Development of a compact, high-performance subwoofer system for live sound

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Introduction

To achieve high level in the low frequency audio range in today's sound systems, large enclosure volume and therefore a corresponding weight of each bass module are essential. Since the University of Applied Sciences Duesseldorf has already developed a compact high performance line array for the frequency range above 90 Hz in 2012, it was obvious to expand it with an adequate subwoofer system, which is equal in compactness and efficiency. For a good interaction between the subwoofer to the existing sound system, a transmission range of 35-100Hz (+/-3dB) was aimed at the planning stage. In addition to the development of a suitable compact enclosure with streamlined design of the bass reflex port, the system should allow different and today's conventional configurations. Depending on the event, it can be necessary to provide a specific or to protect sensitive areas from excessive bass levels. This flexibility and the desired maximum level up to 128 dB_{SPL} had to be taken into account in the choice of loudspeakers, audio controller and amplifier setup. A total of 16 subwoofers were constructed, measured and subsequently configured into a complete system that allows different playback setups by appropriate positioning at the venue and digital signal processing.

Preliminary considerations and simulation

The nature and characteristics of the subwoofer enclosure contributes significantly to the frequency response and efficiency. In addition to the basic choice between a closed box and a bass reflex system, the volume per speaker strongly influences the efficiency at low frequencies. Figure 1 shows the simulation of a speaker with different enclosure volume from 50 to 250 liters. It is evident that the efficiency at low frequencies increases with increasing volume.

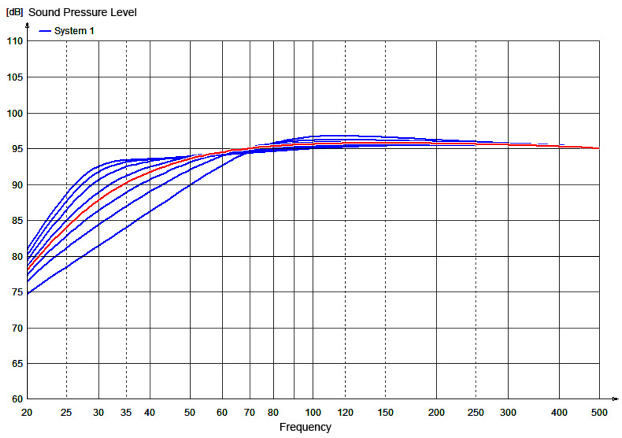

Figure 1: Simulation of a speaker with different enclosure volume from 50 to 250 l. (125 l = red)

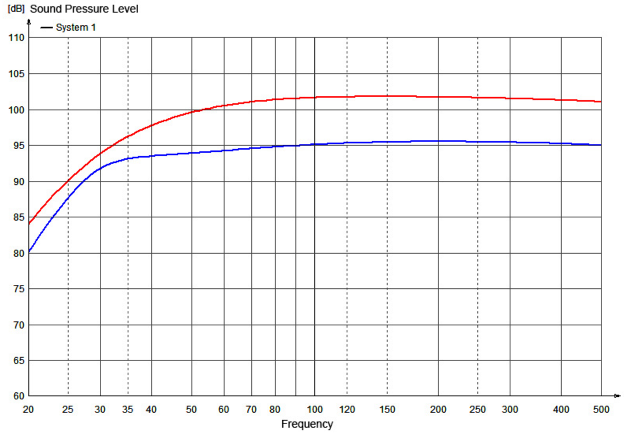

Figure 2: Simulation of one speaker in a 250 l enclosure (blue) compared to two speakers each in 125 l enclosure (red).

But the question is whether high bass level must always go hand in hand with a large enclosure volume. Figure 2 shows a speaker built into a 250 liter enclosure compared to two speakers each into a 125 liter enclosure. The level of the two smaller boxes is 6 dB higher at frequencies above the bass reflex tuning frequency. This increase is made up of 3 dB efficiency improvement due to the increasing membrane area and 3 dB of required power amplification.

Design and measurement

Initially, a speaker was sought which should meet the desired requirements. The choice fell on an 18" chassis with an impedance of 8 ohms, a sensitivity of 95 dB, a maximum RMS power of 1800 watts and maximum program power of 3600 watts. Measurements showed that the sensitivity below 55 Hz was lower than expected and therefore required further action. A construction as a bass reflex system (Fig. 3) with the advantages of the use of the backward emitted sound from the chassis and the higher efficiency at lower frequencies improved the frequency response in the range of 55Hz.

Measurements of the maximum sound pressure (Fig. 4) show an insufficient frequency response down to 35 Hz. Although there is the possibility to compensate the frequency response at moderate levels using a static filter, the maximum sound pressure without significant distortion will remain unchanged. The use of a dynamic equalizer helps to flatten the frequency response up to a level of approximately 120 dB_{SPL}. With further increasing level the required EQ gain will be reduced to allow a maximum level of 128 dB_{SPL} without amplifier distortion.

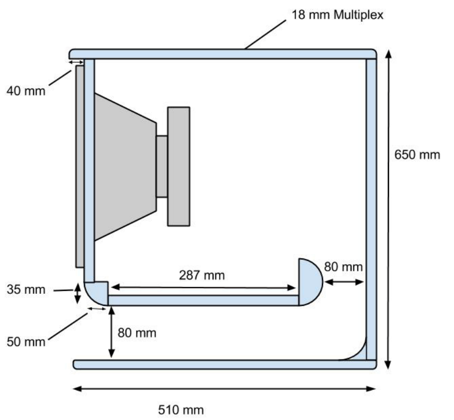

Figure 3: Compact bass reflex cabinet with streamlined reflex port. Net volume of about 126 l; Gross volume of about 168 l; Outside dimension 509x509x650cm.

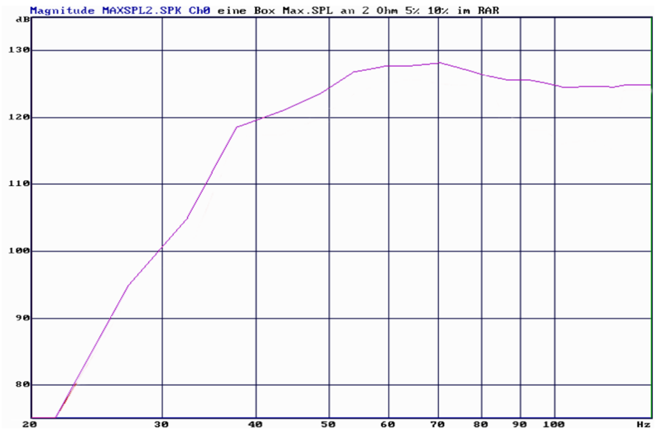

Figure 4: Measurement max. SPL including enclosure.

Cardioid system

In today´s public address system directional subwoofer setups (cardioid setups) become more and more popular. Such systems are used to protect sensitive areas from high level or to spare a concert stage of low frequency sound, to avoid disturbing feedback or unnecessary noise pollution. Here is an example for building a cardioid system.

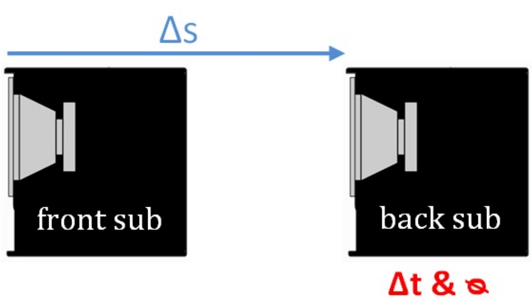

Figure 5: Scheme of a cardioid subwoofer setups; Back-sub with delay Δt and phase inversion.

Figure 5 shows two subwoofers in a distance of Δs standing one behind the other. The rear subwoofer (back-sub) receives an according to equation 1 (with c = speed of sound in air) determined time delay Δt and a phase inversion.

$$\Delta t = \Delta s / c \qquad [s] \qquad (1)$$

$$\Delta s = \lambda / 4 \qquad [m] \qquad (2)$$

Table 1: Constructive summation for Δs = 1.35 m.

Before subwoofer setup				
31, 5 Hz	40 Hz	63 Hz	100 Hz	125 Hz
-90°	-66°	0°	106°	-177°
Behind subwoofer setup				
31, 5 Hz	40 Hz	63 Hz	100 Hz	125Hz
-180°	-180°	-180°	-180°	-180°

Table 1 shows the mathematically determined complex addition in front of and behind the setup. In theory, the rear radiated sound clears independent of frequency completely. In reality, a rear attenuation of approximately 20 dB is achieved (Fig. 6). Disadvantage is that the complex addition in front of the setup for only one frequency (63 Hz in this example) works optimally. The distance Δs is calculated according to equitation 2 from fourth the wavelength of the desired frequency.

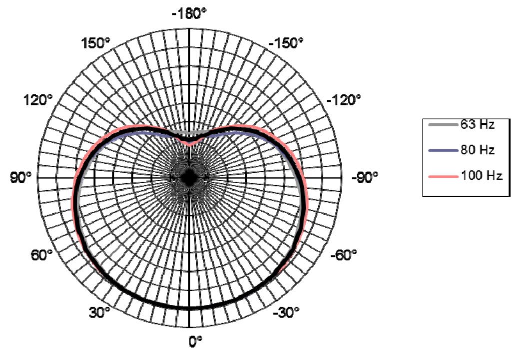

Figure 6: Polar plot; 80 Hz octave (black) of cardioid setup

Results

A total of 16 compact subwoofers were designed to be operated in a group of four each by an amplifier with 7000 watts short term power. This leads to 1750 watts per subwoofer resulting in a maximum level of 128 dB_{SPL}. Depending on the location different configurations (cardioid or non-cardioid) like LR setup, LCR setup or a line sound source are possible. Configured as line sound source the system gives an even coverage of the audience area with a maximum sound pressure level of more than 120 dB at a distance of 50 m.

References

[1] McCarthy B. – Sound System Design and Optimization

[2] Seuken P. - Diploma Thesis 2013

[3] Four Audio Monkey Forest

[4] Software Bassyst für Windows