DIGITAL SIGNAL PROCESSING APPLIED TO THE EQUALIZATION OF THE LOUDSPEAKER ROOM INTERACTION

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1.0 Introduction

It was recognized by loudspeaker manufacturers that the loudspeaker and the room form an acoustical "marriage" which together determine the sound quality perceived by the listener in the room. Efforts by loudspeaker manufacturers in the last decade to further improve the quality of a loudspeaker by improving its free-field or anechoic response have resulted in very high standards of performance. This level of performance however is not available when the loudspeaker is placed in its intended environment: the listening room. This is due to the room modes and sound reflections coloring or altering the response perceived by the listener, no matter what position the loudspeaker or listener occupy in the room.

In the presence of reflecting surfaces, the direct or on-axis sound of the loudspeaker will be summed with the reflections of all the off-axis response and form the total response at the listening position. Room modes which occur in any closed room, no matter what the shape and degree of sound absorption applied, also affect the response at the listening position.

The desire to improve the measured as well as perceived response at any listening location from any typical loudspeaker position led a group of loudspeaker manufacturers to form a research consortium (CARC) and participate in a joint venture with the NRC. The collaboration was called the Athena project, whose purpose was to improve the overall quality of sound reproduction by loudspeakers in rooms with the use of digital signal processing[1] This paper sets out to demonstrate the technical performance of the current CARC/NRC DSP engine and its associated software.

2.0 Effect of Loudspeaker position

For the purposes of this experiment, a single loudspeaker, model CF-150 by State of the Art Electronik, was placed in 12 different locations in the new listening room at NRC. There were six different lateral positions and two different heights. Measurements were made at six different listener locations around a central area. The room with source (S0 to S5) and microphone (M0 to M5) positions is shown in Figure 1. The room at NRC is designed to emulate a typical good quality domestic listening room. The particular loudspeaker was chosen for its flat free field response and its small size, allowing it to be placed at different heights and lateral positions, near or far from the room boundaries. The source positions were chosen to mimic typical loudspeaker positions. The six microphone measurement positions were chosen to cover a usual listening area. Six measurements were made for each loudspeaker position, resulting in 72 total measurements for the unequalized case. The same procedure was used for the equalized case. Based on methods found in the Athena project, all the measurements for a given source position were combined to yield a single response curve. This resulting curve is representative of the perceived response in the listener area, as based on psycho-acoustic testing.

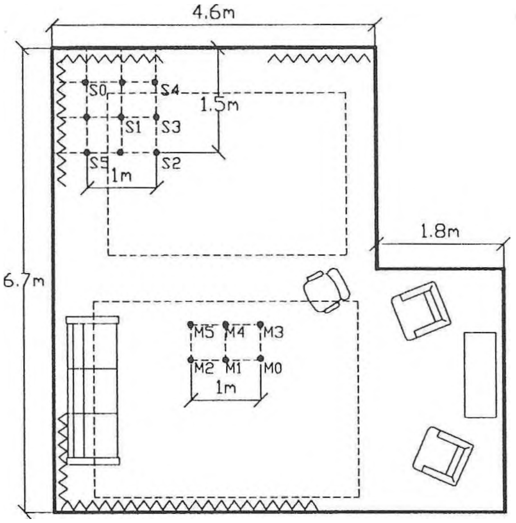

Figure 1. Listening room layout showing source positions S0 to S5 and measurement positions M0 to M5.

The 12 response curves for the unequalized case are shown in Figure 2. The absolute level is arbitrary, and all curves were matched to this arbitrary level using A weighting. The responses show a wide variation of ± 11 dB in the region below 400 Hz. This is due to the effect of room modes and of reflections by the boundaries of the off-axis portion of the loudspeaker output combining in and out of phase with the on-axis output. The loudspeaker is an omni-directional sound source in the low frequencies and its total output is important in determining the resulting response. It is obvious that the large variations in the measured response are due to the room's effect and not dependent on the loudspeaker's response curve. A change in the loudspeaker might tilt the overall envelope of the curves, but not change the deviations from the mean. The response above 400 Hz is quite uniform and independent of source position. Small deviations from a flat response are mostly determined by the loudspeaker and high frequency absorption characteristics of the room.

3.0 DSP Based Equalization

The large variations in response measured at the listening position from the same loudspeaker mean that the listener is completely dependent on the loudspeaker position for the perceived sound quality. This assumes that the loudspeaker has been selected and the room is in its final form. These conditions represent the vast majority of loudspeaker installations in recording studios and home listening environments. Listeners are very rarely at liberty to make geometrical changes or absorption changes in rooms which will improve the response below 400 Hz in a predictable manner. Thus a form of equalization is required which will compensate for the deleterious effects of the room on the loudspeaker. The current

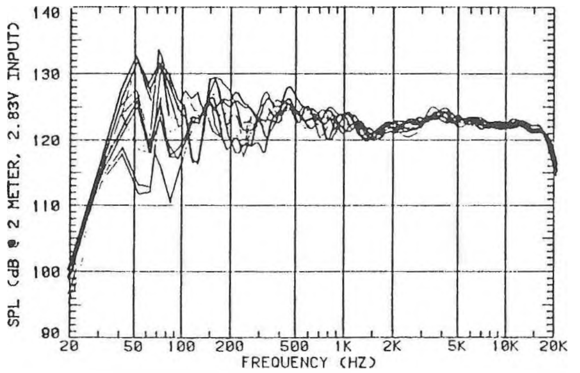

Figure 2. Frequency response measurements for 12 loudspeaker source positions for the unequalized case

method is to measure the response using a microphone and some form of measurement system. Then a 1/3 octave or parametric equalizer is used to set the response to a particular target. Measurements are usually performed at a single listening point and the equalization is adjusted for this single measurement. It was determined during the course of the Athena project that this is not a good solution as judged subjectively. In any case the 1/3 octave frequency centres and filter shapes do not coincide with the peaks and dips in the measured response and parametric equalizers do not have enough bands to accurately correct the measured response. A computer controlled equalization scheme was devised to correct the effects of the loudspeaker position.

The room response can be equalized in the time domain or in the frequency domain, using various weighting and windowing functions. Equalization in the time domain can preserve or improve the overall phase response, while equalization in the frequency domain effectively only equalizes the minimum phase part of the response due to the presence of all-pass phase components in the very complex room response. It has long been known by loudspeaker manufacturers that the frequency magnitude response is the best single element to improve for increasing the fidelity rating of loudspeakers. While listeners may be sensitive to phase effects under certain conditions, the most benefit is obtained by equalizing the magnitude response. This can be combined with some form of impulse response equalization, but only in the limit where the sound reflections being canceled with "inverse" reflections do not impair the perceived quality. It is very important to check the effects on the perceived quality of any added digital equalization, as the ear-brain perception system of the listener is very sensitive to some forms of time aberrations and very insensitive to others in small room acoustics. Equalization which appears good to the eye when the impulse response is viewed may sound very poor to the listener. The sound field is three dimensional and varies in frequency , time and direction of arrival. A purely engineering type of approach to response equalization was generally judged unacceptable by listeners during the course of the Athena project.

The equalization used for the results shown in Figure 3 was based upon 3 years of research in the Athena project. First a target response is determined. For the illustration of the equalizer performance in this paper, a flat target was used with a 4th order low-pass at 18.5 kHz in cascade with a 4th order high-pass at 39 Hz. The band limit characteristic of this target in the low frequency range is required not to overpower the woofer below its natural cut-off frequency while the upper frequency roll-off is required to match the anti-alias filter characteristic due to the 44.1 kHz sampling frequency used. The anti-alias filter response was not compensated for in the measurements. A flat target response in the room is not, *a priori*, the desired target for optimum perceived quality, but was used here for simplicity. Figure 3 shows the result of the responses for 6 equalized loudspeaker positions, S0 to S5, at one speaker height. As can be seen by comparing figure 3 to figure 2, there has been a vast improvement in the response, which now almost perfectly matches the target. The small unequalized frequency response deviations from flat above 400 Hz which were due to loudspeaker's response have been corrected, while the large response deviations due to the loudspeaker-room interaction below 400 Hz have been virtually eliminated. The entire equalization process for 12 speaker positions is completely automatic, requiring no user decisions, and thus eliminates the current practice of user controlled equalization, which has often resulted in overcompensation and colored response.

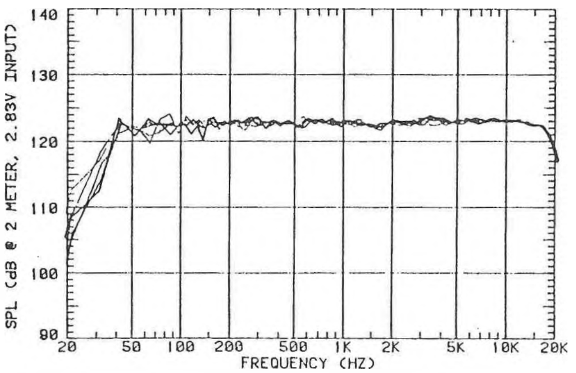

Figure 3. Frequency response measurements for 6 loudspeaker source positions for the CARC/NRC DSP engine equalized case.

4.0 Conclusion

It was shown that variations in responses due to loudspeaker position, measured and combined over 6 listener positions were of the order of ±11 dB. The loudspeaker position was shown to be the dominant effect in the measured response below 400 Hz. It was then shown that the CARC/NRC DSP based engine could reduce the variation in the measured response to ±2 dB, independent of the loudspeaker position. The computations required were accomplished without the need for user interaction, thus permitting full automation of the system. Any target desired could easily be matched. The very high performance of this system will allow us to proceed to the next generation of studio monitor loudspeakers.

5.0 Acknowledgments

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6.0 References

[1] Schuck, P.L., Olive, S.E., Sally, S.L., Bonneville, M.E., Ryan, J.G., Montahan, K.L., Verreault, E. and Toole, F.E., "Perception of Reproduced Sound in Rooms: Some Results of the Athena Project", *12 th International Conference of the A.E.S., June 28-30, 1993.*