stimulus level 70 dB, (h) stimulus level 80 dB, (i) stimulus level 90 dB, (j) stimulus level 100 dB, (k) stimulus level 110 dB, and (l) stimulus level 120 dB for the relationship latency-frequency.

Figure (2) is representing emission responses from the cochlea, which result from the effect of different stimulation levels. The figure (a), (b), (C), (d), (e), (f), (g), (h), (i), (j), (k), and (l) is represents the values of the stimulus levels (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120) dB, respectively. Through the figure (2) is obtained table (1), which allows us to know the waveform behavior of TEOAEs at different stimulation levels.
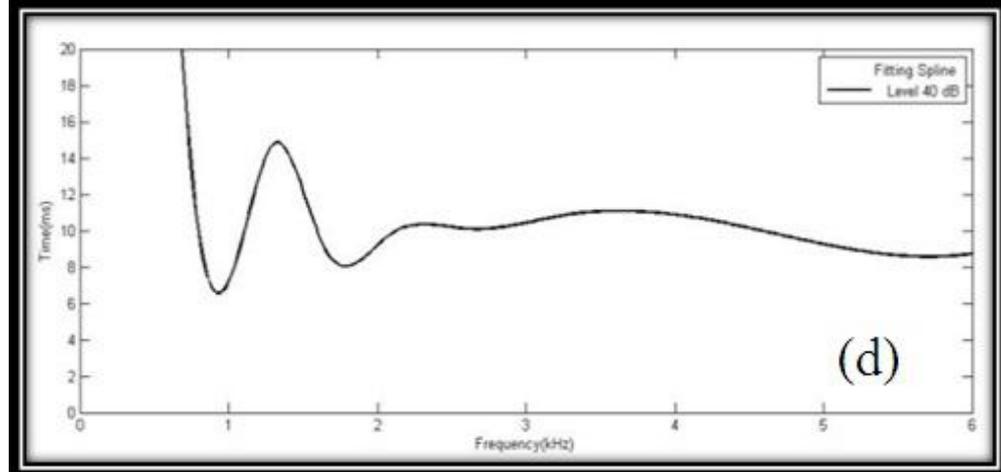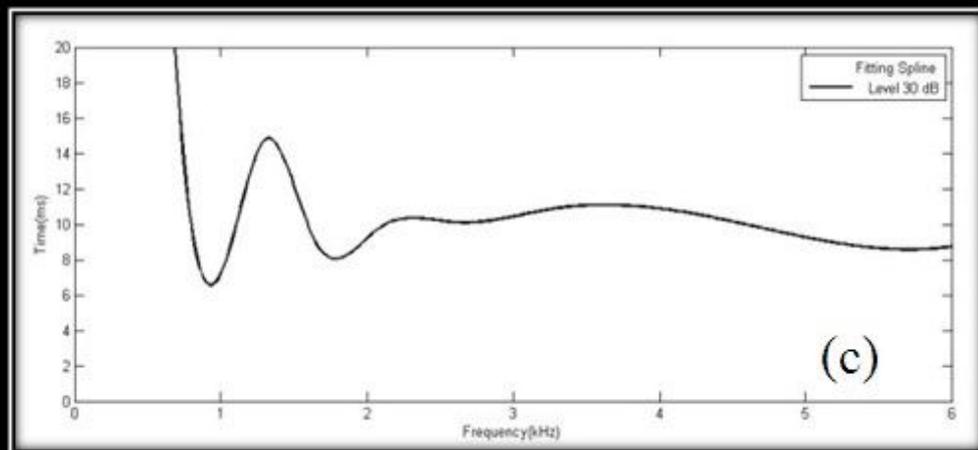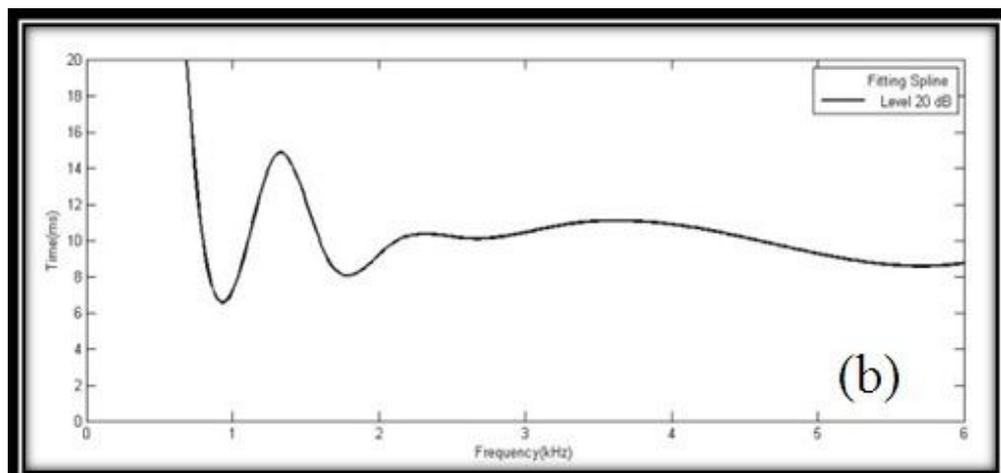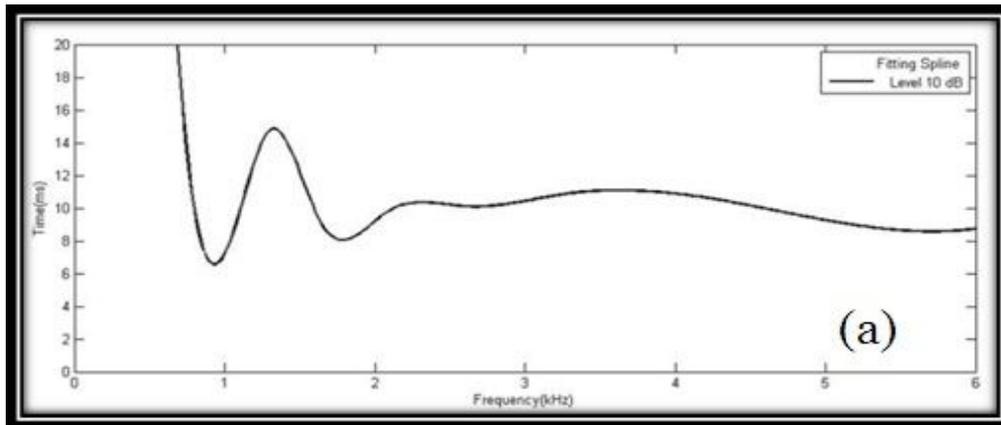
LEVEL	*10 DB*	*20 DB*	*30 DB*	*40 DB*
FREQUENCY	*TIME*	*TIME*	*TIME*	*TIME*
0.8189	*9.0234*	*9.0429*	*9.0429*	*9.0429*
1.0318	*7.9296*	*7.9492*	*7.9492*	*7.9492*
1.3	*14.7851*	*14.7851*	*14.7851*	*14.7851*
1.6378	*9.1796*	*9.1992*	*9.1992*	*9.1992*
2.0636	*9.6875*	*9.6875*	*9.6875*	*9.6875*
2.6	*10.1367*	*10.1367*	*10.1367*	*10.1367*
3.2757	*10.8984*	*10.8984*	*10.8984*	*10.8984*
4.1272	*10.7617*	*10.7617*	*10.7617*	*10.7617*
5.2	*8.9843*	*8.9843*	*8.9843*	*8.9843*

Level	*50 dB*	*60 dB*	*70 dB*	*80 dB*
Frequency	*Time*	*Time*	*Time*	*Time*
0.8189	*9.0429*	*9.0429*	*9.082*	*8.4765*

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1.0318	7.9492	7.9492	7.9687	7.9687
1.3	14.4531	7.9296	7.9296	7.9101
1.6378	9.1992	9.1992	9.1992	9.1992
2.0636	9.4531	9.4335	9.4531	9.4531
2.6	10.1367	10.1367	10.1367	10.1367
3.2757	10.8984	10.8984	10.7617	10.7617
4.1272	8.8671	8.8671	8.9843	9.1015
5.2	8.9843	8.9843	9.0039	9.0039

Level	90 dB	100 dB	110 dB	120 dB
Frequency	**Time**	**Time**	**Time**	**Time**
0.8189	8.4765	8.4765	8.4765	8.4765
1.0318	7.871	7.9101	7.8906	7.9101
1.3	7.9101	5.2148	5.2148	5.2148
1.6378	5.1953	4.8828	4.8828	4.8828
2.0636	9.4726	5.1953	5.1953	5.1953
2.6	10.1562	5.6835	5.6835	3.9648
3.2757	10.7617	10.7617	5.8789	3.3593
4.1272	8.8871	8.8871	8.8867	4.1015
5.2	9.0039	9.0039	9.0039	8.9062

From table 1, we can know effect amount of the different stimulation levels on latency of TEOAEs for each frequency. So we will work on the study of waveform behavior TEOAEs using the relationship of time-frequency for stimulation levels (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 and 120) dB, as follows:

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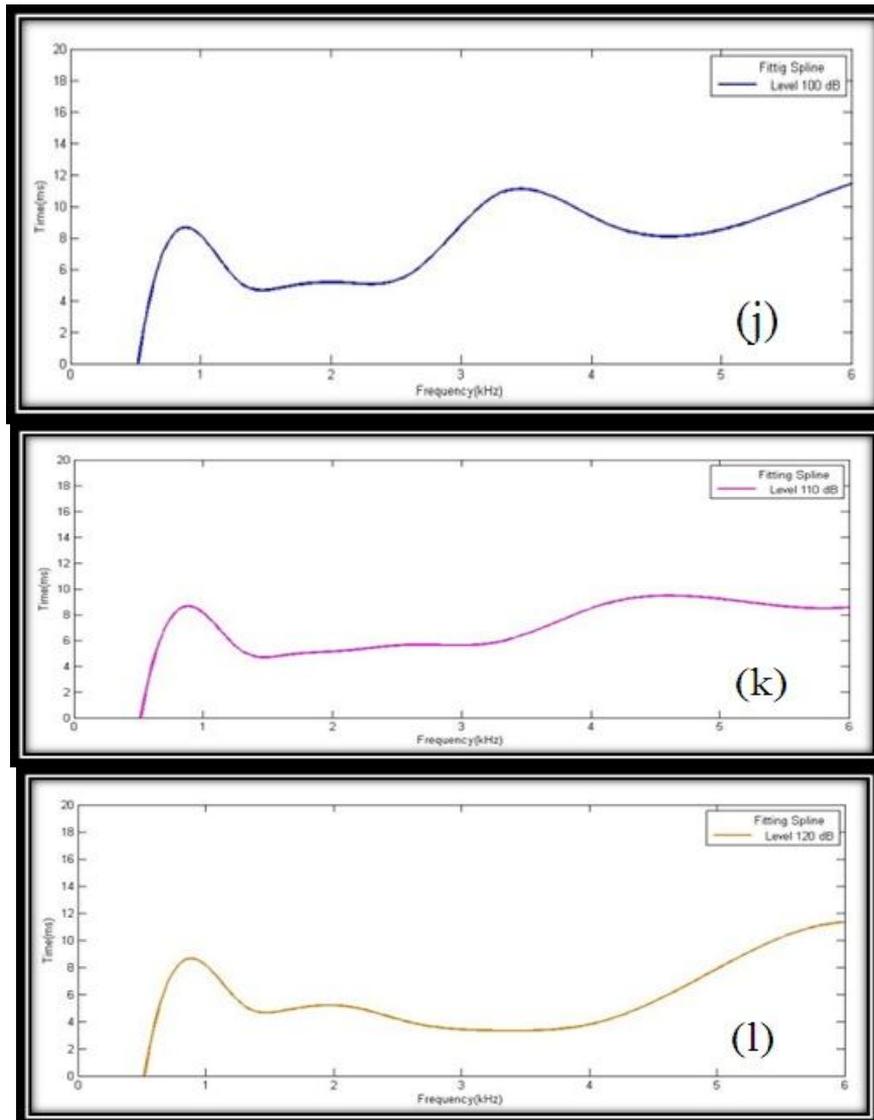**Volume 4, Issue 11, November 2015** **ISSN 2319 - 4847**

Figure (3) shows the waveform behavior TEOAEs in the different stimulation levels for relationship of frequency-latency,(a) stimulus level 10 dB, (b) stimulus level 20 dB, (c) stimulus level 30 dB, (d) stimulus level 40 dB, (e) stimulus level 50 dB, (f) stimulus level 60 dB, (g) stimulus level 70 dB, (h) stimulus level 80 dB, (i) stimulus level 90 dB, (j) stimulus level 100 dB, (k) stimulus level 110 dB, and (l) stimulus level 120 dB.

From figure (3) clearly show the change waveform behavior TEAOEs for the different stimulation levels. To compare the figure (a), (b), (c), (d), (e), (f), (g), (h), (i), (j), (k), (l) in figure (3) are working on collecting them in one figure, in order to discuss easily and clarity of the change waveform behavior TEAOEs.
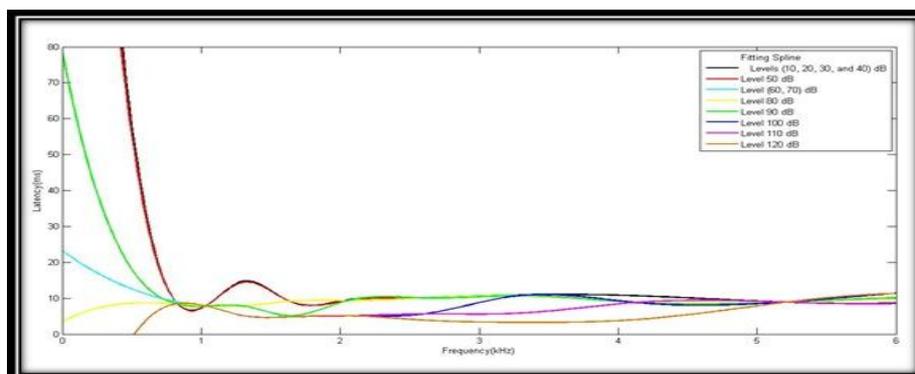

Figure (4) shows the effect of differing stimulation levels on waveform behavior TEAOEs in the relationship of latency-frequency.

Through figure (4) shows changing waveform behavior TEOAEs when each stimulate level, there is special latency for the same frequency, but we find in some of the stimulation levels converged for the waveform behavior TEOAEs is not affected by change the stimulation level, such as levels (10, 20, 30, 40) dB and (60, 70) dB, while level 50 dB very slightly different at the levels (10, 20, 30, 40) dB.

In the low stimulation levels from 10 dB to 40 dB does not appear any difference in the regression "slope curve", but very little difference starts at the stimulation level 50 dB, and the amount of latency in these levels is relatively large compared with the rest of the stimulation levels, this shows that the low stimulation levels go a considerable distance along the basilar membrane of the cochlea (Near the apex). And in the medium stimulation levels from 60 dB to 90 dB there is a clear difference in the regression, except for level 60 dB and 70 dB, and the amount of latency in these levels is much less than the latency for the low stimulation levels, this indicates that the intermediate stimulation levels go distance less than the distance the low stimulation levels along the basement membrane of the cochlea (Between the apex and the base). And in the high stimulation levels from 100 dB to 120 dB, there is a slight difference in the regression at the different stimulation levels, and the amount of latency in these levels is very small compared with other stimulation levels, this shows that high stimulation levels go a short distance along the basilar membrane of the cochlea (Near the base). This is consistent with previous studies [6, 9, 16, 17 and 19].

4. CONCLUSIONS

Different growth rates of TEOAEs describe the different latency which expresses non-linear increase in the region BM as a function of distance in the resonant place [10, 11], and also as a function to the stimulation level [6] to the same frequency.

Figure (4) shows the latency values of TEOAEs changing with the stimulus levels for the same frequency, and this change is subject to an inverse relationship. Therefore, we conclude that the relationship between latency and the stimulus level of TEOAEs is an inverse relationship, and latency is as a function to the frequency and the stimulation level. This is consistent with previous studies [6, 9, 16, 17 and 19].

Form the figures (1) can be concluded that the energy distribution TEOAEs in:

- Low stimulus levels, the energy is concentrated in a small number of points "spots" on the relationship of time-frequency .
- High stimulation levels, the energy are fades about low frequencies in the lowest possible number of spots
- .Middle stimulation levels, be best spectrum for the energy distribution of TEOAEs, because of that the energy spots will be greater in number and more pronounced compared with the other levels (low and high).

This is consistent with previous studies [1, 6, 10, and 11].

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