APPLICATION OF THE GEDDES-LEE MODEL FOR THE SUBJECTIVE EVALUATION OF SOUND EMITTED BY LOUDSPEAKERS

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ABSTRACT
In this work we evaluate the possibilities of the metric proposed by Geddes-Lee (2003) in order to predict the distortion perceived by the hearing. The metric has been applied to a concrete application: the distortion of direct radiation loudspeakers. The radiating systems were an 8 inches loudspeaker mounted on a closed box and a Distributed Modes loudspeaker. The work method has consisted in recording the signal emitted by the radiating system, which was excited at different voltage levels (and therefore different harmonic distortion levels). These systems have been analyzed applying the Geddes-Lee metric. Recorded signals have also been used in a psychoacoustic experiment with a selected hearing of 20 people with ages between 19 and 26 years old.

INTRODUCTION
Along the second half of the XX century a lot of schemes and models have been proposed in order to improve the correlation between objective and subjective assessment of sound systems and loudspeakers. It's well known that THD is a poor measure of perceived distortion. It seems that conventional measurement methods may not provide information well correlated with subjective sound quality. The reason may be due to the complexity of nonlinearity of sound systems and to the complexity of human hearing system. Historically can be said that there have been three main approaches to assessment of nonlinearity: identification models, measurement models and perceptual models [1].

The identification methods try to obtain as much data as it is possible about the system with the purpose of being able to predict the system behavior with an arbitrary signal. In this scope are the Volterra models, NARMAX models and Kippel's works. This first approaching way to the problem is outside the focus of the present work.

The second approach could be denominated measurement methods. The objective is to obtain some symptoms of nonlinearity through certain measurement protocols. In this way would be framed the Total Harmonic Distortion measurements, intermodulation measurements methods, weighting of high order harmonics, stimulus by multitones and more recently the use of the coherence function.

Thirdly would be the perceptual methods. These methods are based on the simulation of psychoacoustic effects responsible for perception of sound quality. Perceptual methods were developed to assist assessment of sound quality in speech and music compression systems since the classical subjective test are usually more expensive and time-consuming. These methods have been developed in two ways: explicit simulation of masking processes and on the other way simulation of psysiological and psychoacoustical effects in hearing system. Nowadays there are two standards: perceptual evaluation of speech quality (PESQ) and perceptual evaluation of audio quality (PEAQ). An example of this kind of works is given in [5].
In this work we are going to use the metric proposed by Geddes and Lee [2], which can be considered as a bridge between the second and the third approaches that have been introduced above. We say a bridge because although this metric does not consider any model of human auditory system is based in the following psychoacoustical assumptions: low level signals are poor maskers, so nonlinearities that affect low level signals are worse that ones that affect high level signals. Moreover, high order nonlinearity produces wide spectrum products that are poorly masked [3].

THEORETICAL BACKGROUND
The main objective of paper [2] was to get a numerical parameter that describes the quality performance of a sound system considering its nonlinear transfer function and the psychoacoustical assumptions mentioned above. Eq. 1 represents the central hypothesis of the Geddes-Lee metric.

\[ G_m = \sqrt{\int_{-L}^{L} \left( \cos \left( \frac{x \pi}{2} \right) \right) \left( \frac{d^2}{dx^2} T(x) \right)^2 dx } \]  

(Eq.1)

In this equation T(x) is the system transfer function. T(x) has the form of a polynomial function as given by eq. 2.

\[ T(x) = \sum_{n} a_n x^n \]  

(Eq.2)

The second derivative of the nonlinear transfer function makes the parameter more sensitive to higher order nonlinearities than lower orders while the cosine-squared function meets the requirement of weighting towards greater values nonlinearities at low signal levels. These were the two main psychoacoustical assumptions considered by the model. Gm values obtained with simulated nonlinear transfer functions were correlated with psychoacoustical evaluations in [4].

In this work we have evaluated real transducers using this metric. We have used eq. 2 with n=3 in order to get the transfer function T(x) for each transducer so it was in the form given by eq. 3.

\[ T(x) = a + b x + c x^2 + dx^3 \]  

(Eq.3)

PROCEDURE
Three loudspeakers with different quality performance have been used. The first one (we’ll call it A) was a 8 inches double cone loudspeaker, the second one (B) was a better quality 8 inches loudspeaker mounted on a closed box and finally, the third (C) was a distributed mode loudspeaker, (DML). All have been excited with the test signal shown in fig.1.
The test signal contained firstly a pure tone and then a musical passage. The first half was used in order to obtain the transference function $T(x)$. The second part was also recorded for being evaluated by a hearing in a psychoacoustical experiment.

The transfer function was obtained experimentally in anechoic chamber measuring the input voltage in the loudspeaker and the sound pressure level produced by the system. Sound pressure was measured in Pa (not in dB) in order to get a relationship between $V$ (input voltage) and $P_a$ (sound pressure). The experimental values measured were adjusted to a polynomical function in the form of eq.3. These magnitudes were then normalised in the $[-1,1]$ range in order to evaluate $G_m$ value. Measurements were done in frequency octaves from 125 Hz up to 8 KHz. Although the theory model assumes $G_m$ to be independent of frequency in a real system like a loudspeaker $G_m$ will be frequency dependent [2]. Obviously, each type of loudspeaker has a different behaviour in different frequency ranges so $G_m$ must be evaluated in its frequency range. Excitation levels range has been different for each loudspeaker. It has been taken considering the manufacturer specifications and we have assumed the maximum level at 100 dB SPL.

We also have done the THD measurement at different input levels in order to represent its variation due to the signal level at the input of the system.

**RESULTS**

**THD measurements**

THD (%) measurements for each loudspeaker are shown in fig.2. Only 125 Hz and 1 KHz are represented here. Graphics show THD variation due to the signal input level increments.

![THD graphs](chart.png)

*Figure 2.* THD vs input level for A, B and C loudspeakers at 125 Hz and 1 KHz.
Gm measurements

On the other hand, the next figure shows the transfer functions obtained for A and C loudspeakers at 125 Hz, 1 KHz and 4 KHz. Only positive part is represented. We assume the curves to be symmetrical in the negative part. As has been commented above input and output magnitudes have been normalized in the range \([-1 \ 1\) in order to apply eq.1.

![Figure 3.-Obtained T(x) functions of A and C loudspeakers at 125 Hz, 1 KHz and 4 KHz.](image)

The T(x) functions have been obtained in the form of eq. 3 by adjusting the experimental values to a polynomial function. The next table shows coefficients values for each curve T(x) and its correlation with experimental data obtained.

<table>
<thead>
<tr>
<th>f (Hz)</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(R^2)</th>
<th>(Gm(f))</th>
<th>(Gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>-0.05</td>
<td>1.31</td>
<td>-0.63</td>
<td>0.34</td>
<td>99.22</td>
<td>0.99179</td>
<td>1.45</td>
</tr>
<tr>
<td>1000</td>
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<td>1.55</td>
<td>-0.89</td>
<td>0.33</td>
<td>99.94</td>
<td>0.99892</td>
<td>1.93</td>
</tr>
<tr>
<td>4000</td>
<td>-0.02</td>
<td>1.31</td>
<td>-0.43</td>
<td>0.14</td>
<td>99.95</td>
<td>0.9995</td>
<td>1.43</td>
</tr>
<tr>
<td>125</td>
<td>3.01\times10^{-3}</td>
<td>1.03</td>
<td>0.04</td>
<td>-0.06</td>
<td>99.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
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<td>0.32</td>
<td>-0.21</td>
<td>99.96</td>
<td>0.9997</td>
<td>0.93</td>
</tr>
<tr>
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<td>0.67</td>
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<tr>
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<td>-0.01</td>
<td>-0.01</td>
<td>99.97</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Coefficient values obtained for each T(x) function and Gm results.
The column \( G_m(f) \) of the above table shows \( G_m \) values obtained at different frequencies for each loudspeaker. In the last column the average between the three values obtained before is written.

**Psychoacoustic Experiment**

About the psychoacoustic experiment, it has been done the following way in order to ask about two main questions:

1. The first match was to find any quality difference between the three loudspeakers. A, B and C loudspeakers were compared by the hearing. A better qualifying of loudspeaker B was expected due to the results obtained in the last two sections. In order to carry out the experiment the hearing was able to listen the recordings through earphones as many times as necessary for each listener. The listener only had to locate on a segment graduated in 10 levels the relative position of each loudspeaker respect to the others considering the perceived distortion. In this segment a low rating means low perceived distortion. The higher the rating the higher perceived distortion. In table 1 averaged ratings are shown.

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>A</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
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<tr>
<td>9</td>
<td>10</td>
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<td></td>
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</table>

Table 2. Subjective ratings of loudspeakers

2. The second main question was if for a given loudspeaker an increasing perceived distortion was observed due to an increasing of the input signal level. In order to carry out this experiment the recording corresponding to 1 volt at the input was reproduced to the listener. Then, the listener was requested to compare it with higher input levels recordings. Of the 20 requested listeners, only 5 perceived an increase of distortion when arriving at 3.5 - 4 volts input level signals. The other 15 listeners needed higher input levels (up to 5.5 - 6 volts) to perceive an increase of distortion.

The same experiment described above was repeated but using now as the reference the 3.5 volt input level recording. Of the 15 people, only 7 perceive an increase in the distortion when arriving at 5.5 - 6 volts. There were 3 listeners who needed to arrive up to the end of the excitation range to perceive any distortion with many difficulties.

**CONCLUSIONS**

From the experiment results we conclude that it’s absolutely necessary to consider \( T(x,f) \). In this case \( G_m \) will be frequency dependent \( G_m(f) \). As shown in figure 3, the transfer function of each transducer has considerable variations depending on frequency. Since \( T(x) \) is a property of the system, frequency must also been considered in order to get an accurate value of \( G_m \). This value should be frequency weighted. Moreover, not all transducers have the same frequency range work, so the weighting method should be appropriate to any kind of loudspeaker. In our case the three loudspeakers have been tested with frequencies included in their work range, even though the case of 125 Hz for loudspeaker C is close to the limit. This limit case shows more clearly the need of a frequency weighting method.

We also have found that the used transducers behaviour at low levels is close to linearity. The data obtained in the first half of excitation range usually correlated well with a linear function while increasing input level generated data with better correlation with a polynomical function. This could explain the difficulties that had many of the psychoacoustic experiment listeners to found any distortion difference between recordings at low input levels.

It should be also interesting to compare the results using higher order polynomical functions as suggested in [2]. We are now working in clarifying other aspects of the experiment such an improvement of the psychoacoustic experiment or a evaluation of \( G_m(f) \) that will be shown in the congress.
References: