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Effect of the quality factor on the distribution frequency - time of the otoacoustic emissions

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Abstract

This study investigated the effect of the quality factor on the otoacoustic emission and frequencies, especially frequency-time distribution.

In the calculations, a range of values were used for the quality factor where the values ranged from 2 to 20, the stimulus level 50 dB is used in the calculations.

It was observed that the results are divided into two parts in terms of the effect of the quality factor. The first part is the lower quality factor values and the second part of the high quality factor values.

There is a clear effect on the distribution of frequency - time to change the coefficient of quality, especially the low values, while this effect is not observed with high values.

Keywords; Quality Factor, Stimulation Levels, Nonlinear Model, TEOAEs, distribution frequency- time.

INTRODUCTION

otoacoustic emissions are sound signals that arise in the human ear cochlea [1], [2]. Was first described by Kemp (1978) when technical progress was able to record these weak signals [3]. The mechanical process resulting from the motion of the membrane works to transfer the wave in the cochlea fluids along the basilar membrane. Therefore, the outer hair cells (OHCs) located on the basilar membrane are part of this mechanical process because they contract and expand. This active process is emitted from an incoming signal to the auditory nerve and the incoming signal is transmitted back to the outer ear canal through the middle ear where it can be detected [4]. Each part of the basilar membrane has a maximal sensitivity to the characteristic frequency with higher frequencies closer to the oval window. This means that the high frequency responses will have the shortest time to move back to outer ear canal. The discovery of otoacoustic emissions has expanded our understanding of the auditory process and an understanding of the operation of the cochlea system.

otoacoustic emissions are measured easily by a probe containing a small microphone that records sounds in the outer ear canal. Transient evoked otoacoustic emissions (TEOAEs) are one of the most important methods used to evaluate the function of the OHCs of the cochlea in neonates and in young children. TEOAEs use the acoustic stimulus or burst tone with a frequency spectrum that can make a large part of the basilar membrane from 1000 to 4000 Hz [4]. This response can be separated in frequency bands to analyze the function of the cochlea. At high frequencies, spectroscopy of the transient response can detected cochlear damage due to noise or toxic drugs of the ear [5], [6],[7].

Many studies have shown that the spectral content of the total OAE explosion tone is concentrated in the frequency range of 1-4 Hz corresponded to with click evoked otoacoustic emission (CEOAE) [8],[9]. However, the same level of stimulation (equivalent click) in the case of tone explosions gives a higher level of OAE. Therefore, those stimuli can give an advantage over standard clicks in some difficult situations.

The human ears, especially the cochlea are bony structure, consisting of three fluid-filled chambers separated by membranes that represent the spectral analyzer of specific frequencies. The basilar membrane at the base responds to high-frequency sounds and at the top of low-frequency sounds [10].

The human ear responds to changes in air pressure to hear sounds in the frequency range from 20 Hz to 20 kHz [11], [12]. Sound frequencies below 20 Hz and above 20 kHz are inaudible [13], [14]. Therefore, the response of the ear to the sound depends on the frequency of the sound as well as the intensity. The ear is more sensitive to frequency in the range of 3000 Hz to 4000 Hz. This is because the sound in the ear canal must be more intense before it is heard. The ear cannot respond to all frequencies in an unbiased method and the sounds of all frequencies can also be transmitted by the skull. In fact, the high frequency of hearing loss decreases with age [15].

The Method and Model

The non-linear model was used in this work to complete the calculations, the nonlinear numerical solution scheme of this model is described in detail [16].

For an advanced model of otoacoustic emission, the interaction between the external sensory cells and the basilar membrane can be schematized as a nonlinear and considered it non-local active system.

From previous studies, in the model by Kim and Xin [17] the pressure applied by outer hair cells on the basilar membrane is assumed proportional to the total pressure on the basilar membrane (BM).

The differential pressure p is determined by the following equations [18].

$$\frac{\partial^2 p(x,\omega)}{\partial^2 x} = K_{\circ}^{2}\sigma_{bm}\,\ddot{\xi}(x,t) \qquad \dots\dots\dots (1)$$

$$\frac{\rho(x,t) + q(x,t)}{\sigma_{bm}} = \ddot{\xi}(x,t) + \gamma_{bm}(x)\dot{\xi}(x,t) + \omega_{bm}^2(x)\xi(x,t) \quad \ldots.(2)$$

$$q(x+\Delta,t) = \alpha(\xi,x,t)p_{BM} = \alpha(\xi,x,t)\rho(x,t) + q(x,t) \ldots..(3)$$

Where:

q: is the additional pressure given by the outer hair cells.

α: is a nonlinear non-local gain factor.

p_{BM} : is the total pressure on the basilar membrane.

ξ : is BM displacement.

α : is defined a saturating nonlinear function.

$$\alpha(x,\dot{\xi},t) = \gamma\left(1 - \tanh\left(\frac{\dot{\xi}_{(x,t)}}{\dot{\xi}_{sat.}}\right)\right) \ldots\ldots\ldots(4)$$

nonlinear gain ($\dot{\xi}_{sat.}$) is defined as, is the basilar membrane (BM) velocity at which nonlinear saturation effects with the following range:

In a tonotopically resonant cochlea, the relation between longitudinal position (x), angular frequency and passive damping constant are set by Green Wood (1990) map[19], [20].

$$\omega_{bm}(x) = \omega_0 e^{-kw^x} + \omega_1 \ldots\ldots(5)$$

$$\gamma_{bm}(x) = \gamma_0 e^{-k\gamma^x} + \gamma_1 \ldots\ldots(6)$$

$$Q = \frac{\omega_{bm}}{\gamma_{bm}} \ldots\ldots\ldots\ldots(7)$$

The result of a numerical simulation (*N*=1000) partitions using a broad-band click stimulus level corresponding to 50 dB.

In this study, the frequency-time distribution of the otoacoustic emissions was studied by studying the effect of the quality factor on frequencies and their effect on the change in the value of the quality factor.

The calculations were carried out using 50 dB, as for the quality factor, a range of values was used, this range includes values 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20.

In order to study the relationship between the quality factor and otoacoustic emissions and its effect on the distribution of frequency-time, a range of frequencies ranging from 0.5 KHz to 6 KHz were chosen. These frequencies are 0.8227 KHz, 1.023 KHz, 1.304 KHz, 1.645 KHz, 2.067 KHz, 2.609 KHz, 3.271 KHz, 4.134 KHz and 5.197 KHz.

Figure 1 shows the relationship between the quality factor and time of frequency 0.8227 KHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 1 shows the time map of frequency 0.8227 KHz with the change in the quality factor values from 2 to 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

RESULTS AND DISCUSSION

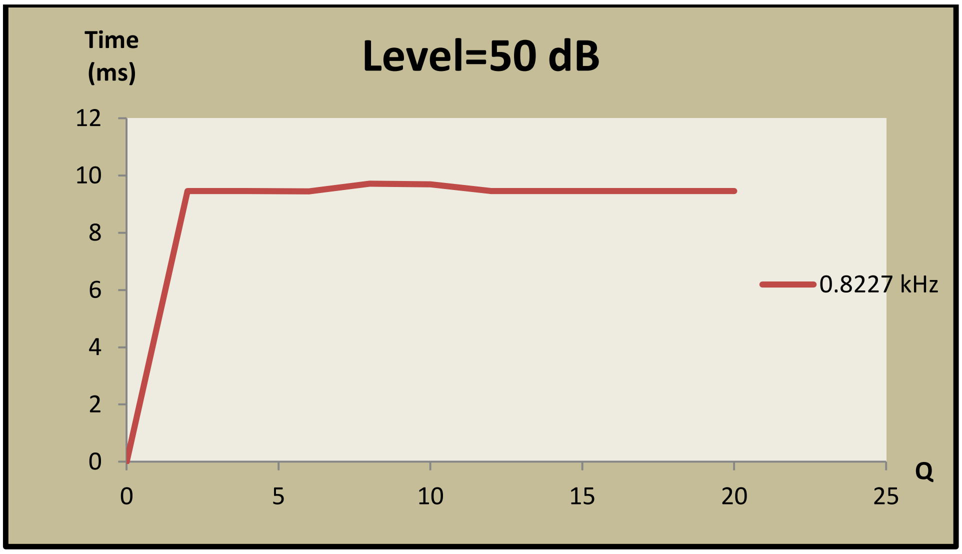

Figure 1. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 0.8227 kHz.

Figure 2 shows the relationship between the quality factor and time of frequency 1.023 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 2 shows the time map of frequency 1.023 kHz with the change in the quality factor values 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2 and it is observed the values from 8 to 10 it has almost the same effect the same affect.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

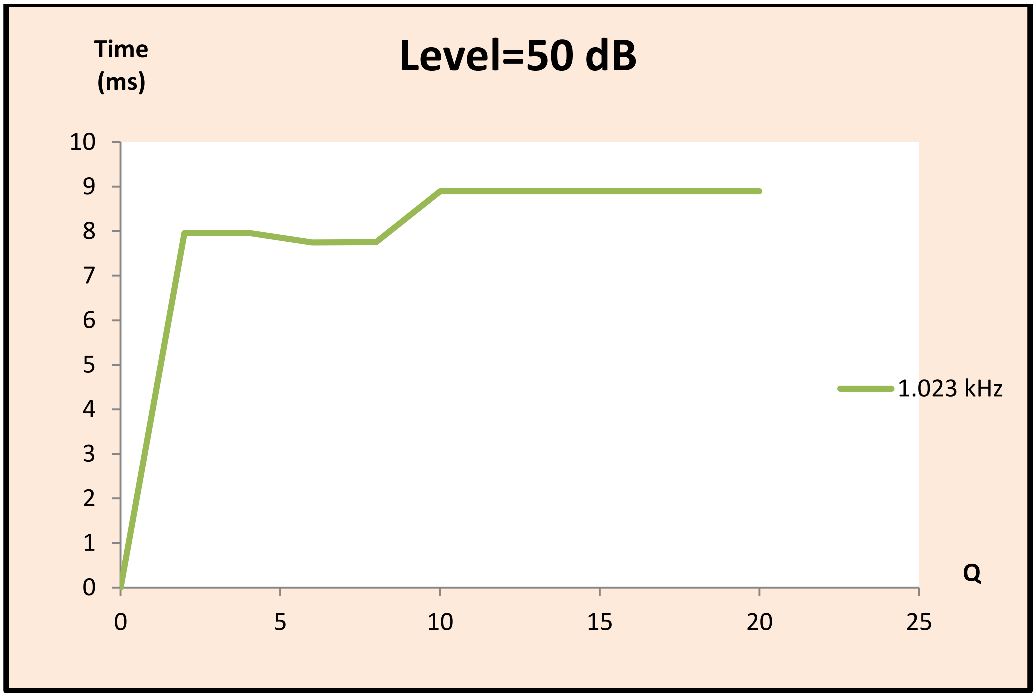

Figure 2. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 1.023 kHz.

Figure 3 shows the relationship between the quality factor and time of frequency 1.304 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 3 shows the time map of frequency 1.304 kHz with the change in the quality factor values 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the values from 2 to 6.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

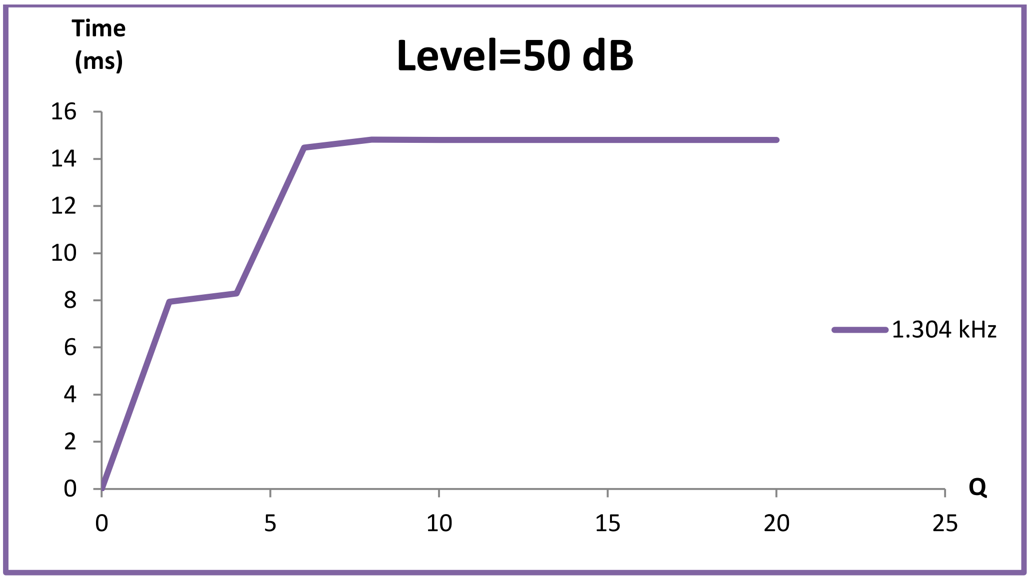

Figure 3. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 1.304 kHz.

Figure 4 shows the relationship between the quality factor and time of frequency 1.645 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 4 shows the time map of frequency 1.645 kHz with the change in the quality factor values from 2 to 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

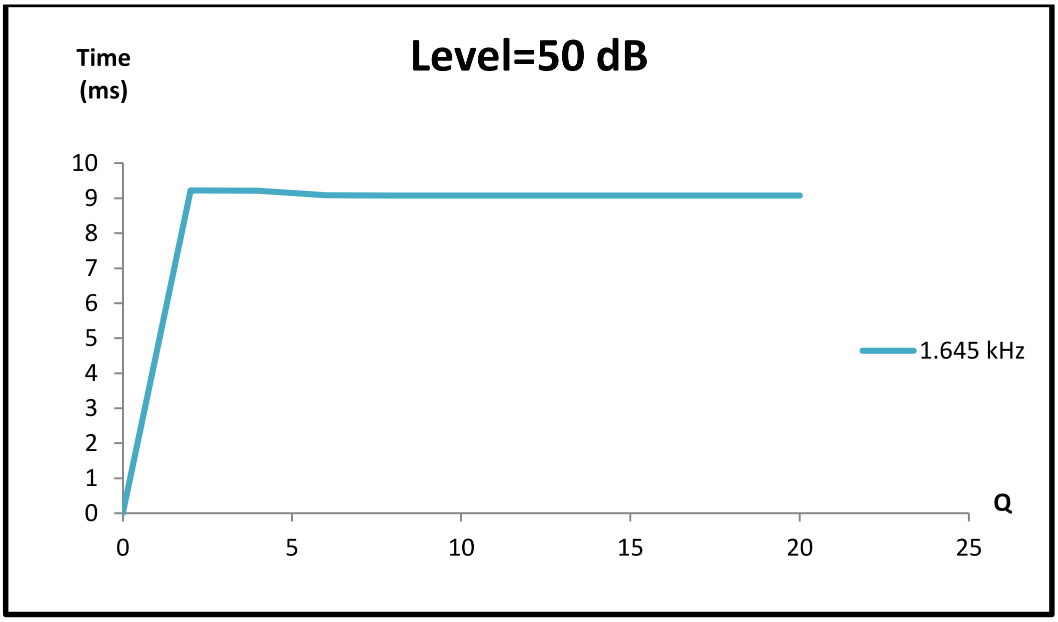

Figure 4. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 1.645 kHz.

Figure 5 shows the relationship between the quality factor and time of frequency 2.067 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 5 shows the time map of frequency 2.067 kHz with the change in the quality factor values 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

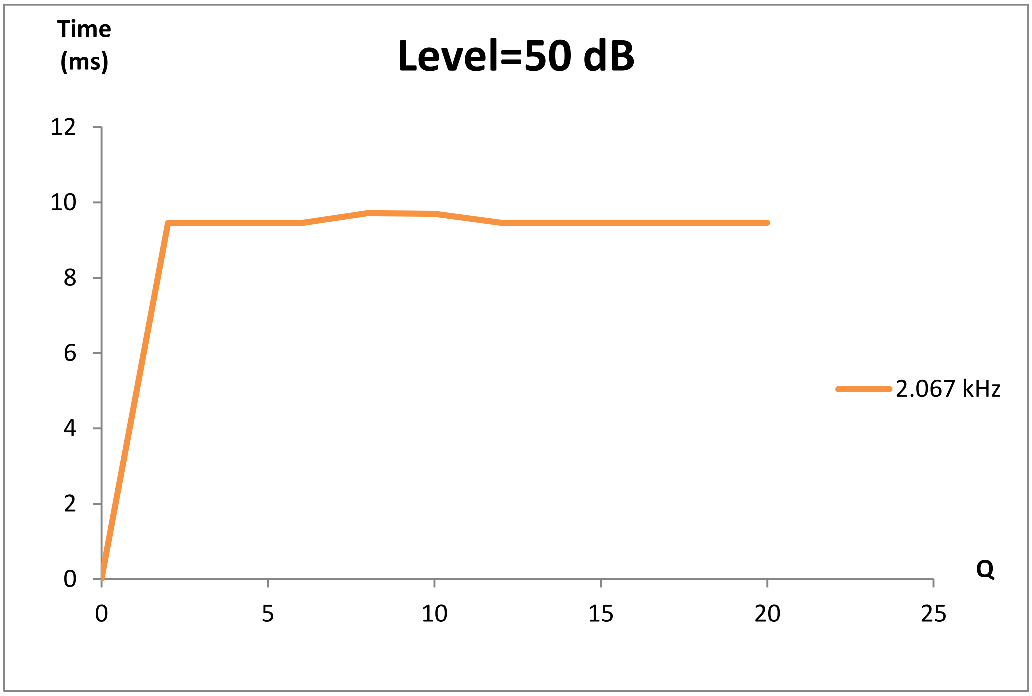

Figure 5. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 2.067 kHz

Figure 6 shows the relationship between the quality factor and time of frequency 2.609 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 6 shows the time map of frequency 2.609 kHz with the change in the quality factor values 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2 and it is observed the values from 6 to 8 it has almost the same effect.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

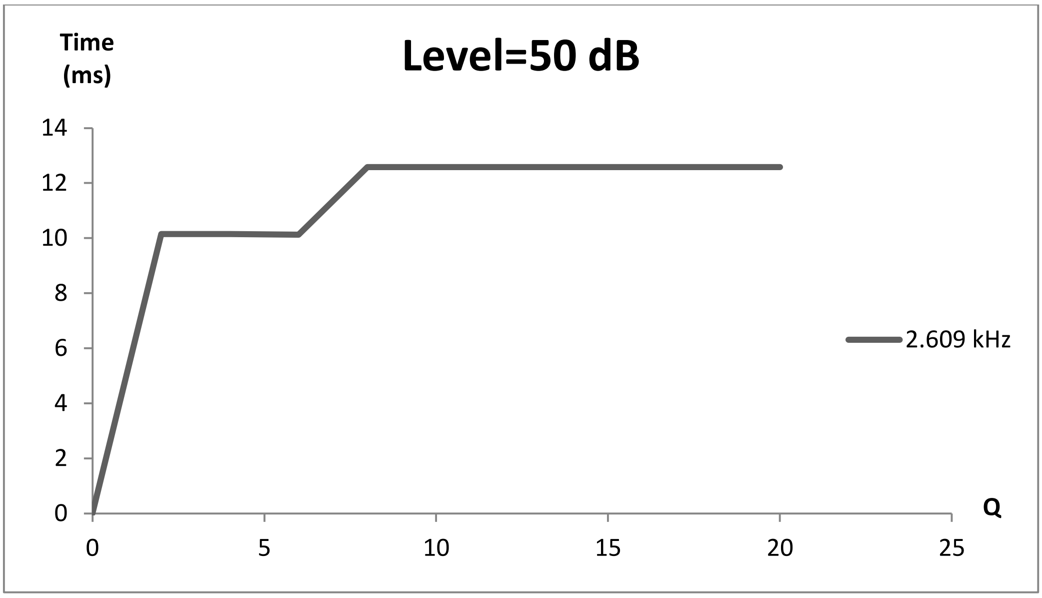

Figure 6. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 2.609 kHz.

Figure 7 shows the relationship between the quality factor and time of frequency 3.271 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 7 shows the time map of frequency 3.271 kHz with the change in the quality factor values 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

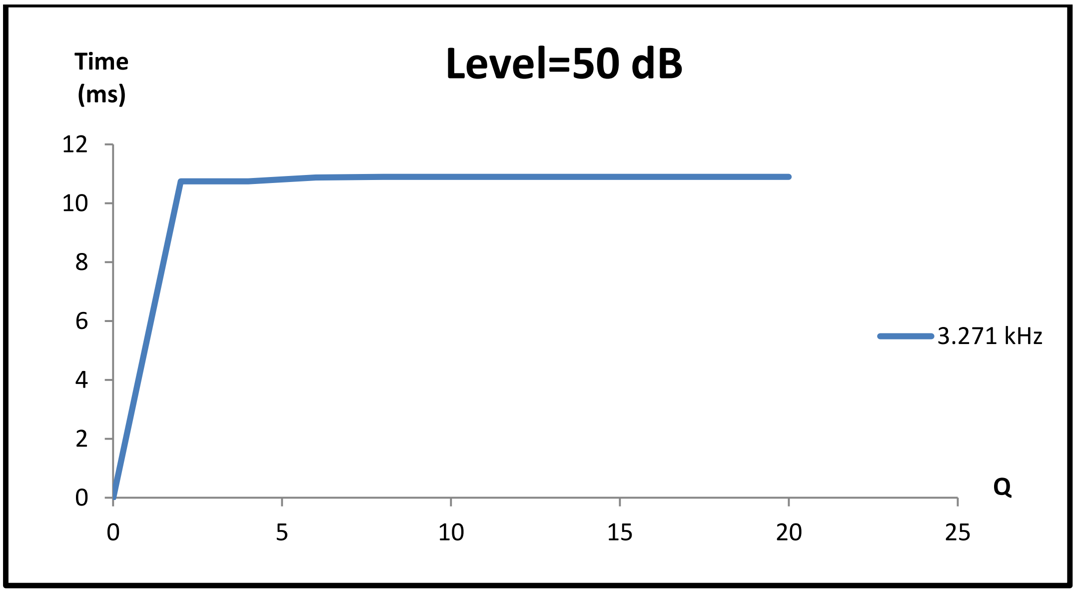

Figure 7. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 3.271 kHz.

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Figure 8 shows the relationship between the quality factor and time of frequency 4.134 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 8 shows the time map of frequency 4.134 kHz with the change in the quality factor values 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable. Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the value 2 and it is observed the values from 4 to 6 it has almost the same effect.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

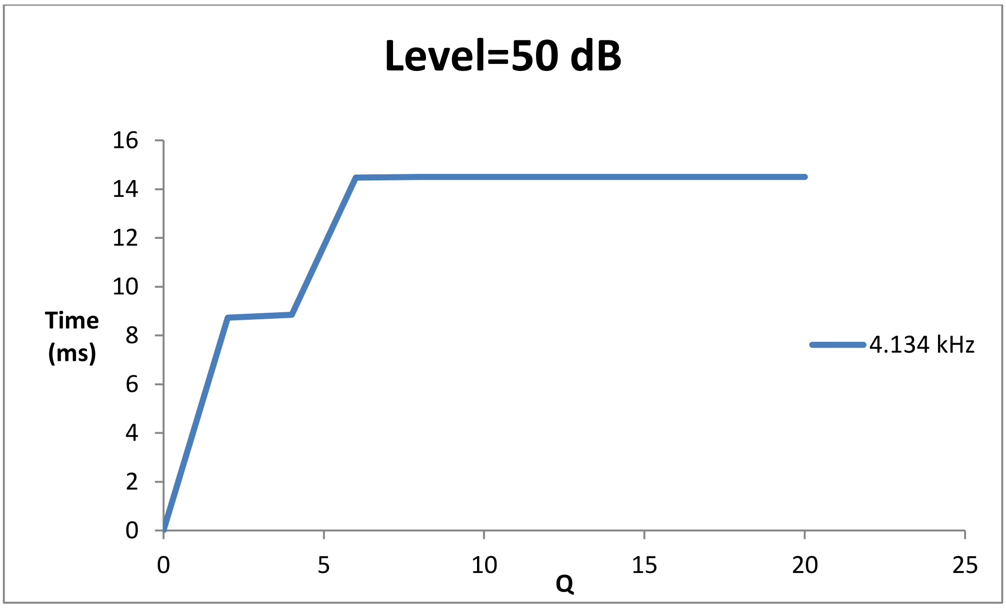

Figure 8. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 4.134 kHz.

Figure 9 shows the relationship between the quality factor and time of frequency 5.197 kHz. This distribution is very important for analyzing the results of the otoacoustic emissions when the quality factor is changed where the stimulus level is 50 dB.

Curve figure 8 shows the time map of frequency 5.197 kHz with the change in the quality factor values from 2, to 20 and the effect of the quality factor on frequency behavior. It is noted that the low values of the quality factors have a clear effect on time-frequency distribution, while the high values of the quality factor have no effect so that the emission time is fixed.

The distribution curve is variable for low values and for high values is stable.

Frequency-time distribution behavior is affected by the low values where it is observed the change of time to frequency according to the change in the quality factor, especially the values from 2 to 8.

While high values do not affect where time is not changed by the change in the quality factor and the time is almost constant.

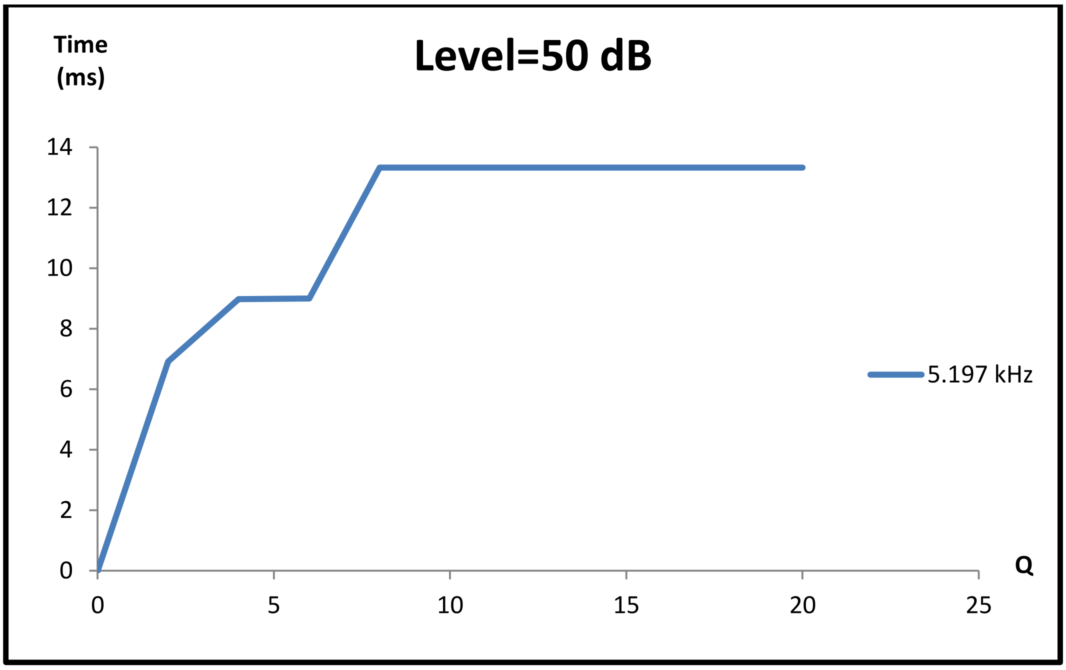

Figure 9. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the frequency 5.197 kHz

Figure 10 shows all cases studied for all frequencies (0.8227, 1.023, 1.304, 1.645, 2.067, 2.609, 3.271, 4.134, 5.197) KHz. The change in the value of the quality factor has a clear effect on the distribution of frequency-time for the otoacoustic emissions, for this reason, the frequency behavior varied so that the frequencies were divided into two different groups. The first group includes the following frequencies: 0.8227 KHz, 1.645 KHz, 2.067 KHz, 3.271 KHz, while the second group includes the following frequencies: 1.023 KHz, 1.304 KHz, 2.609 KHz, 4.134 KHz, 5.197 KHz.

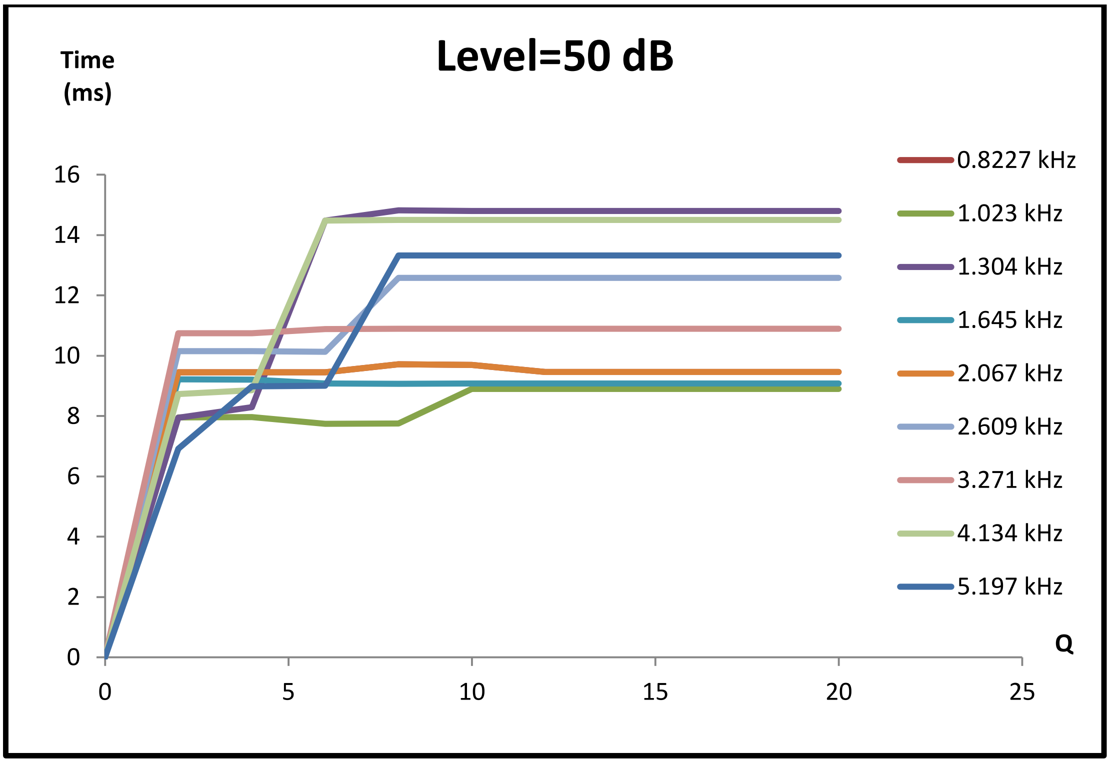

Figure 10. shows the relationship between the quality factor and latency of the transient evoked otoacoustic emission (TEOAE) of the all frequencies.

CONCLUSION

This study investigated the effect of the quality factor on the emission of audio, especially the effect of the frequency-time distribution, where the effect was studied through a range of frequencies. These frequencies are 0.8227 KHz, 1.023 KHz, 1.304 KHz, 1.645 KHz, 2.067 KHz, 3.271 KHz, 4.134 KHz and 5.197 KHz.

It is concluded from the results obtained that the quality factor has a clear effect on the frequency-time distribution of the emission.

It is concluded from this work that the effect of the quality factor on the otoacoustic emissions, especially on the frequency map, namely distribution frequency - time, this effect is different and depends on the value of the quality factor.

For example, the effect of the quality factor on the frequency map is generally estimated to be negligible approximately of the high values of the quality parameters that ranged from 10 to 20, where it is noted that the time of the audible frequencies is almost constant.

As for the effect of the quality factor of the lower values of 10, this effect is very clear to the frequency map, in particular the frequency-time distribution. The frequency behavior as stated in the calculations is variable according to the change in the value of the quality factor

It is concluded that the change in time of frequency by changing the quality factor for very low values is a significant change and a clear example of this case value 2 and the values very close to it, and concludes that the time variability of frequencies for other values is less than the change in the case of values close to 2.

It is concluded through the conclusions obtained through this work that there are various factors that may affect the hearing process so as to reduce the efficiency of hearing and the impact on audible frequencies. These factors may be related to the pattern of the ear and some of the impact of some of them negatively and may be related to age or any other factors. It is concluded that the role of the quality factor is very important to address the effect of these factors that negatively affect the hearing and therefore it is hoped that the role of the coefficient of quality is to improve hearing.

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