Appendix C – Comparison of the performance of the piezoelectric based speaker and a conventional audio electromagnetic speaker.

In this thesis, the control of power train noise and road noise was performed with conventional speakers and piezoelectric based speakers. It was shown that the stereo system speakers performed better than the piezoelectric based speaker at low frequency (below 200 Hz). In this Appendix, the performances of the two sources are compared in order to explain the discrepancies. First, the theoretical displacement of a baffled piston will be presented in order to investigate the required displacement to radiate low frequency sound. Second, the frequency response of the two sources will be studied in order to compare the cut off frequency and low frequency roll off of the sources. Third, the linearity of the sources will be addressed in order to check the suitability for their application in the filtered-X LMS algorithm. During the experiments presented in this section, the sources were positioned on a planar baffle located in an anechoic chamber. The sources were excited with band pass filtered white noise between 100 and 1000 Hz, while the pressure was measured at one meter from the sources in a direction perpendicular to the baffle.

In Appendix B, it was concluded that the piezoelectric based speaker behaved like a piston in the frequency range of the control (below 500 Hz). At low frequency, a conventional speaker has the same type of behavior. While these sources are efficient sound radiators, they require a large displacement of the diaphragm at low frequency. Figure C.1 and Table C.1 show analytical results for the surface displacement of a baffled piston of 6-inch radius necessary to obtain 90 dB at one meter in an anechoic chamber. The curve shows that as the frequency decreases, a higher velocity is rapidly required to obtain the same sound pressure level. Similar curves were obtained for different sound pressure levels; 90 dB was chosen as an example.

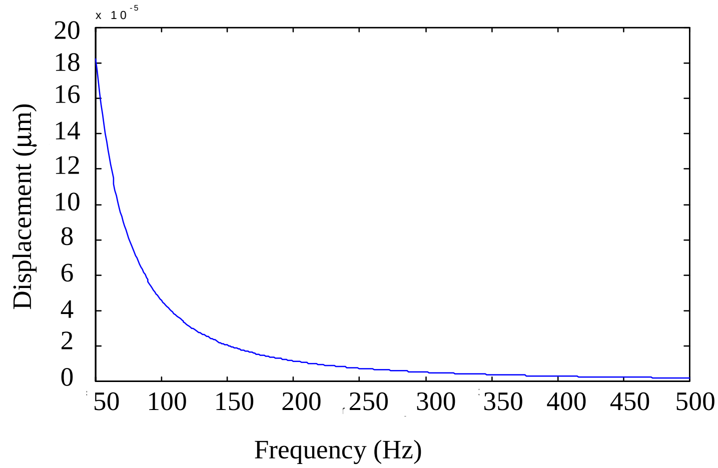

Figure C.1 Displacement of a baffled piston required to obtained 90 dB at 1m (Analytical Simulation)

Table C.1 Displacement required to obtain 90 dB at 1m

Frequency (Hz)	50	100	200
Displacement (μm)	18	4.6	1.1

In order to characterize the frequency response of the sources, the transfer function was measured between the input voltage to the source and the sound pressure level at a microphone located one meter away. The piezoelectric based source was baffled in an anechoic chamber. The input to the source is random noise band pass filtered between 100 and 1000 Hz. The cut off frequency of the device is 200 Hz. At lower frequencies, the sound pressure level drops. Above 200 Hz, the frequency response stays within 10 dB. The maximum input voltage to the source was 45 V RMS in the 100 to 1000 Hz frequency band. At higher voltage, the source starts to rattle indicating non-linearity, probably because of the balsa wood connectors. In these conditions the maximum pressure level is 80 dB at 350 Hz. The maximum voltage input acceptable for normal use of the double amplifier drivers is 80 V RMS. Table C.2 shows the SPL that would be obtained if the source could be driven at this voltage without rattling.

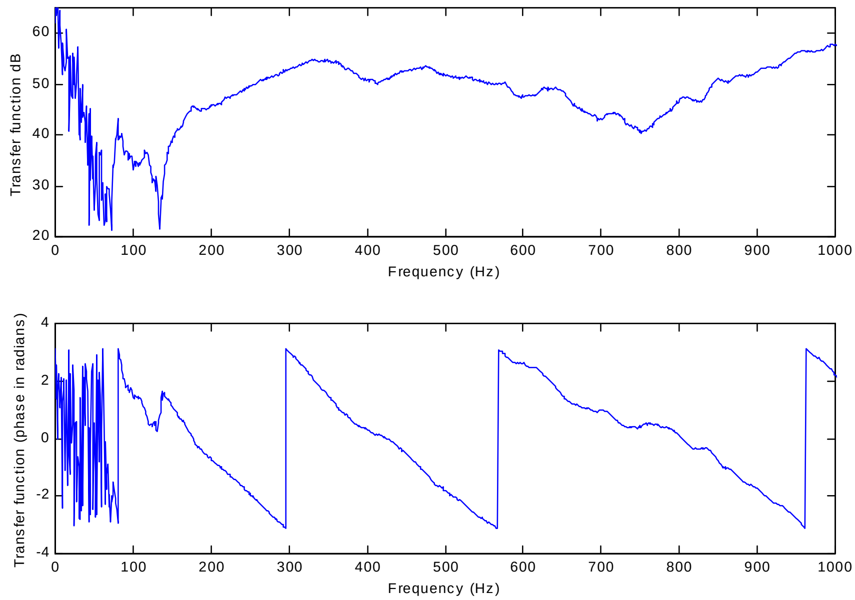

Figure C.2 Transfer function of the piezoelectric based source between the input voltage and the SPL measured at 1 m

Table C.2 Maximum theoretical sound pressure level obtained with the piezoelectric based source (at 1m)

Frequency (Hz)	150	200	250	350
SPL (dB)	72	75	80	90

As a comparison to the piezoelectric based speaker, the same test was performed with the conventional speaker. Figure C.3 shows the transfer function between the input voltage and the sound pressure level for the conventional speaker. The experiment also was conducted in an anechoic chamber, with the conventional speaker located on a planar baffle. The SPL is measured with a microphone located one meter from the source. The cut off frequency of the conventional speaker is at 450 Hz. The maximum sound pressure level is 89 dB at 500 Hz in the frequency band when the source is driven with an input voltage of 1 V.

When the sources are driven with 1 V RMS, the SPL measured with the conventional source is higher than the SPL measured with the piezoelectric based source, even though the cut off frequency of the conventional source occurs at higher frequency. However, the piezoelectric based source can be driven with a much higher voltage than the conventional speaker. The piezoelectric based source can be driven with an input voltage up to 80 V RMS, if the rattling noise is neglected, and 45 V RMS otherwise. Table C.2 shows the SPL for discrete frequencies assuming the piezoelectric based source is driven with an input voltage of 80 V RMS at the frequency of interest. Under these conditions, the maximum SPL is 90 dB at 350 Hz. The conventional speaker can not be driven with input voltage as high 80 V RMS. Typically the speaker can be driven with input voltage of 5 V RMS. Under these conditions, the maximum SPL generated by the conventional speaker is 105 dB at 500 Hz. At lower frequencies, close to 200 Hz, the SPL is 80 dB. In conclusion, the response obtained with the conventional speaker is much higher than the response obtained with the piezoelectric based source in the entire frequency range, even though the cut off frequency of the piezoelectric speaker is much lower than the cut off frequency of the conventional speaker. At frequencies below 200 Hz, the response of the advanced source is very low, because of the very steep low frequency roll off. This confirms that it is not possible to achieve active noise control of road noise or power train noise at low frequency (below 200 Hz for road noise and below 150 Hz for power train noise).

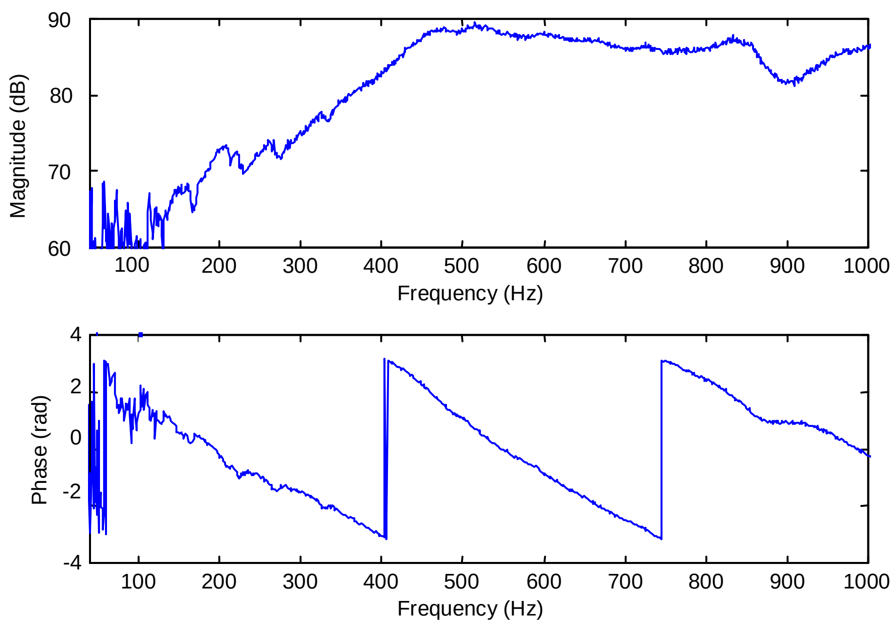

Figure C.3 Transfer function of the conventional speaker between the input voltage and the SPL measured at 1 m.

Figure C.4 shows the transfer function for the piezoelectric source computed with two input voltages. The blue line shows the transfer function measured with an input voltage of 43 VRMS. The red line shows the transfer function measured with an input voltage of 18 VRMS. Above 500 Hz, the two curves are superimposed, which means than the device is linear at these frequencies. At lower frequencies, the two curves do not superimpose, and therefore the device is not perfectly linear at low frequencies (below 500 Hz).

Figure C.5, shows the same type of curves measured using the conventional speakers. The transfer function was measured with three different input voltages. Above 250 Hz, the three curves are perfectly superimposed. However, the device is not very linear for frequencies lower than 250 Hz. The conventional speaker is globally more linear than the piezoelectric based sources at frequencies below 1000 Hz.

As pointed out in section 2.3, linearity of the sources is an assumption made in the feed-forward algorithm. However, during the experiment, good control was obtained with both sources. Linearity issues were avoided by performing the system identification of the path between the control source and the error sensor with an input voltage close to the input voltage required to control the disturbance. The result is, the source does not have to be linear for a wide range of input voltage, but only for input voltages close to the control output.

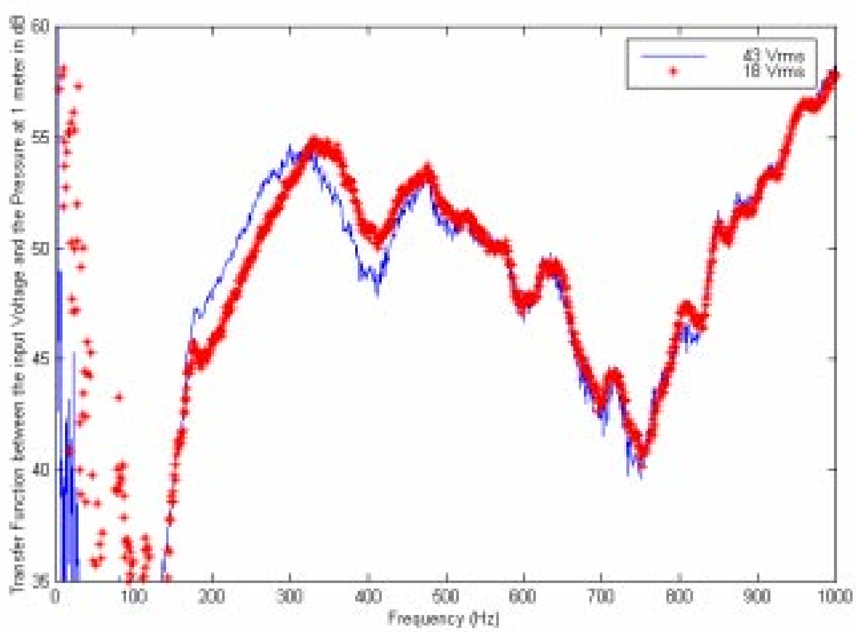

Figure C.4 Linearity of the piezoelectric based source

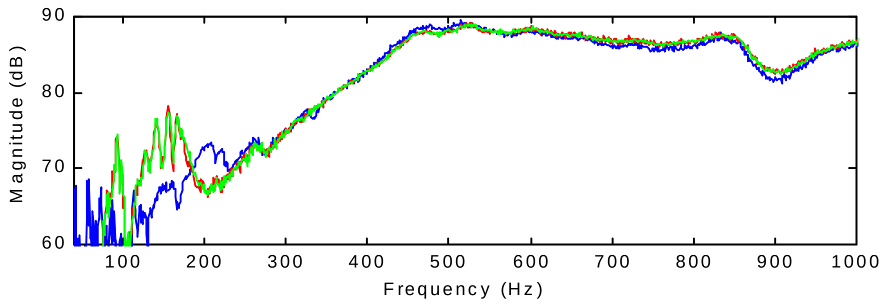

Figure C.5 Linearity of the conventional speaker

In conclusion, it was shown that the frequency response of the piezoelectric based speaker was low compared to the response of the conventional speaker. This is due to the steep low frequency roll off at 200 Hz of the piezoelectric based source. This result is consistent with those obtained in the control of road and power train noise. Another contributing factor to the better low frequency performance of the conventional speaker is that voice coil actuator typically generate higher displacement, which is critical for low frequency sound reproduction. Both speakers had linearity issues but these issues could be circumvented by performing the system identification within an expected range of linear operation.