Acoustic Overview

Version 1.0

IMPORTANT INFORMATION AND DISCLAIMERS

Version 1.0, August 2001

Revision History

Revision	Document Update	Date
1.0	Initial release	August 2001

Contents

1. Introduction

The acoustic emission of a system is increasingly important for computer systems to move into silent environments. The acoustic noise sources in a system are usually the cooling fans, the power supply fan, the hard drives and the peripherals. Both fan noise and hard drive noise are important factors that need to be addressed.

The first and most important option in noise control is the reduction of source emissions. The acoustic emission of a system, for instance, can be reduced by selecting quieter fans and hard drives. Selecting quieter components is not always a viable solution with given design, cost and performance constraints, and to achieve the 4.0 BA goal, the chassis has to contribute to noise control.

With a traditional chassis design, fan speed control can be used. Fan speed control balances thermal and acoustic loads by adjusting the fan speed based on the thermal requirements. In the present investigation, the fan speed control algorithm is based on the external ambient temperature. There are two ways to implement fan speed control: (1) place a thermistor on the fan and adjust the fan speed based on the inlet temperature or (2) use temperature sensors and a control chip on the motherboard to adjust the fan speed. Fan speed control is implemented on new Intel® desktop boards, based on Intel® 810, 815, and 850 chipsets. More information on thermistor based fan speed control and Intel® Active Monitor fan speed control hardware implementation and software is given in Section 2.

The acoustic attenuation of noise sources in today's chassis is virtually non-existent. This means that the chassis does not reduce noise produced from internal noise sources. In fact, in many cases there is amplification due to the chassis: the noise level under installed conditions is higher than the sum of the individual noise sources when placed outside of the chassis. For fan noise, part of this increase is caused by the backpressure effect that is introduced when a fan is placed inside a chassis. In this report, guidelines are presented to quantify this effect and to develop a low impedance system that is typically beneficial for acoustics. In traditional chassis designs, fans are attached directly to the sides of the chassis, and there is a direct line-of-sight from the outside to the fan. Mounting of the fan is critical, and any obstructions close to the intake will strongly amplify the emitted sound. In addition, vibrations that are introduced by imbalanced fans are directly transmitted to the chassis. Hard drive vibrations are also directly transmitted to the chassis enclosure and contribute to the emission from the enclosure panels.

This acoustic design guideline starts with the first step in an acoustic design process: a description of the acoustic goal. Acoustic levels should be estimated in the early design stage to study thermal/acoustic trade-offs with fan speed control setting. This enables making the right trade-offs in the design stage, selecting components, and setting a realistic target. This is extremely important, because after these choices are made, the remaining solution space is severely constrained.

In Section 3, fan speed control implementation is discussed. Because the current design only requires one fan to be speed controlled, and the control algorithm is based on the ambient temperature, the implementation of speed control is relatively simple, cost efficient and robust. Both thermistor based control, which offers a very attractive and robust solution, and board level fan speed control are outlined.

Section 4 describes the component selection process. A simple sound power summation allows making first order estimates of emissions in the design stage. Sensitivity studies with respect to component emissions can be performed, allowing an efficient performance/cost/acoustic analysis. The fan and hard drive selection process is outlined, using the sound power summation and more detailed investigations using a fan plenum.

Section 5 concerns the component placement and mounting methods. It contains general practical guidelines for the designer when placing and installing components into a system. This section is followed by two design examples: a micro-tower design with rear air intake, and a mini-tower design with a front to back airflow design. Finally, general conclusions are presented.

2. Design Goal

The first step in the acoustic analysis is to formulate a design goal. This can be separated into two parts:

- Define the target setup according to which the product will be tested
- Quantify the target value for the product

2.1 Target Setup

Acoustic testing procedures are well documented and standardized. ISO 7779 and ECMA 74, for instance, outline procedures to determine the acoustic emissions of computer and business equipment. ISO 9296 and ECMA 109 describe the procedures to determine the declared noise emission values. A list of standards and relevant organizations is given in Appendix B.

The primary quantity to be measured and declared in acoustics of computer and business equipment is the emitted sound power, per ISO 9296. This quantity allows comparing different systems and to quantify the overall emitted acoustic energy. Traditionally, sound pressure measurements were carried out at operator and bystander positions. Although these values are not suited for an overall comparison of products, these sound pressure levels are helpful in identifying acoustic problems at specific positions that are of importance to the user. In view of these considerations, ISO 9296 states that both sound power and sound pressure levels are to be declared. In order to avoid confusion, sound pressure levels are typically expressed in dBA, decibels, whereas sound power levels are preferably expressed in terms of BA, Bels, see also ISO 7779 and ISO 9296.

Three standard setups are available for acoustic testing:

- Sound power measurements
- Sound pressure measurements with the floor standing setup
- Sound pressure measurements with the desktop setup

In the present guidelines and the corresponding validation reports, sound power and sound pressure measurements with both the desktop and the floor standing setup were carried out. General descriptions of these test setups and measurement procedures are given in Appendix C. For more detailed descriptions the reader is referred to the ISO standards, as outlined in Appendix B.

2.2 Target Value

In the present study, an acoustic goal of 4.0 BA emitted sound power in the idle mode, measured according to ISO 7779 at 23±2 °C, was chosen. Evidently, the acoustic performance of a system is a product differentiator. System performance, size, cost, and acoustic performance are closely related. Therefore, the acoustic design goal depends on the product positioning in the market. The goal of 4.0 BA was chosen based on an overview of current systems.

Figure 1 shows that there is a large variation in system emissions, ranging from 3.0 BA to more than 5.0 BA. The systems with low emission levels are typically low performance systems, or high performance systems that incorporate fan speed control. The systems with higher emissions are typically high performance systems that do no incorporate noise control techniques. There is a trade off between general performance, acoustic performance, cost and size. The acoustic design model assists in determining a realistic design goal for the system of interest. Note that an extremely low acoustic level can be considered as over design. When the noise of the system is in the ambient background, lowering the level even further does not provide any additional acoustic benefit, but likely has cost, size, or even performance consequences.

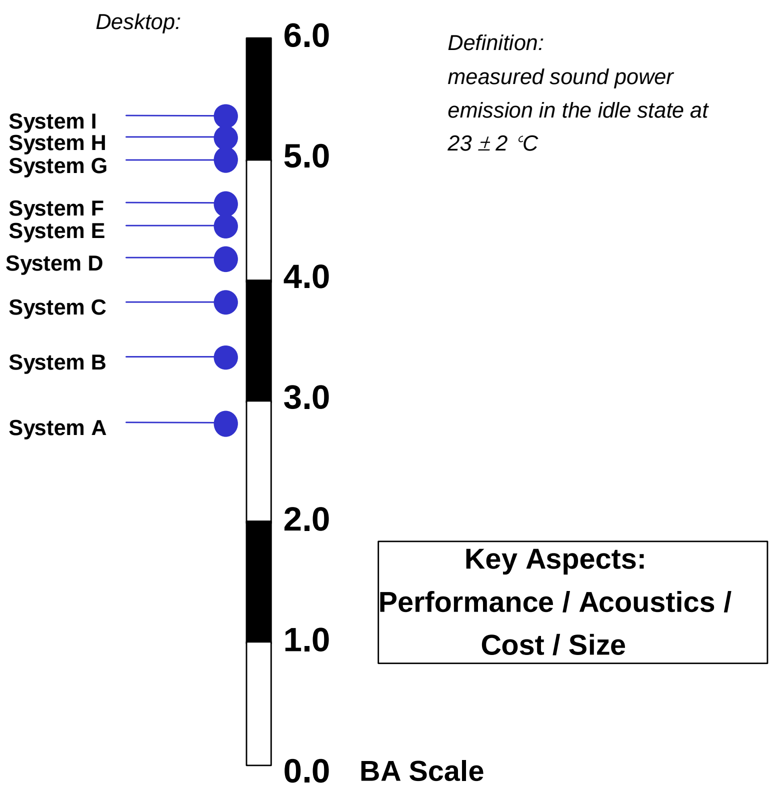

Figure 1. Example of Acoustic Performance of Today's Systems

The target of 4.0 BA was chosen as a good trade off between performance, acoustics, and cost. From an acoustic point of view, a product with an emission of 4.0 BA can be considered as competitive. A sound power emission of 4.0 BA or less will results in sound pressure levels at operator and bystander positions that are within background levels in relatively quiet user environments. For reference, a VCR at play was measured at 3.2 BA, and the lowest sound power that can be measured with a reasonable degree of accuracy in the anechoic chamber used in the present investigation is about 3.0 BA. Note that the sound power target was set for the idle mode, here being the mode in which the unit is powered and the processor may run at full power.

Figure 2 gives an overview of the standards and regulations on acoustics. It shows that in order to meet all product requirements, a declared emission in the idle mode should be lower than 4.8 BA, and the declared emission in the active mode should be lower than 5.5 BA. These labels are voluntary Engineering Change Order (ECO) labels.

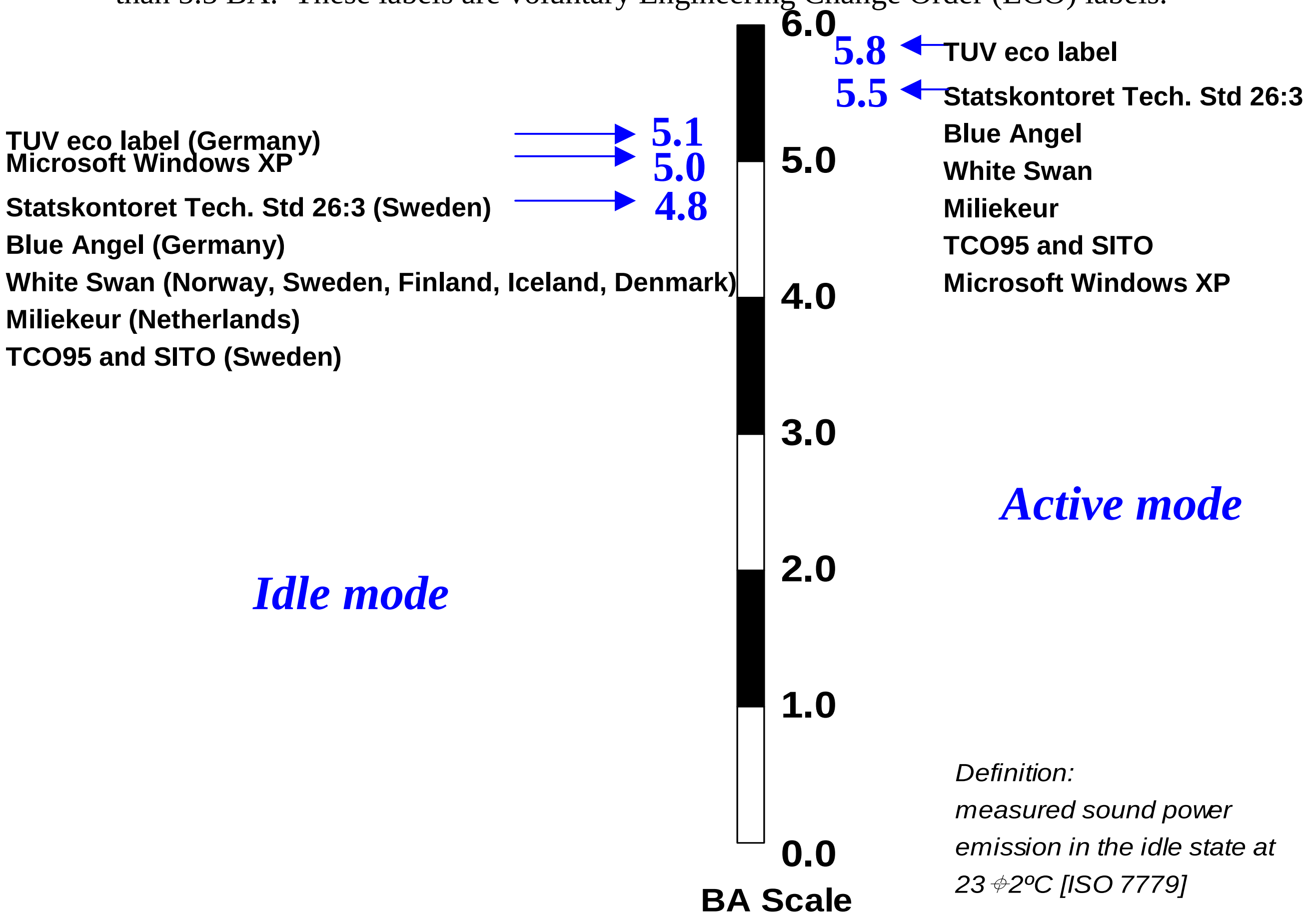

Figure 2. Overview of Guidelines and ECO Labels

2.3 Sound Quality

The target for the current design was set in terms of sound power. Most standards and ECO labels are formulated in terms of sound power. Sound pressure experiments were carried out to identify any potential issues at specific positions, for example operator and bystander positions. The spectral content of the signals was collected for analysis. In addition to sound power and sound pressure values, the acoustic performance of a product is determined by its sound quality. This involves aspects of psychoacoustics, related to the perception of sound. Sound quality analysis needs to be evaluated on an individual product basis, and is not within the scope of the present general design guideline.

3. Fan Speed Control Implementation

Fan speed control is the most important acoustic ingredient of the present design. A big advantage of the present design with a 92-mm system fan and a duct is the simplicity of the fan speed control implementation. In an example ATX chassis, the power supply only supplies cooling for itself. Therefore, the voltage of this fan can be run at a fixed low speed. The only ingredient to be thermally controlled is the system fan. Since there is only one fan and it draws air directly from the outside, either via a front intake or a rear intake, the preheating of air going into the fan is very low and the operating conditions for the fan are well defined. This is a very important aspect that facilitates the implementation of fan speed control. It allows an implementation that is decoupled from the other chassis ingredients.

3.1 Thermistor Based Control

Thermistor based control uses the temperature of the air entering the fan to adjust the fan speed. Since the air intake temperature is well defined, this fan speed control option is easy to implement for the current design. In addition, it is robust because it does not require any detailed knowledge about the temperature distribution in the chassis itself. Figure 3 shows the desired fan speed control mechanism for the 92 mm x 92 mm x 25-mm fan used in the example ATX chassis.

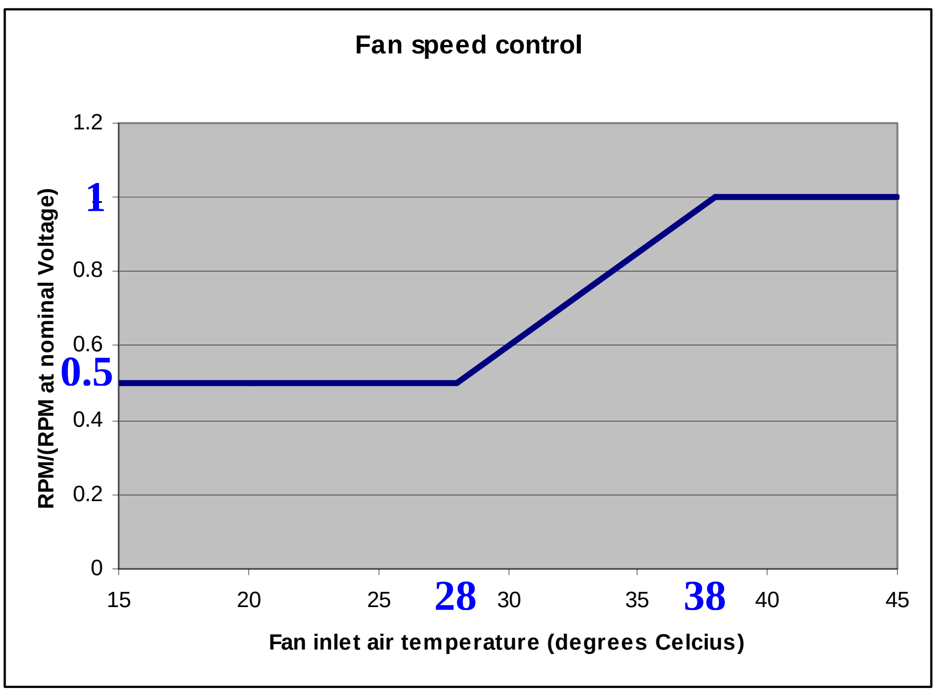

Figure 3. Fan Speed Control Curve of an Example ATX Chassis System Fan

Thermal requirements dictate that the system fan runs at a nominal voltage at an external ambient temperature of 35 °C. For external ambient temperatures below 25 °C, the fan can run at approximately half the nominal RPM, with a linear ramp between 25 °C and 35 °C. A maximum preheating of 3 °C is assumed between external ambient temperature and the fan inlet temperature. Therefore, the fan speed control curve for an example ATX chassis is:

- RPM is 0.5 times the nominal RPM for fan air inlet temperatures below 28 °C
- RPM is nominal RPM for fan inlet temperatures above 38 °C
- Linear RPM increase with temperature between 28 °C and 38 °C

Evidently, the airflow requirements for the fan have to be met. For this reason, the scale in Figure 3 was non-dimensional.

Thermistor controlled fans are available from a variety of manufacturers. Figure 4 shows the results of measurements on a set of thermally controlled fans. The figure shows that the fans perform according to given specifications and are suited for application. Note the offset in temperature on the horizontal axis.

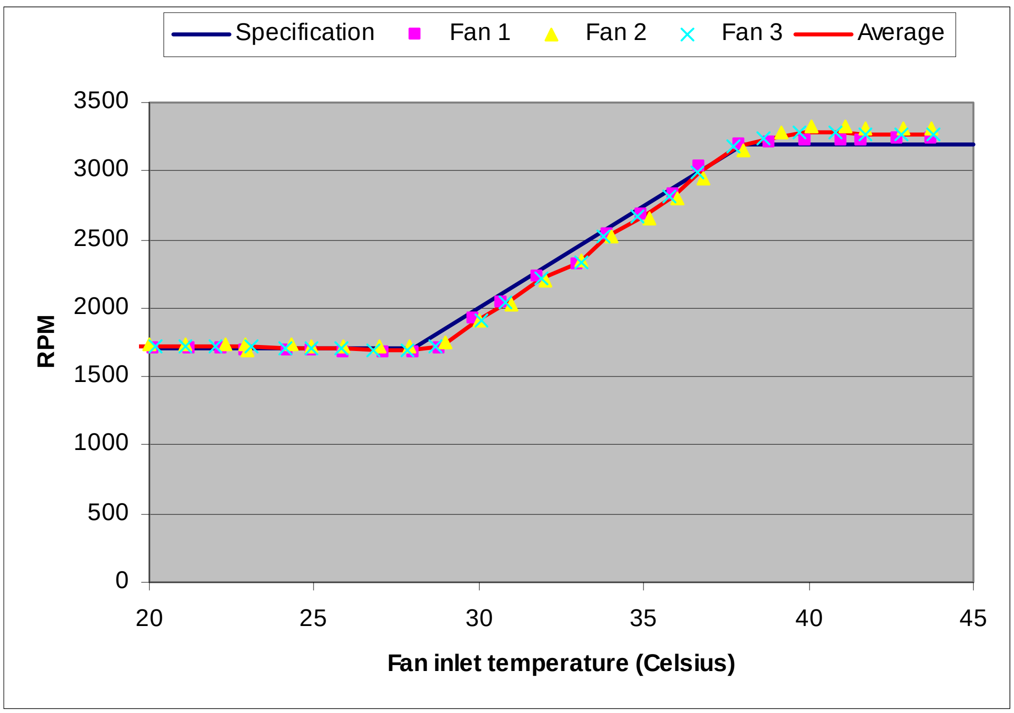

Figure 4. Fan Speed versus Temperature Curves

3.2 Board Level Control

Board level control uses a control chip on the board to control the fan speeds. The chip can use multiple inputs and is typically able to control multiple outputs. One of the essential aspects in developing a control strategy is to establish the relation between sensor temperatures and required fan settings. For example, thermal sensors on the board or the junction temperature are used as inputs. There is a preheating of the air at the sensors that depends on system configuration, layout, and loading. Therefore, knowledge of and control of these variables is necessary to successfully implement this type of fan speed control solution

Link to the Intel® World Wide Web site for information on Intel® Active Monitor.

4. Component Selection

The first step in component selection is to quantify the contributions of individual noise sources and to establish the sensitivities with respect to component emissions. In the second step, a more detailed evaluation of individual components should be carried out.

4.1 Sensitivity Study

A sensitivity analysis can be performed using a system level sound power prediction. The sensitivity with respect to the component emissions is investigated. The data that is used for the sensitivity analysis is summarized in Table 1. The "present experiments" refers to the components that were used in the second design example, the mini-tower.

The data is based on information that is available on the acoustic performance of fans and hard drives given current manufacturer sound power data. There is a significant variation in the noise emission of components, and the sensitivity of the design with respect to this aspect is analyzed. In addition, the influence of the chassis attenuation is visualized. With such an analysis, the acoustic performance of the system can be estimated in the design stage, and the right trade-off can be made. Fan speed control settings can be investigated, using the thermal requirements, and different solution options, for instance fan speed control settings and the number and sizes of fans, can be compared.

The system level sound power can be obtained by assuming that the individual sources are incoherent, uncorrelated:

$$L_{wa} = LOG10\left[\sum_{i=1}^{n} 10^{L_{wai} - \Gamma_i}\right]$$

In this formula L_{wai} is the sound power emission of the noise source I, and Γ_i is the attenuation for that noise source. The emission of the fans is assumed to be related to the CFM according to:

$$L_{wa} = a * LOG10(CFM) + b$$

where a and b are coefficients that characterize the fan. The volumetric flow rate is related linearly to the voltage supplied to the fan through:

$$CFM = \left[\frac{V}{V_{\max}}\right] * CFM_{\max}$$

Hence one finally obtains:

$$L_{wa} = a * LOG10\left(\left[\frac{V}{V_{\max}}\right] * CFM_{\max}\right) + b$$

where V_{max} is the nominal voltage and CFM_{max} is the volumetric flow rate at that voltage.

Table 1. Data for Sensitivity Analysis

Component	**Description**	**Emission/Attenuation (BA)**
Power supply	Quiet	L_{wa} = 5.053·LOG10(CFM)-3.271
	Present fan	L_{wa} = 4.965·LOG10(CFM)-2.665
	Noisy	L_{wa} = 4.965·LOG10(CFM)-2.665
System fan	Quiet	L_{wa} = 5.177·LOG10(CFM)-4.075
	Present fan	L_{wa} = 5.279·LOG10(CFM)-3.825
	Noisy	L_{wa} = 5.999·LOG10(CFM)-4.917
Hard drives	Quiet 5400 RPM	L_{wa} = 2.9
	Noisy 5400 RPM	L_{wa} = 3.5
	Quiet 7200 RPM	L_{wa} = 3.2
	Present 7200 RPM drives	L_{wa} = 3.2 and L_{wa} = 4.2
	Noisy 7200 RPM	L_{wa} = 4.2
	Quiet 10000 RPM	L_{wa} = 3.7
	Noisy 10000 RPM	L_{wa} = 4.7
Attenuation	System fan	Γ = 0.2
	Hard drives idle	Γ = 0.4
	Hard drives active	Γ = 0.8

4.1.1 Power Supply

The influence of the power supply noise emission on the total system noise level is given in Figure 5. Note that, in order to study the effect of the power supply emission, the other components in the system were not changed: the other components are the same components that were used in the present investigation.

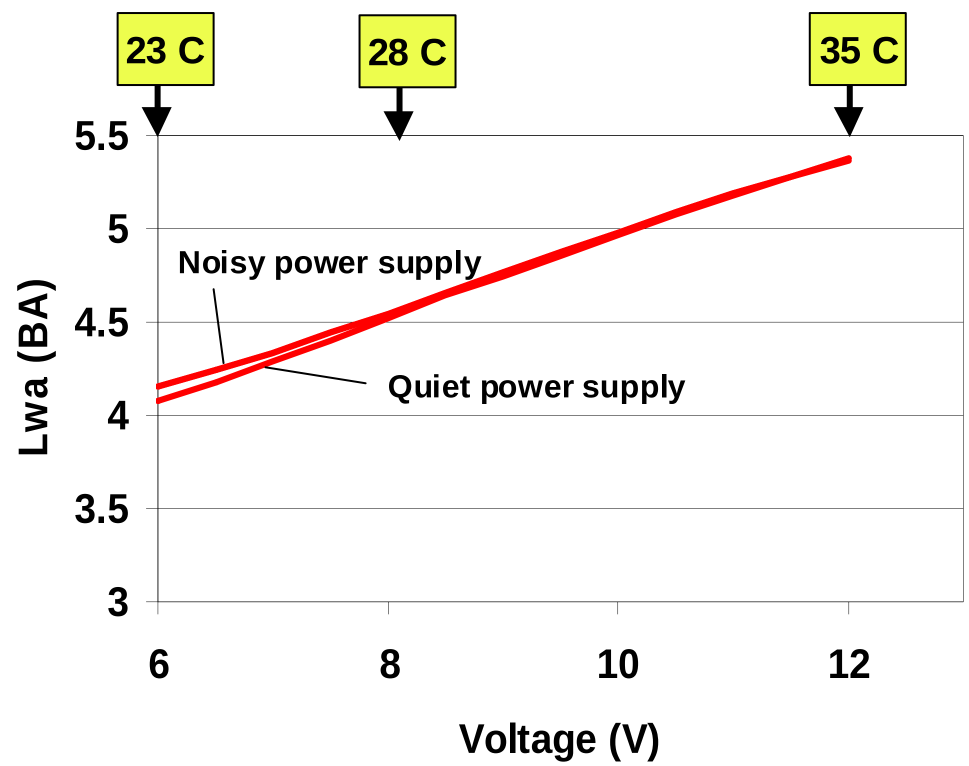

Figure 5. Sensitivity of System Emission With Respect to Power Supply Emission

On the vertical axis, the emitted sound power, in BA, is given. On the horizontal axis, the fan voltage is given. This fan voltage varies with external ambient temperature, as indicated in the top of the plot. For an external ambient temperature of 35 °C, the fan would run at 12 volts. At an external ambient temperature of 23 °C, the fan would run at 6 volts. These fan voltages, as a function of external ambient temperature, are given by the thermal requirements at that temperature. Figure 5 shows that the influence of the power supply emission variation is not very large. The other noise sources in the system are dominant and therefore the power supply influence is limited.

4.1.2 System Fan Emissions

Figure 6 shows the influence of the system fan noise emission on the total system noise level.

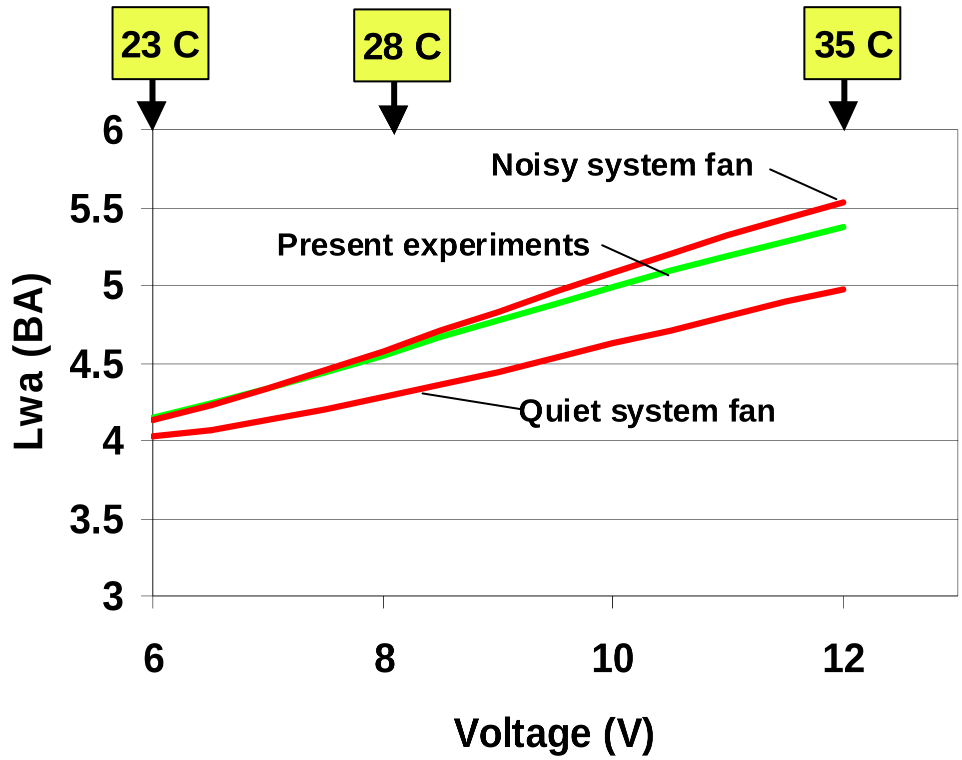

Figure 6. Sensitivity of System Emission With Respect to System Fan Emission

Figure 6 shows that the system fan has a large influence on the acoustic emission of the total system. The variation in acoustic emissions between fans causes a large variation in system emission. At 6 V the variation is about 0.2 BA, and at 12 V the variation increases to more than 0.5 BA. The fan that was used in the present experiments was a relatively noisy fan. At low voltages it is the noisiest fan. The graph shows that a relatively quiet fan has a large influence on the system emission, especially at higher voltages. At lower voltages the hard drives become important noise sources and the relative importance of, and the sensitivity with respect to, the system fan emission decreases.

4.1.3 Hard Drive Noise Emissions

The influence of hard drive emission on the system noise level was investigated for 5400-, 7200-, and 10000-RPM drives. It is assumed in this sensitivity analysis that there is one hard drive in the system. Note that in the present experiments, two 7200-RPM drives were used.

4.1.3.1 5400 RPM

Figure 7 shows the influence of the hard drive emission on the total system noise level as a function of the system fan voltage.

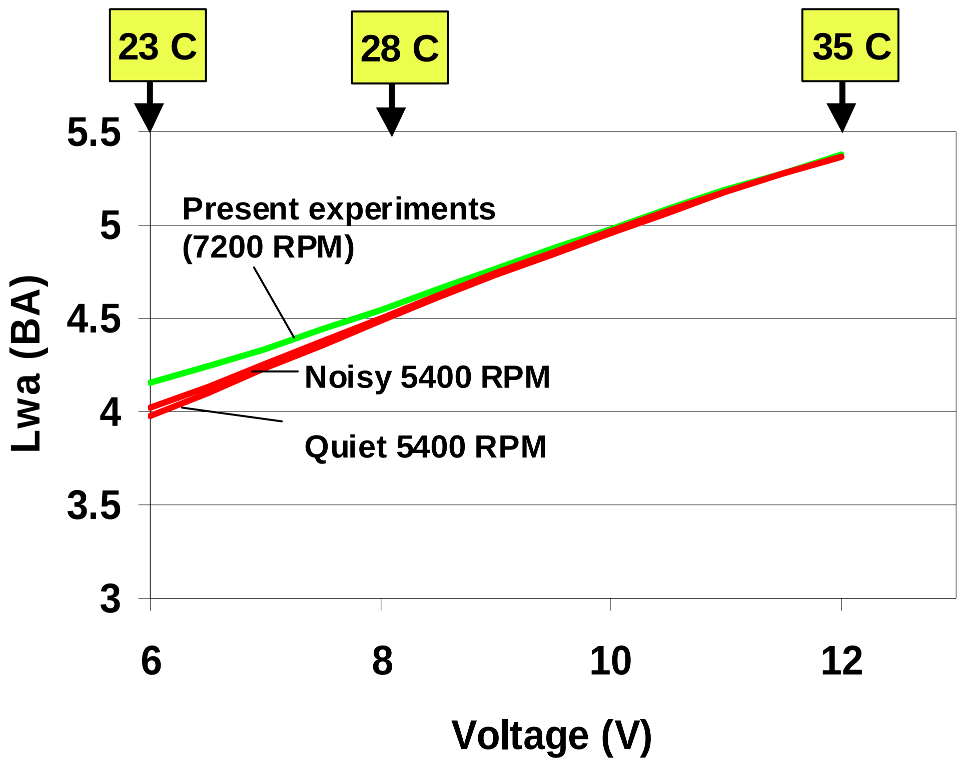

Figure 7. Sensitivity of System Emission With Respect to Hard Drive Emission: 5400 RPM

Figure 7 shows that the sensitivity of the present system with respect to these emissions is low. Table 1 shows that the emission of 5400-RPM hard drives in the idle mode ranges from 2.9 BA to 3.5 BA. Accounting for the attenuation, the strength of this noise source is low compared to the other sources in the system, especially the main system fan. Figure 7 shows that the 7200-RPM drive that was used in the present experiments is noisier than 5400-RPM drives.

4.1.3.2 7200 RPM

Figure 8 shows the influence of the hard drive emission for 7200-RPM drives on the total system noise level as a function of the system fan voltage.

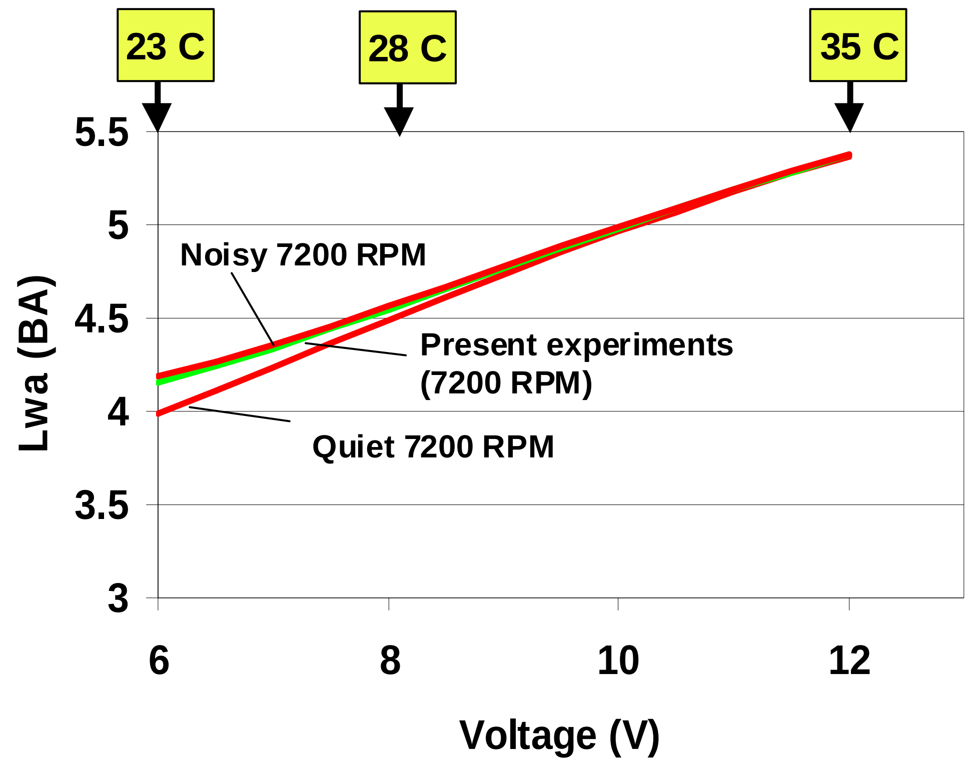

Figure 8. Sensitivity of System Emission With Respect to Hard Drive Emission: 7200 RPM

Figure 8 shows that there is significant variation at low system fan voltages. The noise emission of 7200-RPM drives varies between 3.2 BA and 4.2 BA (see Table 1). Accounting for the chassis attenuation, there is still a significant contribution to the system noise level at low fan voltages. Because of this fact, there is an asymptote in the curve for low voltages. Further lowering the fan voltage at such a point would not be very useful, because the hard drive is now the main noise source. The 7200-RPM drive that was used in the experiments was the noisiest drive in this category and thus represents a worst case scenario.

4.1.3.3 10000 RPM

Figure 9 shows the influence of the hard drive emission for 10000-RPM drives on the total system noise level as a function of the system fan voltage.

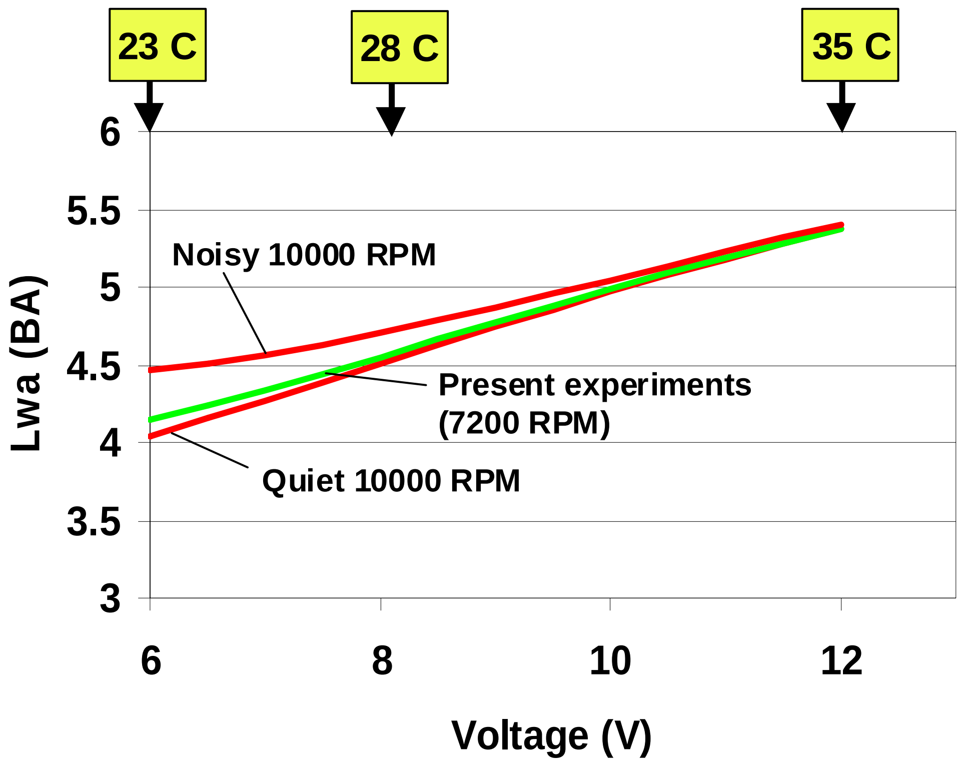

Figure 9. Sensitivity of System Emission With Respect to Hard Drive Emission: 10000 RPM

Figure 9 shows that there is a large variation at low system fan voltages. The noise emission of 10000-RPM drives varies between 3.7 BA and 4.7 BA. Accounting for the chassis attenuation, there is still a very large significant contribution to the system noise level at low fan voltages. Because of this fact, there is an asymptote in the curve for low voltages. Again, further lowering the fan voltage at such a point would not be very useful, because the hard drive is now the main noise source. The noise emission of the 7200-RPM drive that was used in the experiments compares with that of a relatively quiet 10000-RPM drive.

4.1.4 System

In the previous sections the influence of each individual component was analyzed. All other parameters were held constant in the analysis to the parameters that were used in the present experiments. Figure 10 shows the system noise emission in idle mode as a function of system fan voltage, when all the quietest or noisiest components are selected.

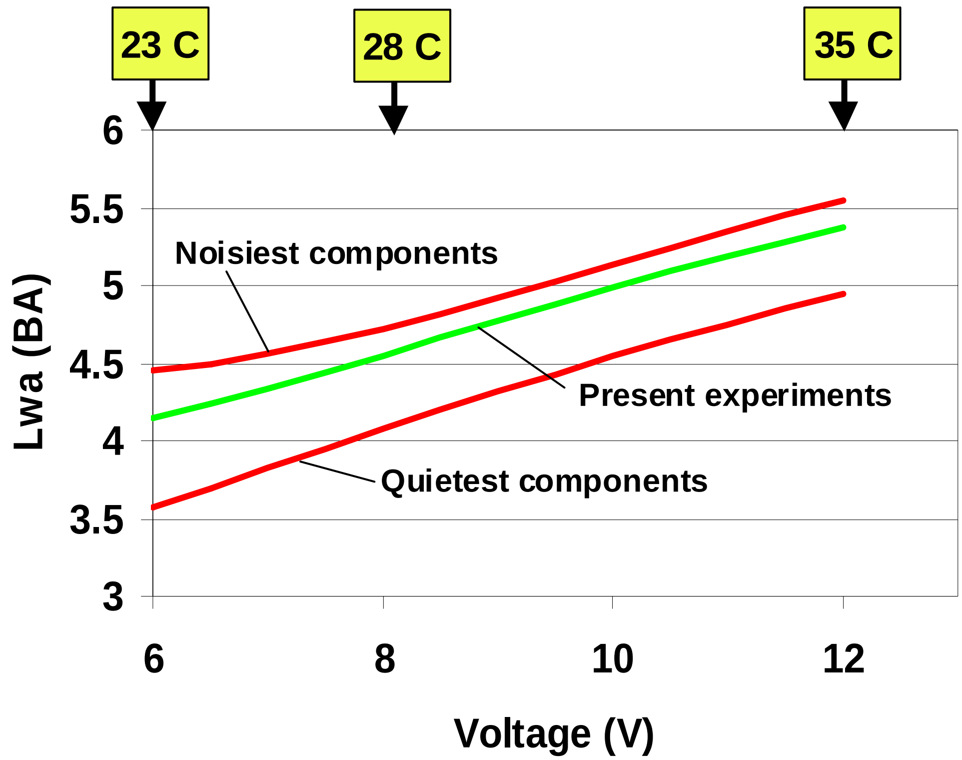

Figure 10. Sensitivity of System Emission with Respect to Component Emissions

Figure 10 shows that there is a wide variation in system emission. By selecting quiet components, a difference of more than 0.8 BA can be achieved compared to the noisiest components. The variation at higher voltages is primarily caused by the variation in system fan emission, whereas the variation at lower voltages is primarily caused by the variation in hard drive emission. Figure 10 shows that the components that were used in the present experiments are significantly noisier than the quietest solution. Thus, the acoustic performance of the mini-tower system can be improved by selecting these quieter components.

4.1.5 Chassis Attenuation

In the experiments for the mini-tower, it was found that the bezel attenuation was approximately 0.2 BA (this number was not accounted for in the previous sensitivity results). The influence of the chassis attenuation on the system noise level was analyzed. Figure 11 shows the emitted sound power of the system for three cases:

- System fan and hard drive attenuation
- Only system fan attenuation (no hard drive attenuation)
- No attenuation

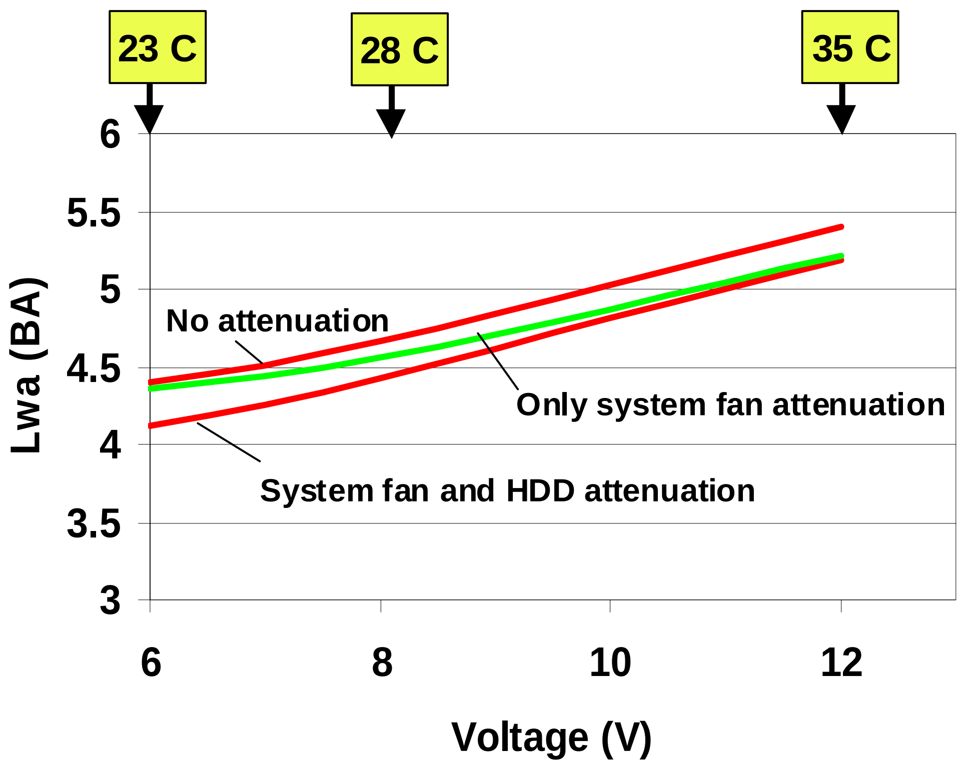

Figure 11. Sensitivity of System Emission with Respect to Chassis Attenuation

Figure 11 shows that there is a contribution from the chassis attenuation. The system fan attenuation is effective for higher voltages, where the system fan is the main noise source. The hard drive attenuation is important at low voltages only, where the hard drive is a significant noise source. The figure shows that the overall chassis attenuation is about 0.3 BA.

4.2 Fan Selection

The sound power model can assist in a first order estimate of fan emissions and assist in the fan selection process. Like indicated in previous sections, the sound power model does not incorporate the backpressure effect of the fan.

In order to select the appropriate fan for the application of interest, this effect should be quantified. Fan manufacturers typically publish a fan curve and the acoustic emission at free flow rate, often in terms of the sound pressure level at one meter from the inlet. A fan plenum can be used to quantify the sound power level as a function of backpressure, as outlined in detail in ISO 10302. This sound power emission curve assists the designer in selecting quiet components.

A picture of a fan plenum is given in Figure 12. It consists a plenum with a thin polyester film on a wooden frame. The fan is mounted on the mounting panel. At the back of the plenum, there is a slider opening that can be used to adjust the pressure in the plenum (the backpressure on the fan). The pressure is read from a pressure ring behind the mounting panel assembly. The thin polyester film is transparent to sound, but not to airflow. The whole plenum is placed in the anechoic chamber and the sound power level can be determined as a function of backpressure. For more detailed information the reader is referred to ISO 10302.

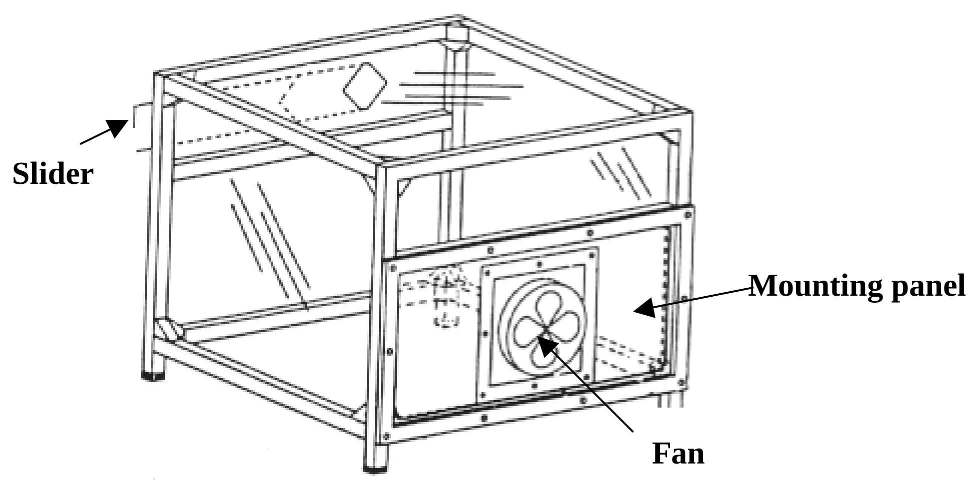

Figure 12. Schematic Drawing of Fan Plenum

An example analysis of the backpressure effect was conducted for the 92 mm x 92 mm x 25-mm fan used in the current design. The maximum airflow of this fan is approximately 55 CFM and the maximum pressure is approximately 0.19 inches of H_2O. Figure 13, Figure 14, Figure 15, and Figure 16 show the fan curves for three system fans. System impedance curves for various systems and sound power curves at different voltages of the fan. Note that the horizontal axes are pressure drop, not flow rate.

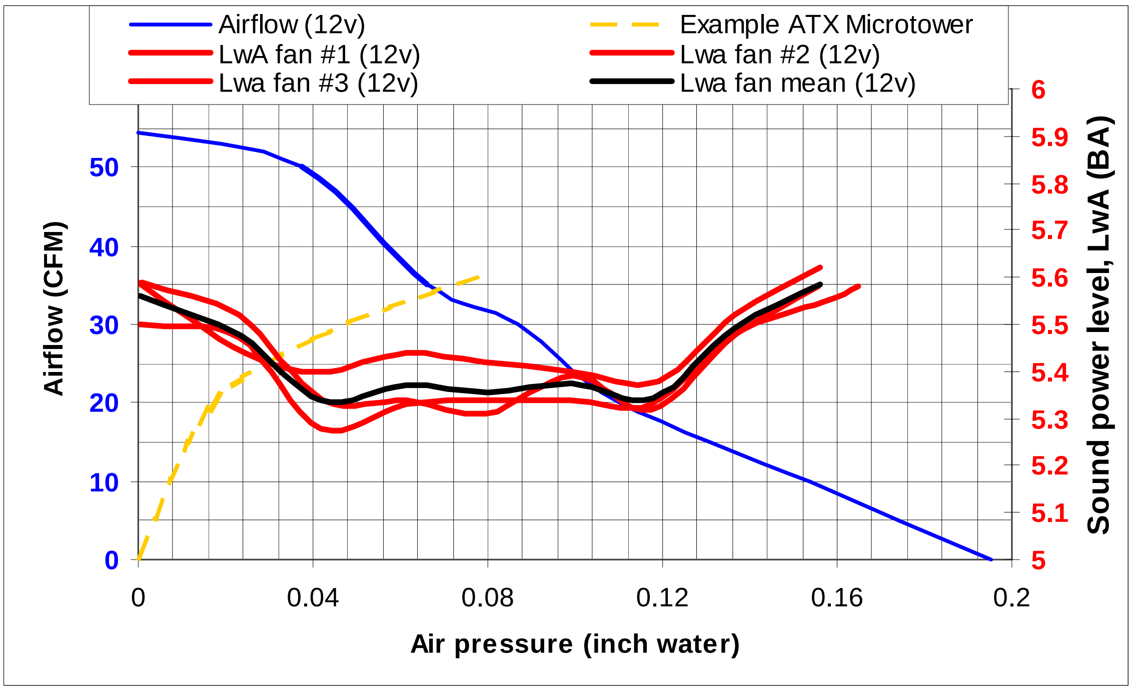

Figure 13. System Fan: Airflow, System Impedance, and Sound Power at 12 V

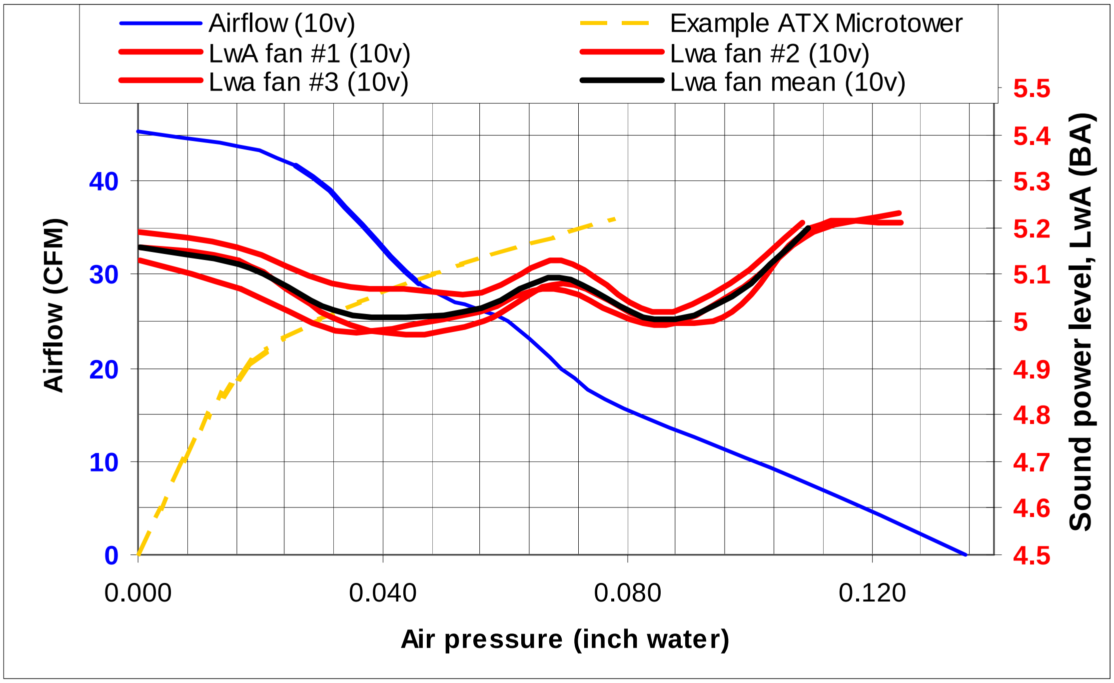

Figure 14. System Fan: Airflow, System Impedance, and Sound Power at 10 V

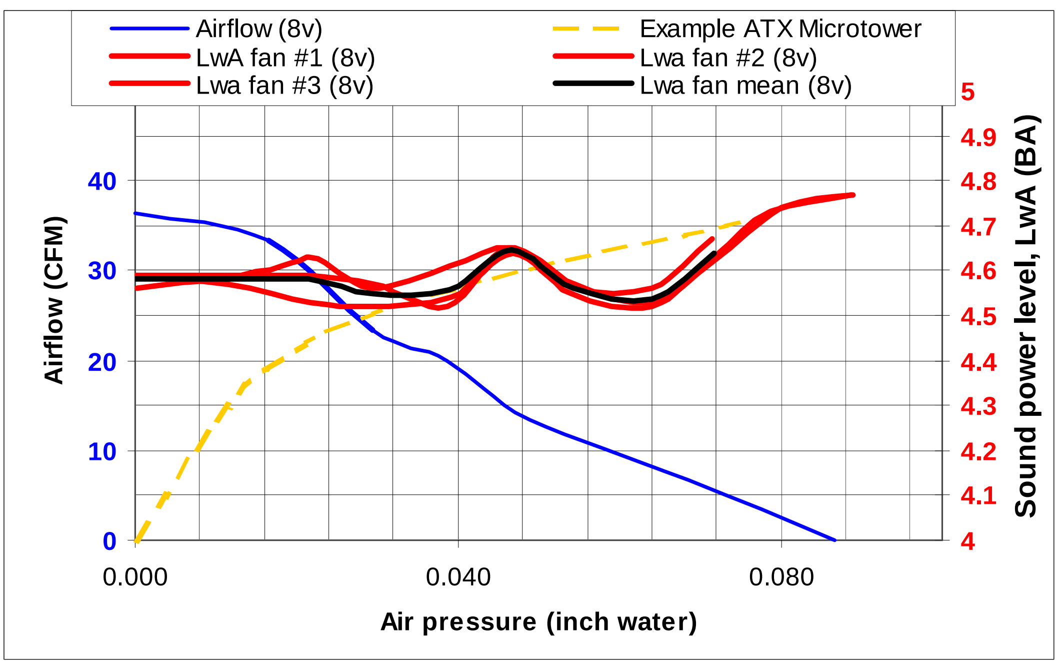

Figure 15. System Fan: Airflow, System Impedance, and Sound Power at 8 V

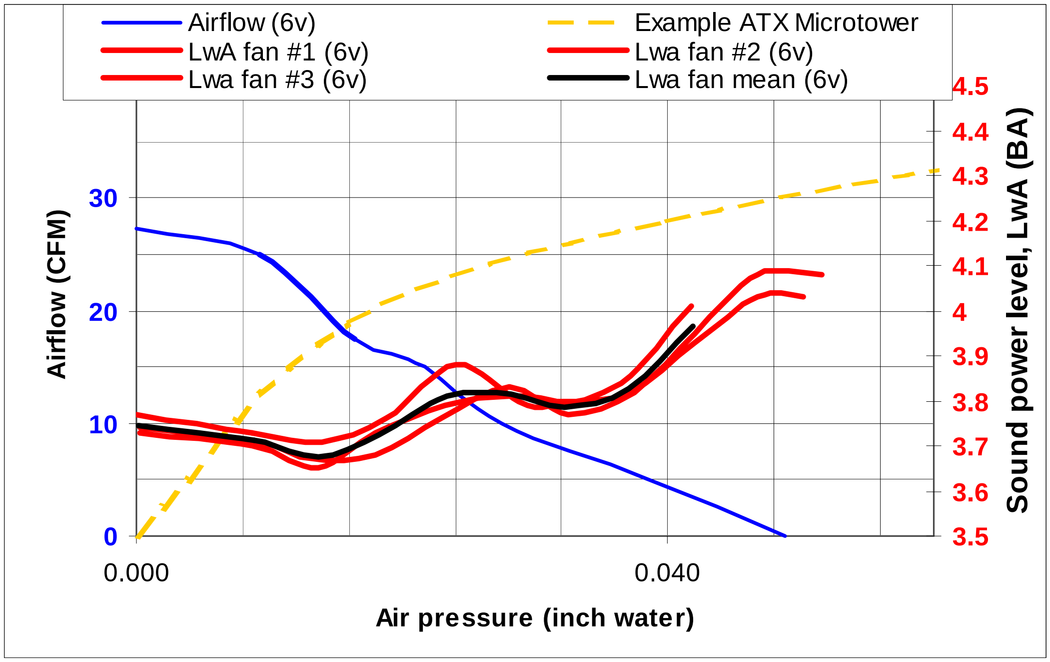

Figure 16. System Fan: Airflow, System Impedance, and Sound Power at 6 V

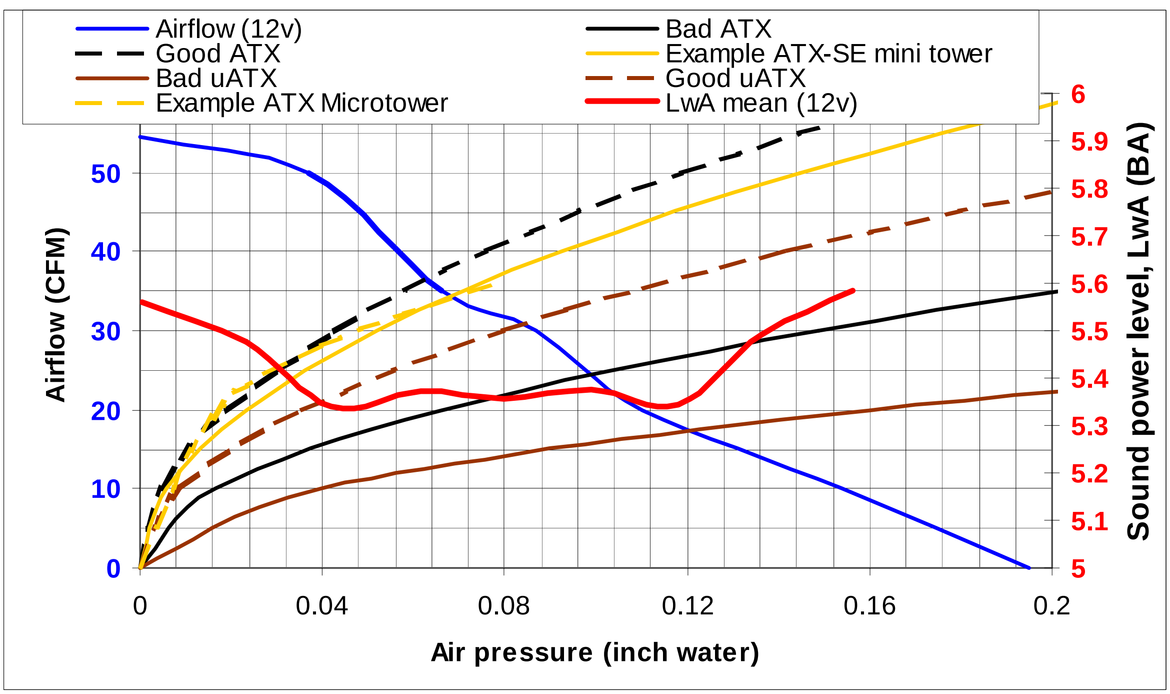

Figure 17. System Fan: Airflow, System Impedance, and Sound Power at 12 V

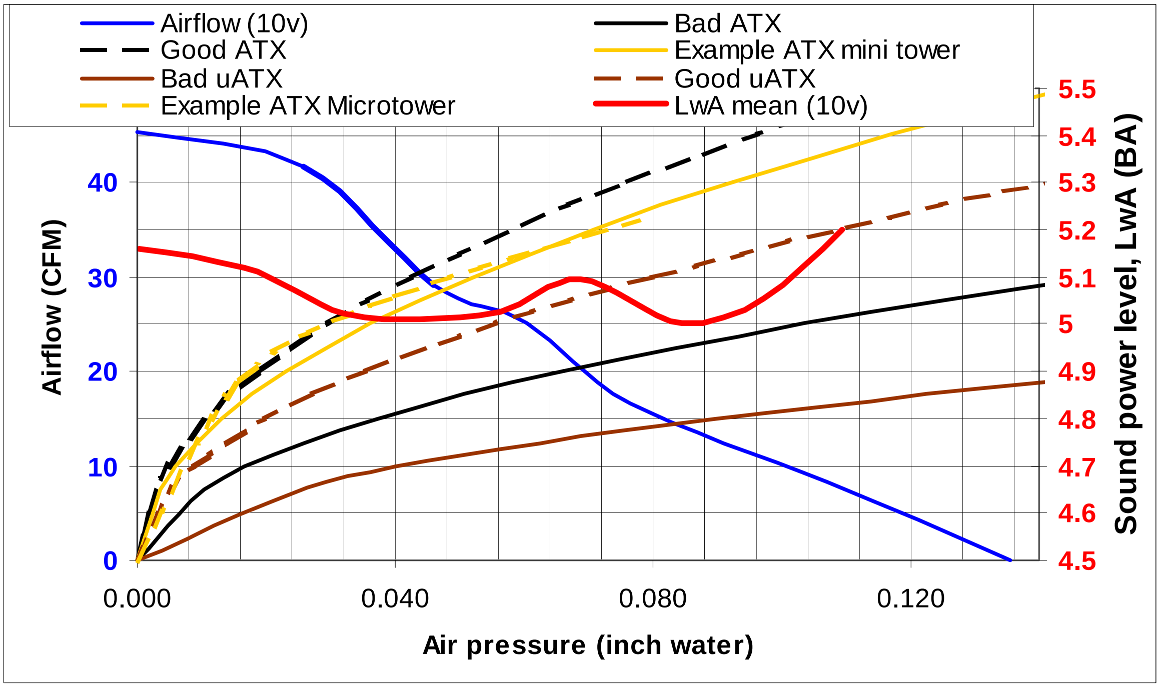

Figure 18. System Fan: Airflow, System Impedance, and Sound Power at 10 V

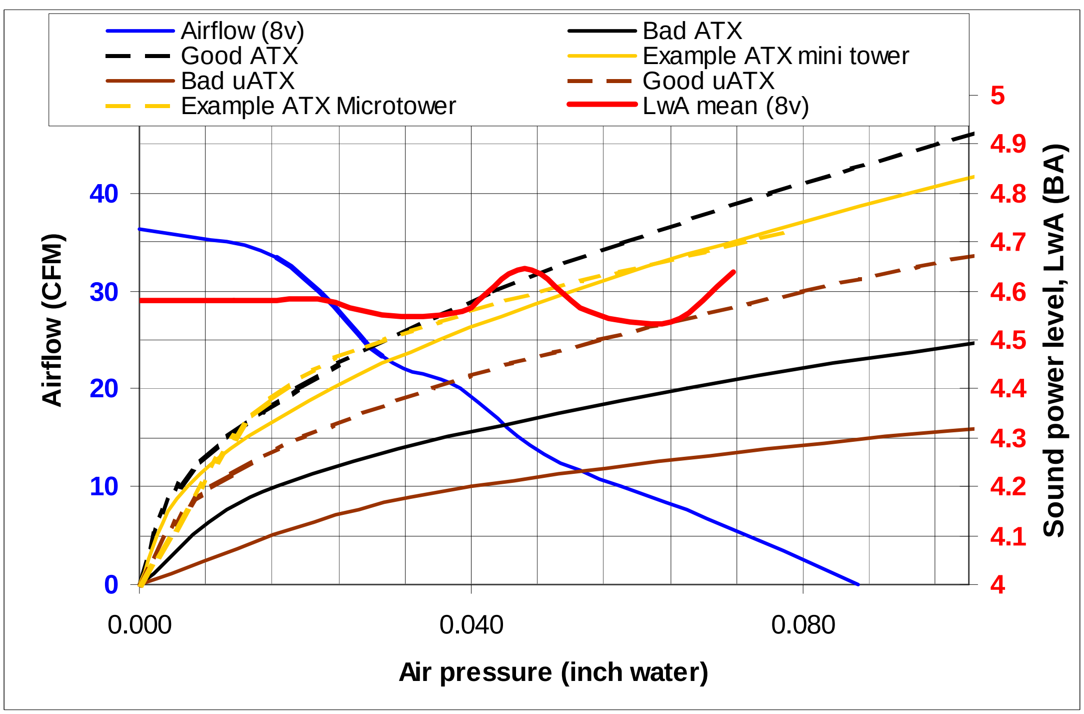

Figure 19. System Fan: Airflow, System Impedance, and Sound Power at 8 V

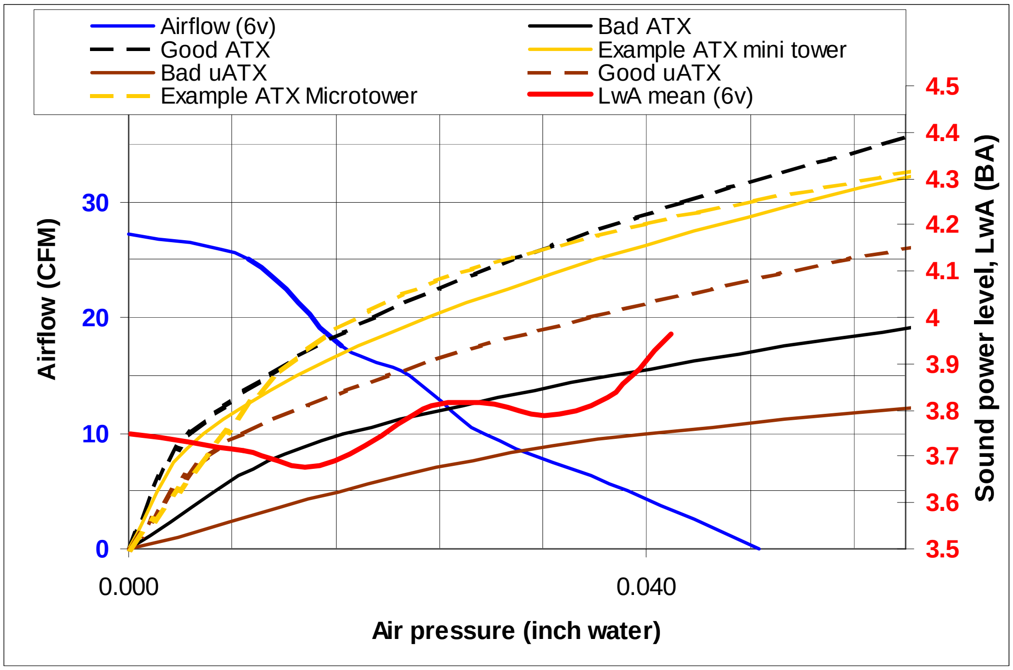

Figure 20. System Fan: Airflow, System Impedance, and Sound Power at 6 V

Figure 13, Figure 14, Figure 15, and Figure 16 show the emission of the fan as a function of the backpressure. The emission of the current fan is relatively flat: variations due to backpressure are within 0.2 BA. However, the magnitude of this variation depends on the fan of interest and may vary with for instance size and manufacturer. Typically, the emissions of fans are minimal around 20 % to 40 % of the maximum backpressure of the fan. Thus, it is typically beneficial to develop a low impedance system with a low-pressure drop.

Figure 17, Figure 18, Figure 19, and Figure 20 include the fan curve for the fan and the system impedance curves for a variety of systems with different form factors. The intersection of the fan curve and the impedance curve gives the fan operating point. The corresponding sound power emission can then be read from the emission curve. The figures illustrate the benefit of a low impedance system: the operating points can change drastically because of changes in back pressure. This may result in increased noise levels. It can be seen that the backpressure is related to form factor. Due to the reduced amount of vent area and the component density of the systems, smaller systems, like microATX, tend to have higher impedance than larger systems, like ATX. The figures show that the example ATX micro-tower and mini-tower designs are low impedance systems, with the operating point located around the minimum in the noise emission curve. The example ATX mini-tower and micro-tower thus provide efficient designs from an acoustic point of view.

Figure 21 summarizes the results for the various chassis. Sound power as a function of voltage is given for the different systems. It also includes results from the sound power model (backpressure effect neglected) and free-flow condition (measured with the fan plenum at zero backpressure). The figure shows that the variations are small, due to the relative flatness of the noise emission curve of this particular fan.

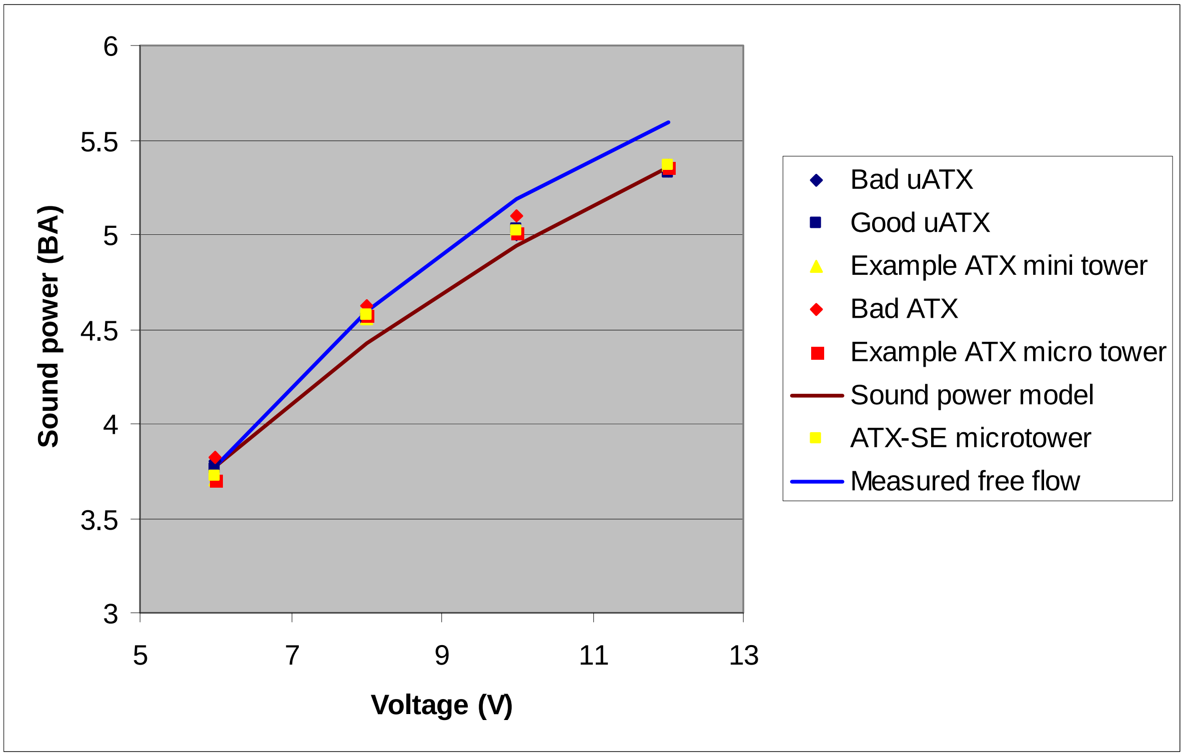

Figure 21. System Fan Emission at 6 V for Various Chassis Including Backpressure Effect

In summary, the fan selection process, in combination with the chassis development, is as follows:

- Select a fan with a low sound power emission, based on manufacturer data, using for instance, the sound power model. Include fan speed control settings to simulate the benefits of speed control and make trade-offs between, for example, the size of fans, the number of fans, the hard drive emission, and other given design constraints.
- Develop a low impedance chassis, for example, following the two design examples that are given in this guideline.
- Determine the fan sound power emission curve as a function of backpressure. Obtain this curve, if available, from the manufacturer or determine it with the fan plenum.
- Determine the fan operating point and the corresponding sound power emission. The operating point should preferably be around the minimum in the sound power emission curve, which is typically located between 20 % and 40 % of the maximum backpressure.

4.3 Hard Drive Selection

The selection process for hard drives is as follows:

- Select a hard drive with a low sound power emission, based on manufacturer data, using, for instance, the sound power model. Include fan speed control settings for fans to simulate the benefits of speed control and make trade-offs between, for example, the size of fans, the number of fans, the hard drive emission, and the other given design constraints.
- Include both the idle and active mode in the analysis. Drives may be quiet in the idle mode, but the emission in the active mode can be significantly higher. Not only the noise emission of the drive is important, but also the vibration levels. These vibration levels determine the magnitude of the structural excitation of the chassis. Reduction of these vibration levels will reduce the transmission of vibrations to the chassis enclosure, where they will efficiently radiate.

5. Component Placement and Mounting

5.1 Fans

The following general acoustic design suggestions are made for system fans:

- Avoid placing obstacles, like grids, in the direct vicinity of the fan, especially at the fan intake. Obstructions that are located within one fan thickness of the fan can potentially increase the noise emission by as much as 0.6 BA to 1.5 BA, and, in addition, introduce strong tonal components.
- Fan speed control is the most important acoustic ingredient of the present design. A big advantage of the present design with a 92-mm system fan and a duct is the simplicity of the fan speed control implementation. In the example ATX chassis, the power supply only supplies cooling for itself. Therefore, the voltage of this fan can be run at a fixed low speed. The only ingredient to be thermally controlled is the system fan. Since there is only one fan and it draws air directly from the outside, either via a front intake or a rear intake, the preheating of air going into the fan is very low and the operating conditions for the fan are well defined. This is a very important aspect that facilitates the implementation of fan speed control. It allows an implementation that is decoupled from the other chassis ingredients. There are two ways to implement fan speed control: (1) place a thermistor on the fan and adjust the fan speed based on the inlet temperature or (2) use temperature sensors and a control chip on the motherboard to adjust the fan speed. Board level control uses a control chip on the board to control the fan speeds. The chip can use multiple inputs and is typically able to control multiple outputs. One of the essential aspects in developing a control strategy is to establish the relation between sensor temperatures and required fan settings. For example, thermal sensors on the board or the junction temperature are used as inputs. There is a preheating of the air at the sensors that depends on system configuration, layout, and loading. Therefore, knowledge and control of these variables is necessary to successfully implement this type of fan speed control solution. More information on fan speed control is given in Section 2.
- Soft mount the fan in the duct. Fan imbalance generates structural vibrations that are transmitted to the chassis and the duct. To minimize this structural transmission, isolation mounts are used to decouple fan motion from the chassis and the duct. The fan is mounted in the duct with isolation mounts. Decoupling the fans from the chassis and duct results in a reduction in emitted sound power, and more importantly, of the tonal components that are introduced by the fan imbalance. Obviously, it has to be ensured that the system passes shock and vibration tests.
- Choose a fan that has sufficient performance, but is sufficiently quiet, for example, a bearing type.

- Front air intake: front to back airflow. The air intake of the duct system is located at the front of the chassis. An advantage of this approach is the minimization of recirculation effects. Disadvantages, compared to a rear intake, are the more complicated duct design and the larger pressure drop in the duct system. A larger pressure drop may affect the acoustic emission, since the fan voltage might have to be adjusted. The front intake enables a baffle (bezel) that eliminates the direct line-of-sight to the fan. Internal ducting provides airflow to the processor and to the add-in card area. Openings to the interior of the chassis short-circuit noise control solutions and negate attenuation of noise from the internal sources and thus should be minimized. Obstructions in the airflow that generate noise, especially on the intake side of fans, should be avoided. The air exhaust of the system is located on the back of the system. This separates intake and exhaust and minimizes recirculation effects. In the case of a front air intake, there are higher sound pressure levels towards the front of the chassis: the operator positions. The bezel should reduce this effect by eliminating the line-of-sight to the fan. An extremely important design requirement for the bezel is the depth. If the bezel depth is chosen too small, the emitted noise levels will be strongly amplified because the fan is choked. The cross-sectional area of the air intake at the end of the bezel should be larger than the area of the fan. In addition, avoid any obstructions in the bezel that generate noise. The inside of the bezel may be lined with a thin absorbing lining to provide additional attenuation, although the overall effect of this is relatively small. The material should be open-cell foam with a sheet lining that prevents dust contamination but allows sound penetration. The minimum acoustic foam thickness should be 0.6 cm (0.25 inch). This is a standard available thickness.
- Rear air intake. In this case the air intake is located at the rear of the chassis. Advantages, compared to a front air intake, are the simple duct design and the low-pressure drop of the intake and duct system. A disadvantage of a rear intake is the increased sensitivity with respect to recirculation. Because the fan is located at the rear of the chassis, most of the noise is directed away from the user. Typically, the sound pressure levels, at a given distance from the chassis, are about 0.2 BA lower at the front because of these directivity effects.
- For both the front and rear intake, fans generate vibrations with specific frequencies corresponding to the rotational motion. These vibrations can excite specific structural or acoustic resonance in the chassis or components of the chassis, especially the duct. Avoid coincidence of noise radiating structural or acoustic resonance frequencies and rotational frequencies of fans. The following equation defines the blade-passing frequency for fans:

  $$\text{Blade Frequency} = (\text{RPM}) \times (\#\ \text{Blades})/60$$

  where RPM is the rotational speed of the fan in revolutions per minute and # Blades is the number of blades for the axial fan. A typical value is seven. The blade-pass frequency is measured in Hertz (Hz). For example, if the fan speed is 3250 RPM, the blade-passing frequency is 379 Hz. If a fan-speed-control strategy is used, the blade-pass frequency changes as a function of the external ambient temperature.

- The fan excitation has peaks at the blade pass frequency and its higher harmonics. Typically, the first three contain the most energy. Adding ribs or increasing material thickness can stiffen the assembly. Structural ribs must not degrade airflow within integrated air ducts. Ribs should be oriented parallel to the airflow direction in this case. With the help of finite element models, the supporting structure can be optimized. The sensitivity with respect to duct excitation is reduced by soft mounting the fan in the duct and may be further reduced by an optional damping layer on the inside of the duct. The duct can be lined with a thin absorbing lining. It is open cell type foam with a minimum thickness of 0.25 inch. It is attached to the duct with an adhesive polymer sheet. This sheet provides additional damping to the structural vibrations of the duct. In order to avoid dust contamination, the lining is covered with a thin sheet that is transparent to sound but not to dust.
- Avoid mounting fans or ducts to large flexible surface, like side covers, that are potentially efficient radiators.

5.2 Hard Drives

The following general acoustic design suggestions are made for hard drives:

- Soft mount the drives. The hard drives are mounted using grommets. This minimizes the transmission of vibrations from the drives to the chassis. Special attention must be given to the design of the grommets and the drive carrier. The effectiveness of the grommet depends on the compression. If the compression of the grommet is too large, the isolation effect will diminish. In addition, rotational vibration frequencies of hard drives that adversely affect the performance should be avoided. It must be verified that the mounts meet the manufacturer's requirements with respect to rotational vibration levels. Rotational vibration levels of drives are measured with accelerometers. The two main mounting parameters governing the dynamic behavior of the system are the mass of the drive and the stiffness and damping of the mounts. For hard drive noise, thin absorbing linings and damping treatments can further reduce the sound emission.
- Choose a drive type with sufficient performance, but low acoustic emissions.
- Eliminate the line of sight to the hard drives.
- Avoid mounting drives or drive carriers to large flexible surface, like side covers, that are potentially efficient radiators.

6. Design Example 1: Micro-Tower with Rear Intake

An example ATX micro-tower chassis prototype has one hard drive, CD/DVD-ROM, and floppy drive. The hard drive that is used in the tests is a 7200-RPM SCSI drive. The drive is new and relatively quiet in the idle mode. The emission in the active mode is representative of general 7200-RPM drives.

The motherboard in the unit is fully operational. The motherboard did not contain any noise generating components, such as fans that would contaminate the noise emission from the system. A configuration with one 92 mm x 92 mm x 25-mm system fan was used with a maximum airflow of 55 CFM and a maximum pressure drop of 0.19 inches H_2O. In order to simulate the effects of fan speed control, the noise emission of the system was determined at different fan voltages, ranging from 6 V to 12 V. The external ambient temperature determines the fan speed for the main fan. For an external temperature of 23 °C, a system fan voltage of 6 V is required to cool the chassis. For an external ambient temperature of 35 °C the system fan voltage should operate at 12 V.

A system power supply was used to control the voltages supplied to the fans. It was located outside the anechoic chamber, so as not to contaminate the noise emission measurement. The power supply of the system contains a 80 mm x 80 mm x 25-mm fan, DC 12 V, with a maximum airflow of 31 CFM and a maximum pressure drop of 0.11 inch of H_20.

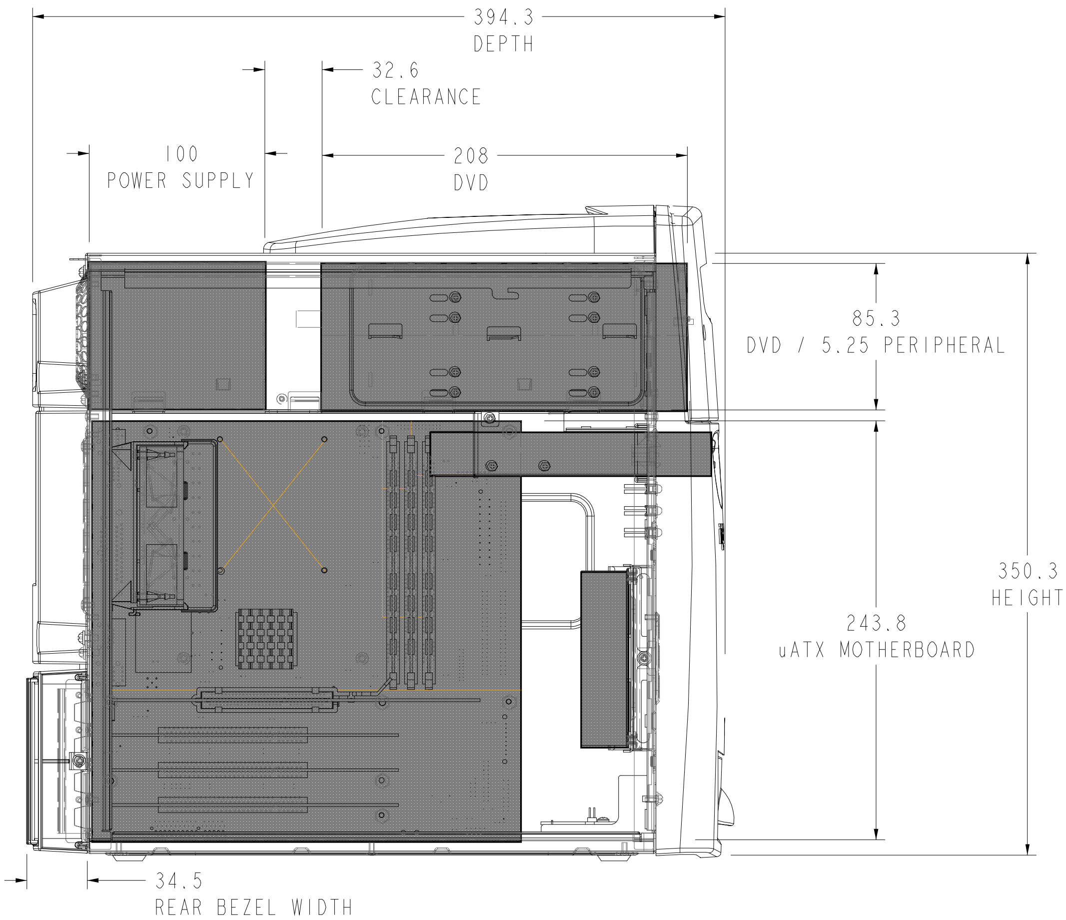

Figure 22. Micro-Tower Layout

The layout of an example ATX micro-tower chassis is given in Figure 22. The main air inlet is located at the back of the chassis. A duct directs the airflow to the processor area and the add-in cards (see Figure 23). With this approach, a single 92 mm x 92 mm x 25-mm system fan is sufficient to cool these components. The fan is mounted in the fan holder. The fan holder is attached to the rear waveguide. The ducting is integrated into the side cover for easy assembly and access. The power supply is located in the top of the chassis and exhausts out of the back.

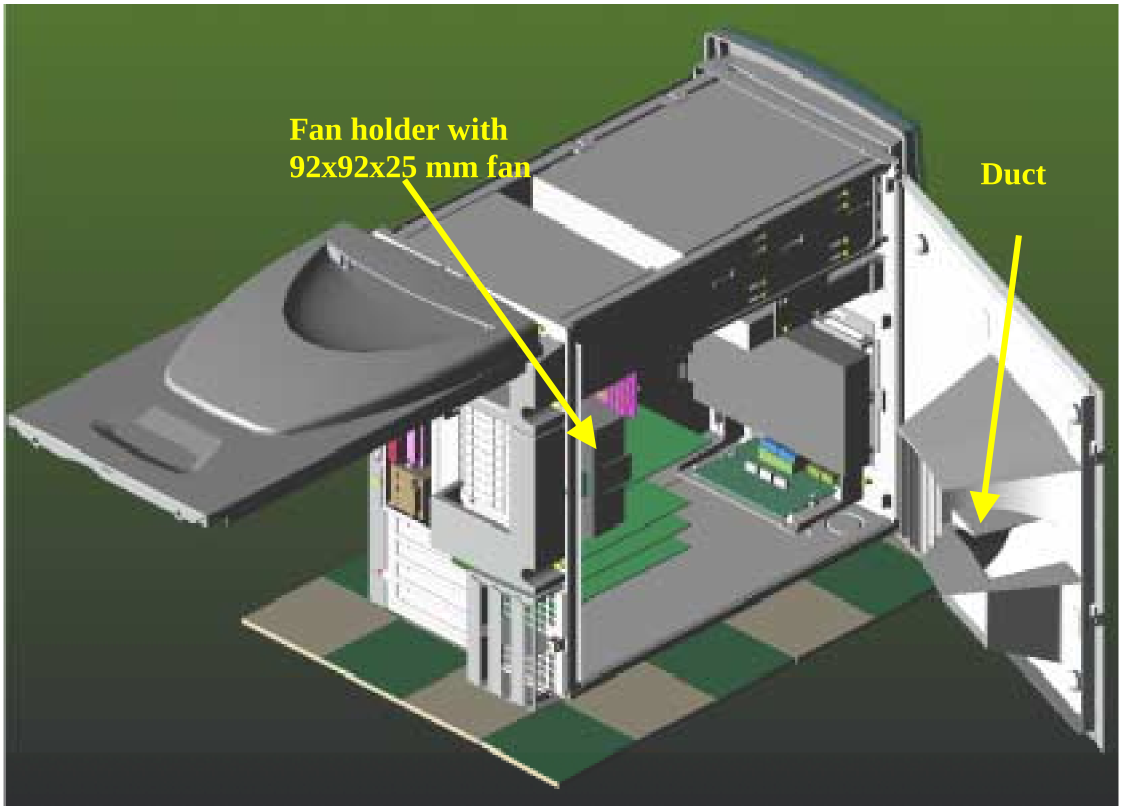

Figure 23. Micro-Tower Design

The present ATX design example incorporates design features that provide integrated solutions for thermal, structural, EMI, and acoustics. In the present validation testing, special attention is paid to the following aspects from an acoustical point of view:

- Isolation mounts on hard drives
- Isolation mounts on the system fan
- Fan speed control for the system fan
- Fan speed control for the power supply fan

6.1 Power Supply Noise Emission

The acoustic emission of the power supply unit was determined for different fan voltages in order to quantify the effect of fan speed control. The results are given in Figure 24[1].

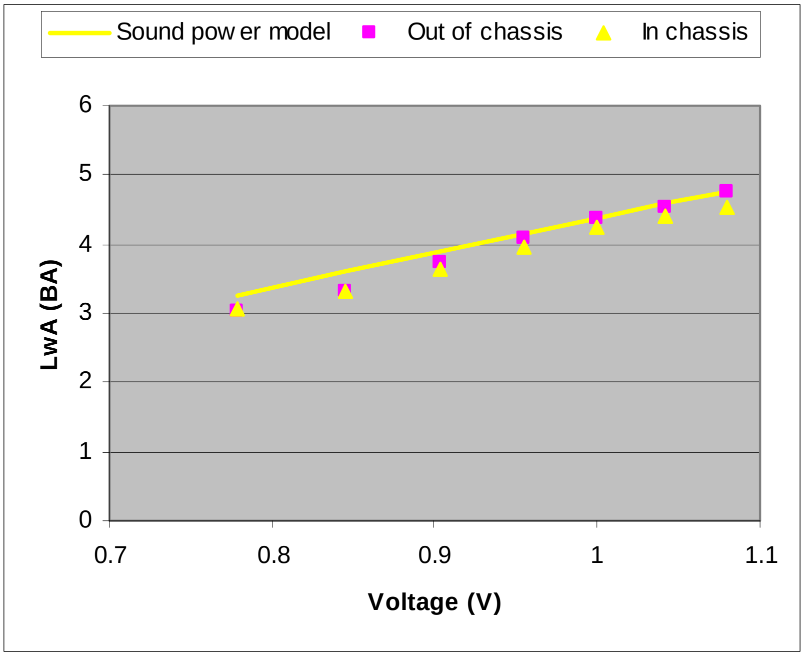

Figure 24. Power Supply Emission

Figure 24 shows that the acoustic emission of the power supply is relatively low. The sound power emission at 12 V is about 4.5 BA. The sound power emission at 6 V, corresponding to an external ambient temperature of 23 °C, is about 3.1 BA. The influence of installation in the chassis is small: the acoustic emission does not change drastically. Therefore the sound power estimation can be used to give a reasonable estimate of the sound power level. Figure 24 shows that the agreement between prediction and measured results is fair[2].

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[1] The test matrices with all measured values are given in the example ATX micro tower validation report

[2] This model is a first order estimate, because it does not include the effect of backpressure on the acoustic emissions. Emitted sound power is based on fan emissions at zero backpressure using manufacturer sound power data.

The measured sound power emission as a function of the RPM is given in Figure 25. When the fan is installed in the system, the RPM drops, as expected.

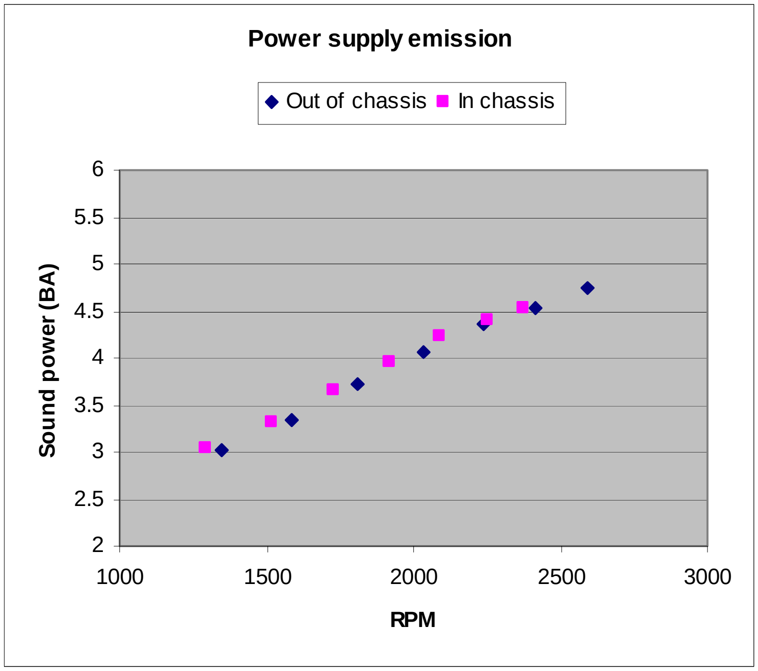


Figure 25. Power Supply Emission as A Function of RPM

6.2 System Fan Noise Emission

The acoustic emission of the main fan was determined for different voltages in order to quantify the effect of fan speed control. The results are given in Figure 26.

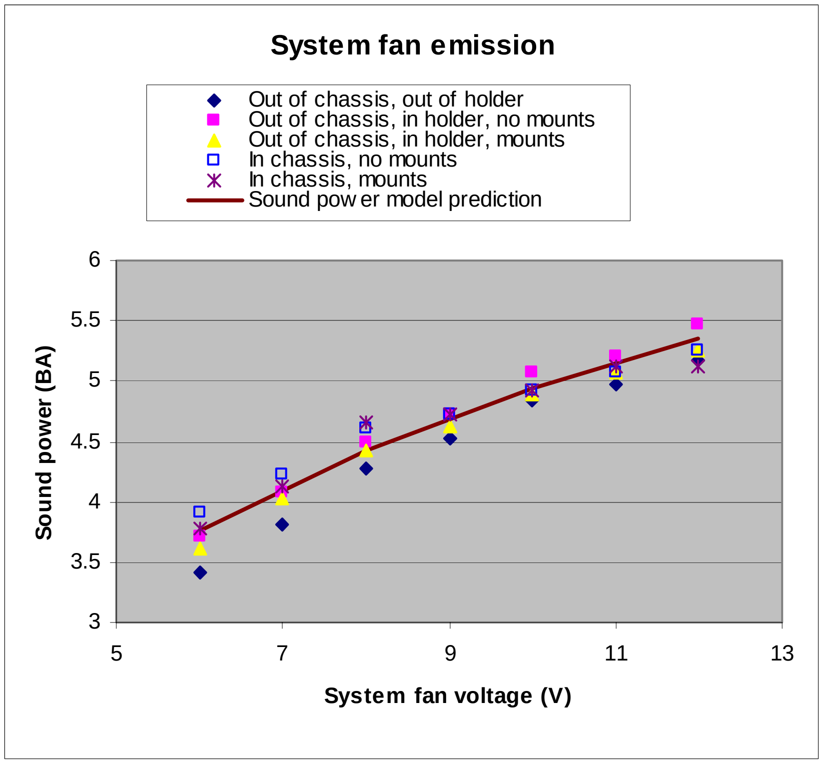


Figure 26. System Fan Emission

Figure 26 shows that the acoustic emission of the system fan at 12 V is about 5.2 BA. The sound power emission at 6 V, corresponding to an external ambient temperature of 23 °C, is about 3.8 BA. Fan acoustic emissions, in terms of emitted sound power **levels**, typically are related to the logarithm of the fan voltage or RPM. The agreement between experimental results and sound power predictions is reasonable. It is important to keep in mind that the model is intended as a design instrument in that facilitates thermal/acoustic trade-offs in the very early design stage, when the system layout and configuration, the number and size of fans, are chosen. Figure 26 shows results from experiments with the fan outside of the chassis and results from experiments under installed conditions when the fan is installed in the system, the emission increases. Due to back pressure effects and the generation of flow noise, the noise levels are higher. The influence of the fan holder on the acoustic radiation is apparent in Figure 26 by analyzing for instance the emission outside of the chassis under the different conditions. When the fan is mounted in the holder in the absence of mounts, the emission shows a significant increase. The fan transmits vibrations to the holder, and the holder has a relatively large area and radiates sound efficiently.

When fan mounts are used the emission decreases because it reduces the transmission of vibrations to the holder. The influence of mounts can also be observed under installed conditions in the chassis. The measured sound power as a function of RPM is given in Figure 27.

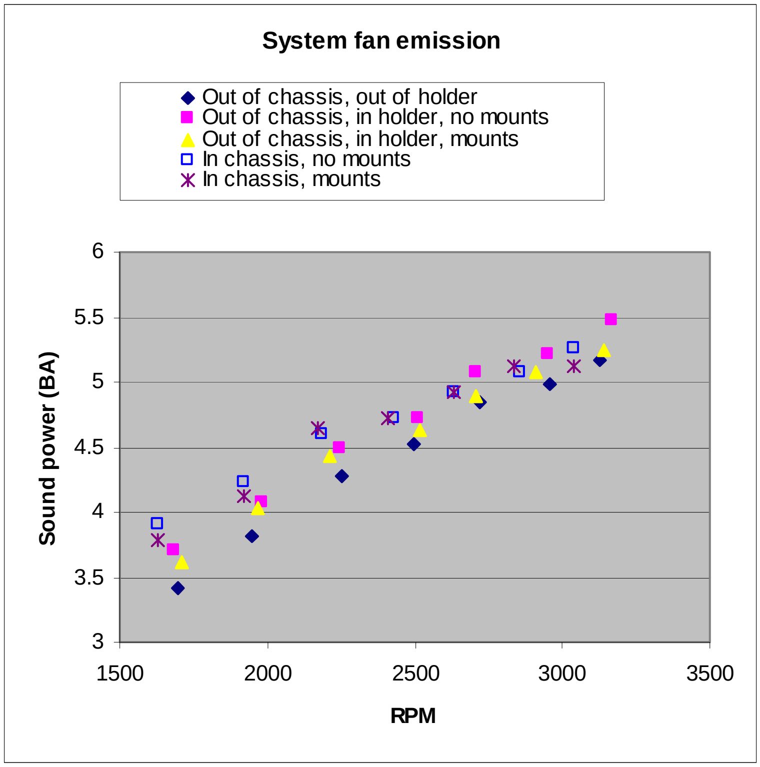


Figure 27. System Fan Noise Emission as A Function of RPM

Figure 27 shows that, when the fan is installed in the system, the RPM decreases. Due to the back pressure that the chassis introduces, the RPM drops.

6.3 Back Pressure Effect

In order to characterize the performance of the system fan, the emission was measured as a function of back pressure. A fan plenum, as described in ISO 10302, was developed for this purpose. Impedance curves were obtained for several systems. The results for the current fan are given in Figure 28, Figure 29, Figure 30, and Figure 31.

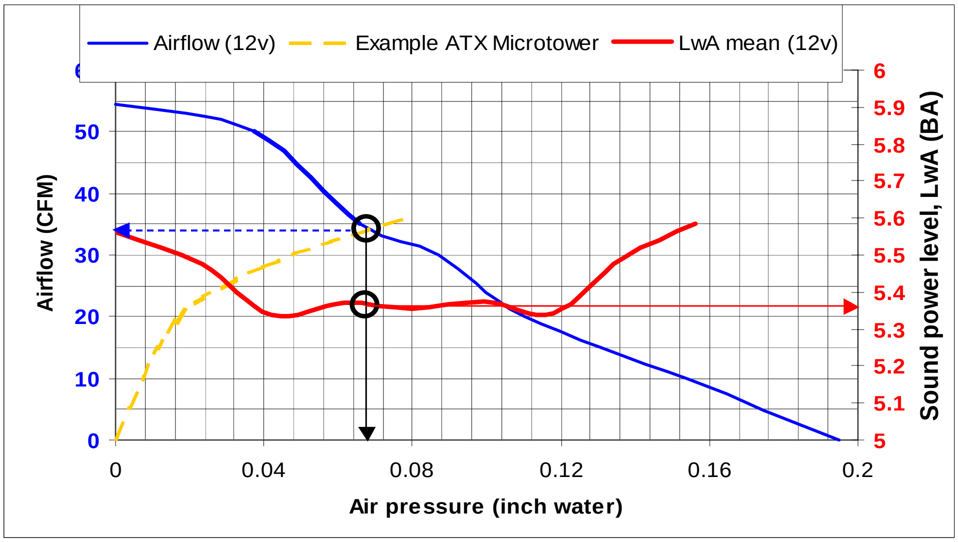


Figure 28. System noise emission as a function of back pressure at 12 V

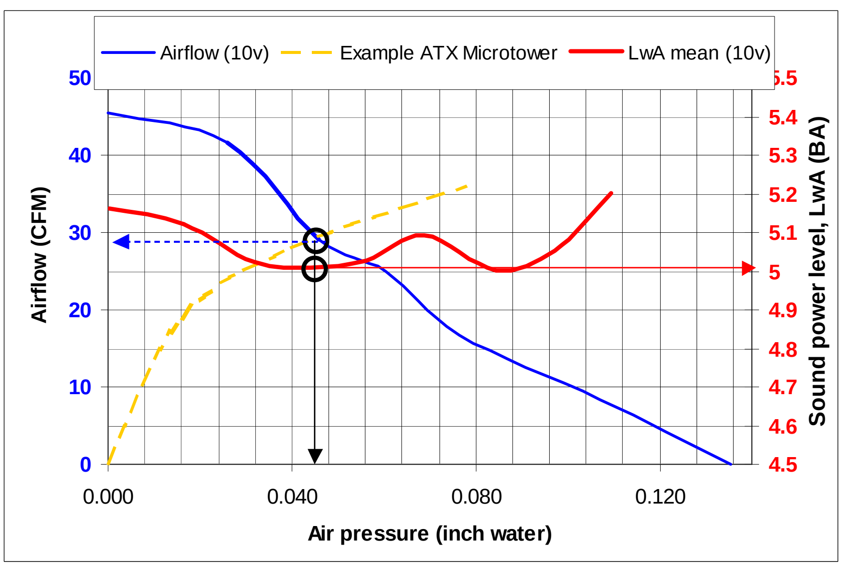


Figure 29. System Noise Emission as A Function of Back Pressure At 10 V

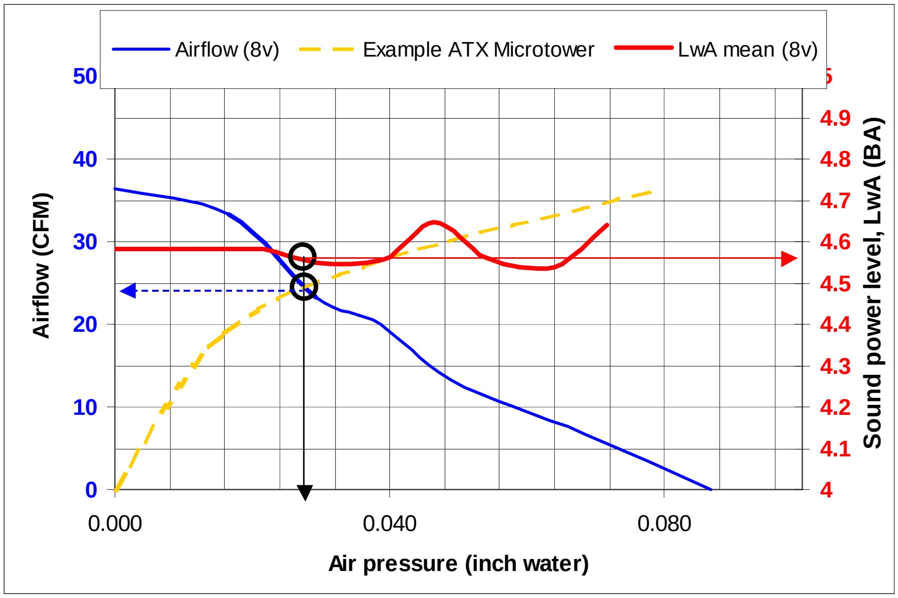


Figure 30. System Noise Emission as A Function of Back Pressure at 8 V

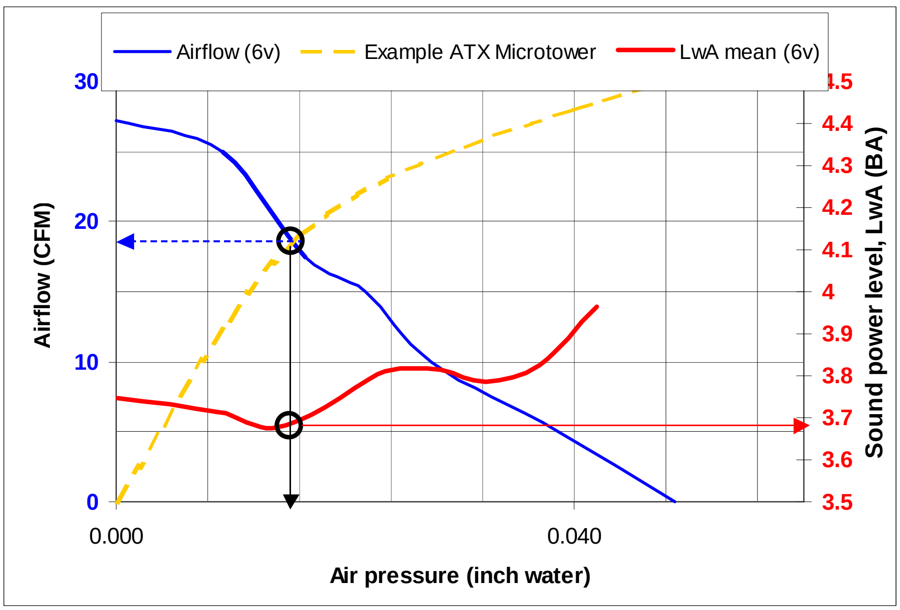


Figure 31. System Noise Emission as A Function of Back Pressure at 6 V

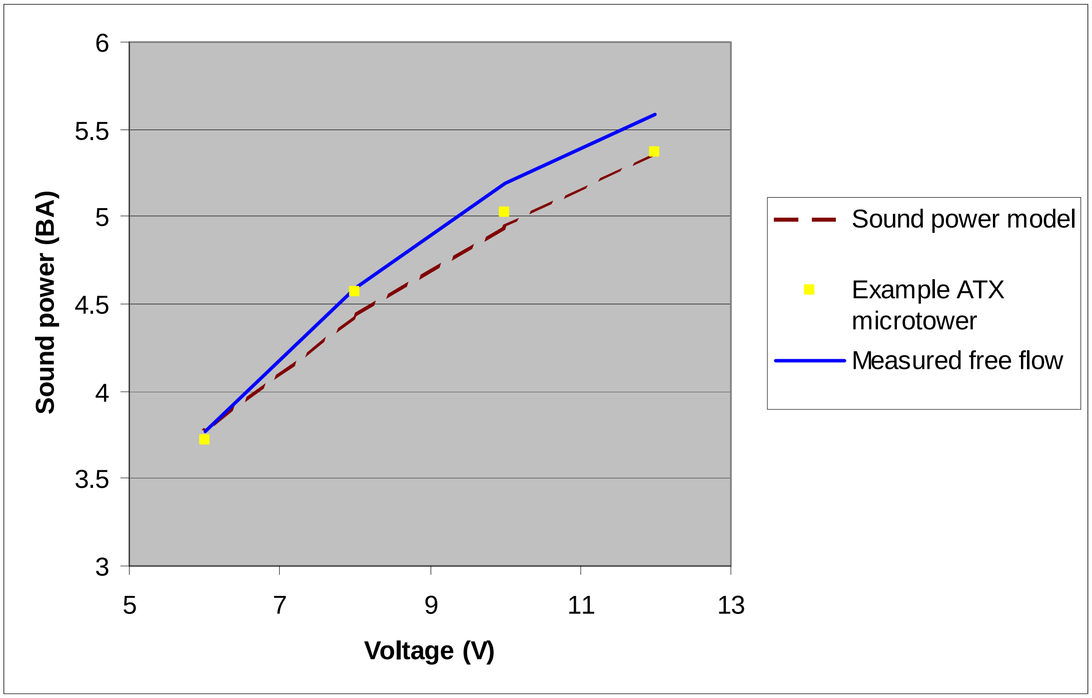


Figure 32. System Noise Emission as a Function of Voltage for Micro-Tower Chassis

Figure 28, Figure 29, Figure 30, and Figure 31 show the emission of the fan as a function of the back pressure. The emission of the current fan is relatively flat: variations due to back pressure are within 0.2 BA. However, the magnitude of this variation depends on the fan of interest and may vary with, for instance, size and manufacturer. Typically, the emissions of fans are minimal around 20 % to 40 % of the maximum back pressure of the fan. Thus, it is usually beneficial to develop a low impedance system. Figure 28, Figure 29, Figure 30, and Figure 31 also show the fan curve for the fan and the system impedance curve for the micro-tower. The intersection of the fan curve and the impedance curve gives the fan operating point. The corresponding sound power emission can then be read from the emission curve. The figures illustrate the benefit of a low impedance system: the operating point for the micro-tower is located around the minimum in the noise emission curve.

Figure 32 summarizes the fan plenum results. Sound power, as a function of voltage, is given for the example ATX micro-tower (measured values), the sound power estimation model (backpressure effect neglected) and free flow condition (measured with the fan plenum at zero backpressure). The figure shows that, especially at low voltages, the variations are small. At higher voltages the deviations are between 0.1 BA and 0.2 BA. Thus, the sound power model gives a good first order estimate of the emitted sound power in the design stage.

6.4 Noise Emission Of Hard Drives

In order to test the emission of hard drives, the power supply fan and the system fan are turned off and the emitted sound power of the drives are measured in seek mode and idle mode (see Tables 4, 5, 6, 7 and 8). The results are summarized in Figure 33.

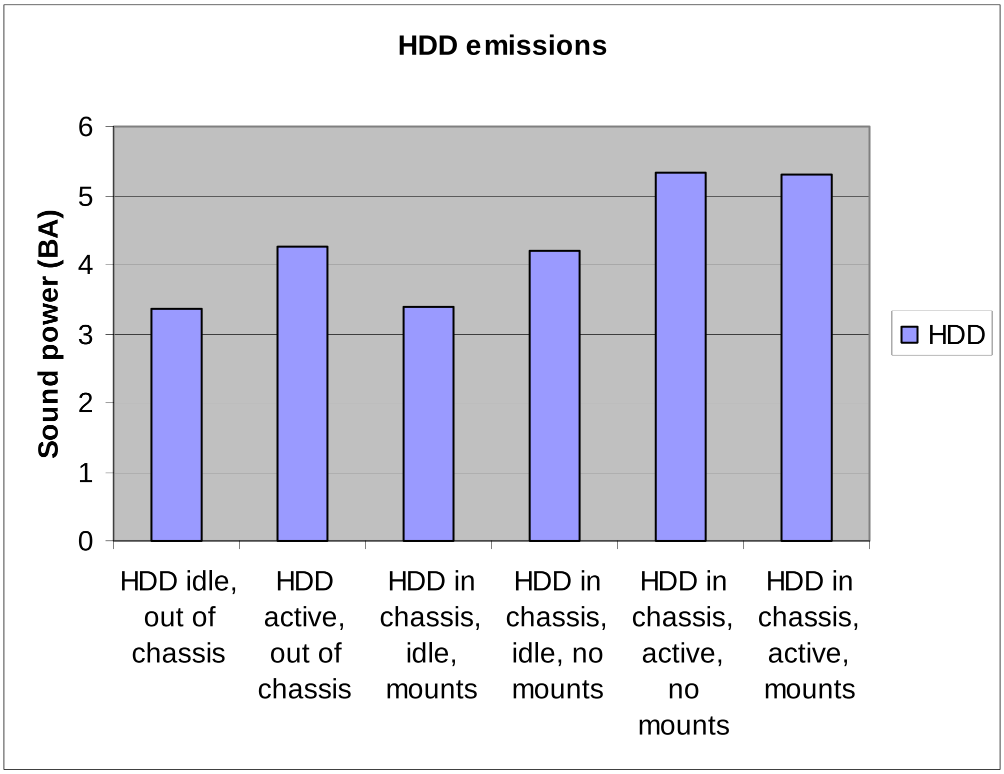


Figure 33. Hard Drive Emissions

The manufacturer specification for the drive emissions is a typical A-weighted sound power emission of 3.2 BA in the idle state for the Quantum drive. Figure 33 shows that this corresponds well with the value that was measured outside of the chassis. The emission in the active mode was measured at 4.3 BA, a representative value for 7200-RPM drives. When the drive is installed in the chassis, emissions tend to increase due to vibration coupling. Figure 33 shows that the mounts efficiently reduce the emitted sound power in the idle mode. However, in the active mode there still is a significant increase in sound power when the drive is installed in the chassis. This example demonstrates the importance of selecting quiet components.

6.5 System Noise Emission

Figure 34 shows the measured system noise emission levels in the idle and active state. It also includes the predicted results using the simple sound power summation model.

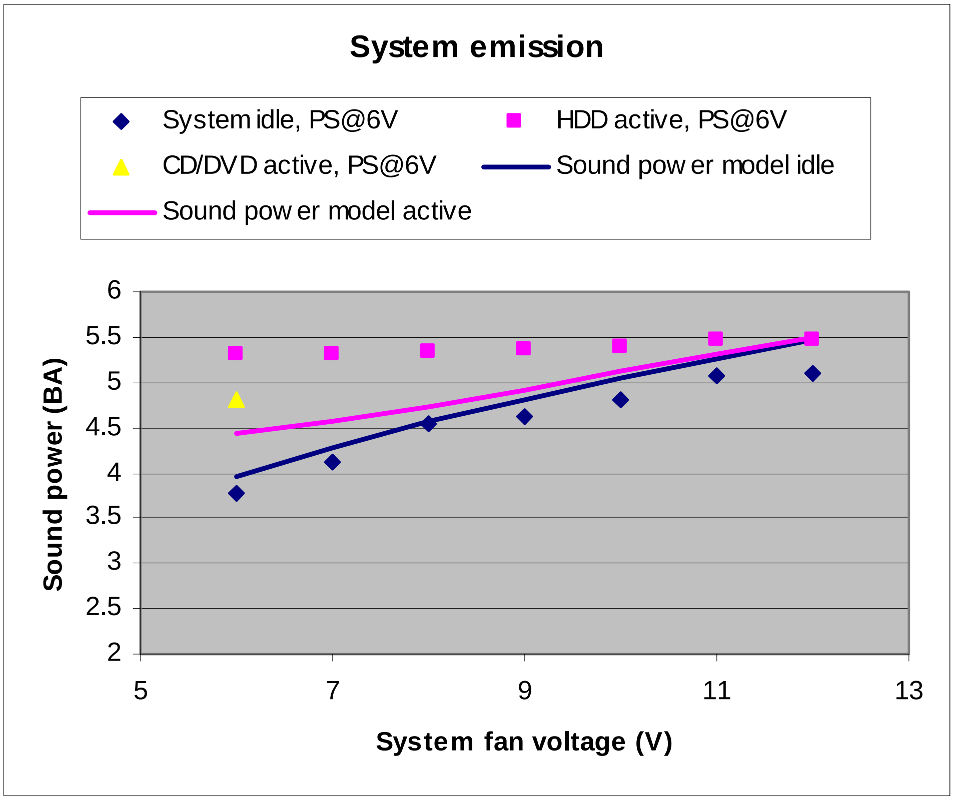


Figure 34. System Level Emissions

Figure 34 shows the total system noise emission level as a function of voltage. Note that the system fan voltage was varied in this case, while the power supply fan voltage was fixed at 6 V. The total system noise emission at 6 V is 3.8 BA. At this voltage, the most important contributor to the system noise level in the idle mode is the system fan. Evidently, this depends on the type of hard drive that is being used.

In the previous sections, it was demonstrated that the noise emission levels of the components could be estimated to a reasonable degree of accuracy with the sound power model, based on manufacturer data. These component level estimates are combined into a system level prediction in Figure 34. It is assumed that the noise sources are incoherent and uncorrelated. This means that the presence of one source does not affect the sound emission of the other source. Since the sources are incoherent and uncorrelated, the energies of the sources can be summed to obtain the total system emitted energy.

Figure 34 shows that there is fair agreement between the measured system noise levels and the predicted noise levels in the idle mode. Thus, the assumption that the sources are incoherent and uncorrelated seems to be justified. Note that the sound power predictions were validated first on the component level, and that these results are now used in this system level prediction. This offers a model for the designer to conduct a sensitivity analysis. The influence of changes in a component to the overall system noise level can be estimated to a reasonable degree of accuracy with this simple, straightforward model, in the design stage. Note that the resulting system level noise prediction as a function of voltage is not a linear relationship because of the logarithmic summattion.

The agreement between sound power model results and experimental values in the active mode is not good. This is due to the vibration coupling between the hard drive and chassis. The amplification, introduced by this phenomenon, was not included in the spreadsheet estimate. It is possible to include an attenuation or amplification value in the model, but in the early design stage of a product detailed information, necessary to estimate or quantify the amplification in the absence of a prototype, is in most cases not available.

6.6 Directivity Diagrams

6.6.1 Desktop Setup

The results of the sound pressure measurements are used to construct a very simple directivity diagram. This approach provides a first insight into the directional characteristics of the sources under consideration. The four bystander positions are located at the same distance from the source on the front, left, right, and rear respectively. The positions are denoted as:

- BF: Bystander Front
- BR: Bystander Right
- BL: Bystander Left
- BRe: Bystander Rear

The results for the sound pressure measurements are given in the polar plots in Figure 35, Figure 36, and Figure 37.

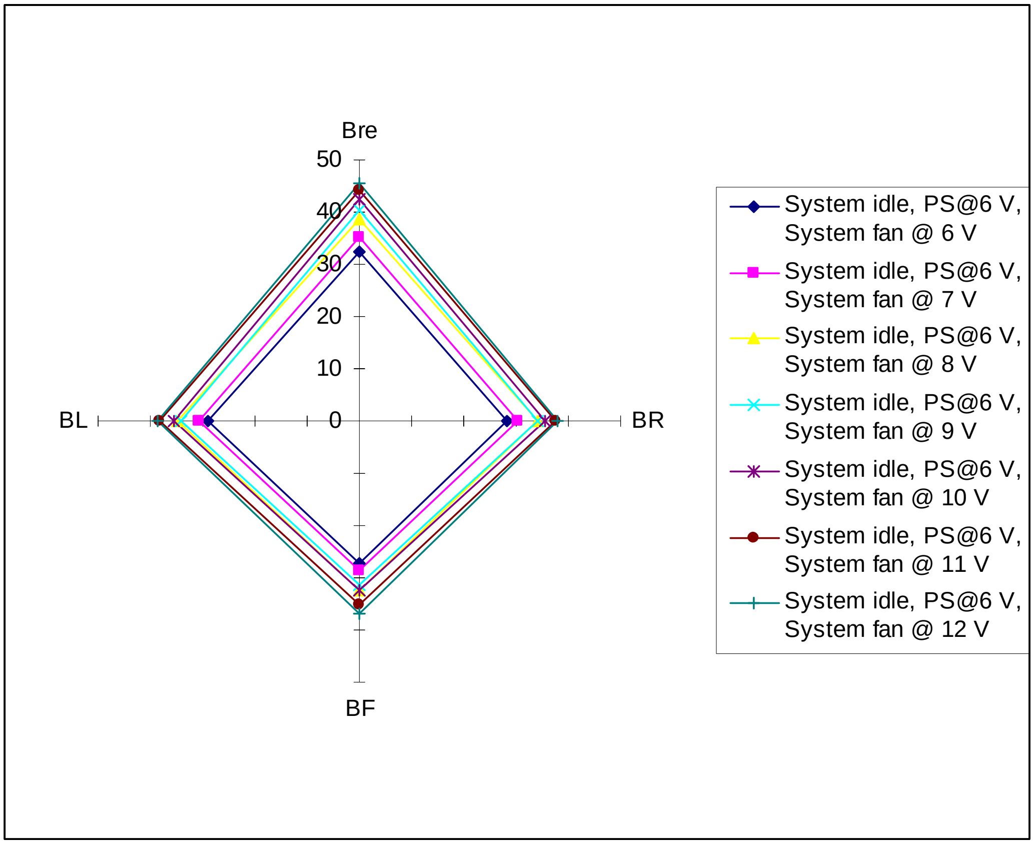


Figure 35. Directivity Plots With Sound Pressure Data on Bystander Positions for Desktop Setup

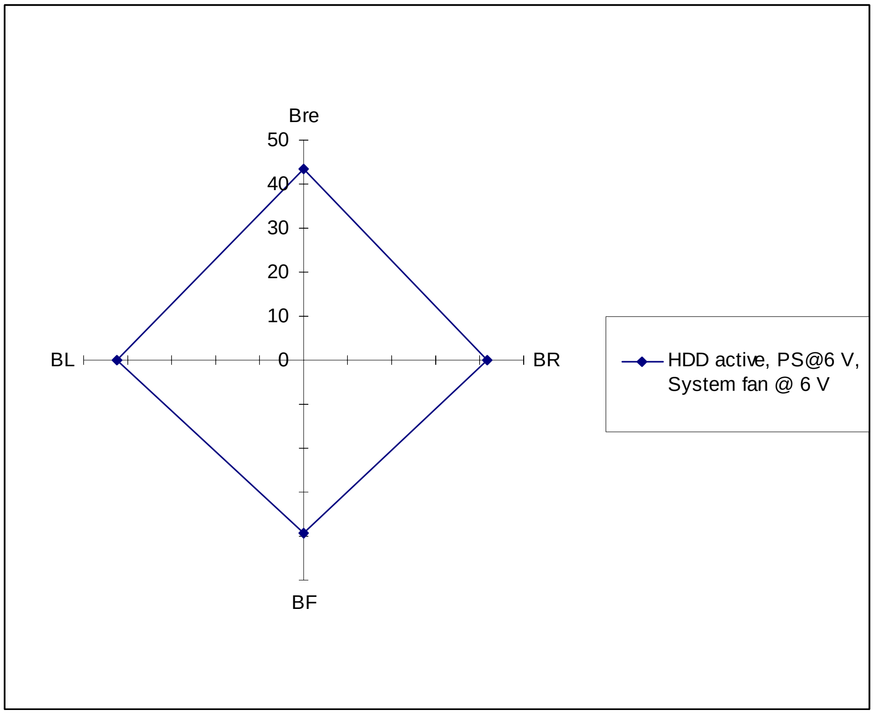


Figure 36. Directivity Plots With Sound Pressure Data on Bystander Positions for Desktop Setup

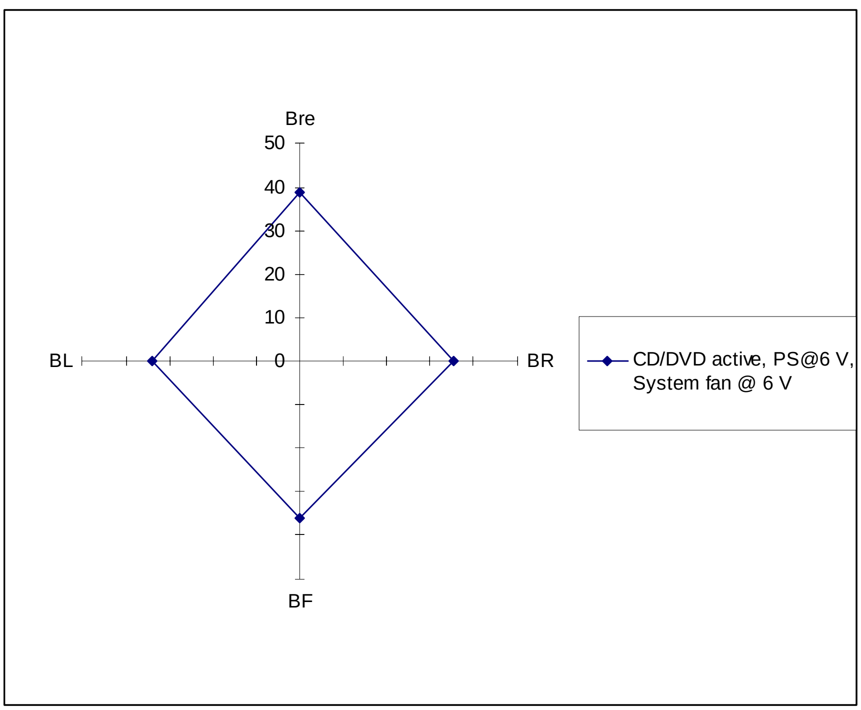


Figure 37. Directivity Plots With Sound Pressure Data on Bystander Positions for Desktop Setup

Figure 35 shows that the emission of the system is directional, with the predominant emission directed towards the rear. Evidently, this is because the power supply fan and the system fan are located at the rear of the chassis. This is an important observation, since it is undesirable to have a high directivity towards the user. Typically, sound pressure levels are 2 dBA to 3 dBA lower at the front of the chassis compared to the sound pressure level at the same distance from the rear. Figure 36 shows that, although the drive is located at the front of the chassis, the main radiation is directed towards the rear because of the vent openings. Figure 37 shows the directivity plot when the DVD drive is in the active mode.

6.6.2 Floor Standing Setup

The results of the sound pressure measurements are used to construct a very simple directivity diagram. This approach provides a first insight into the directional characteristics of the sources under consideration. The four bystander positions are located at the same distance from the source on the front, left, right and rear respectively. The positions are denoted as:

- BF: Bystander Front
- BR: Bystander Right
- BL: Bystander Left
- BRe: Bystander Rear

The results for the sound pressure measurements are given in the polar plots in Figure 38, Figure 39, and Figure 40. Similar observations as for the desktop setup can be made.

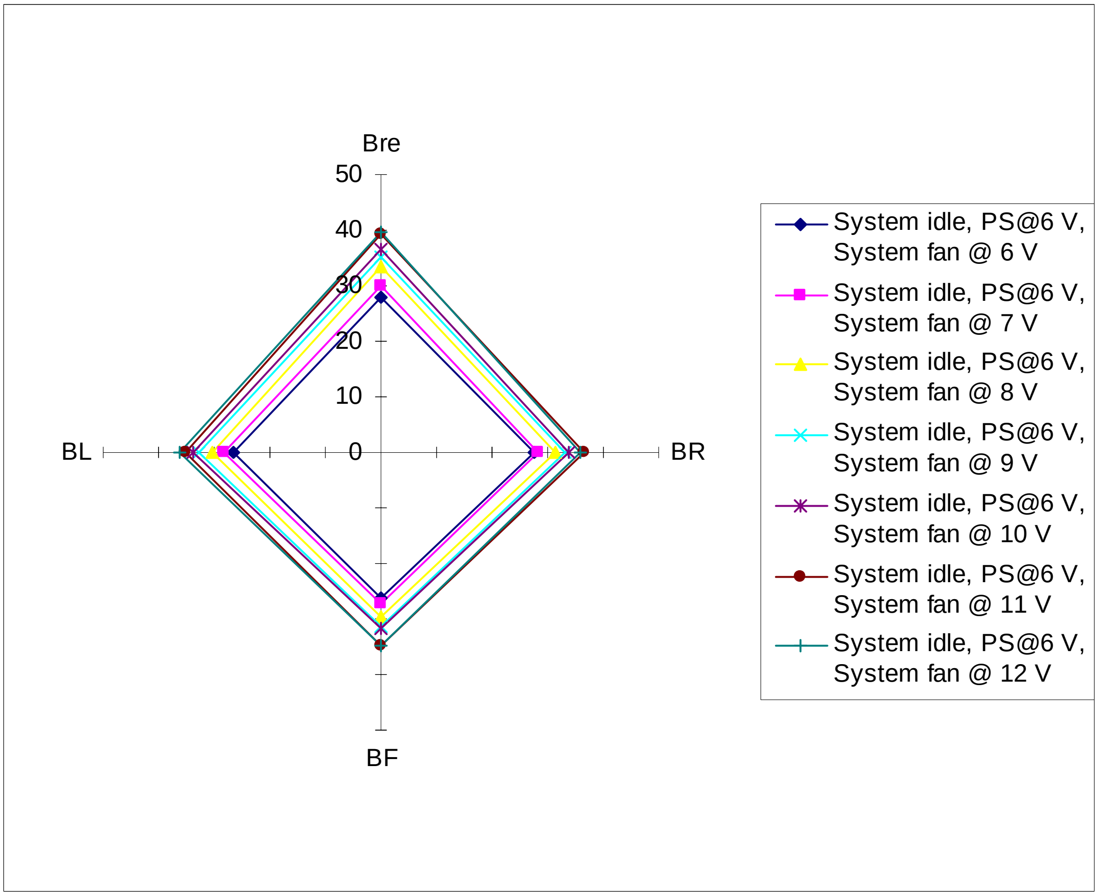


Figure 38. Directivity Plots With Sound Pressure Data on Bystander Positions for Floor Standing Setup

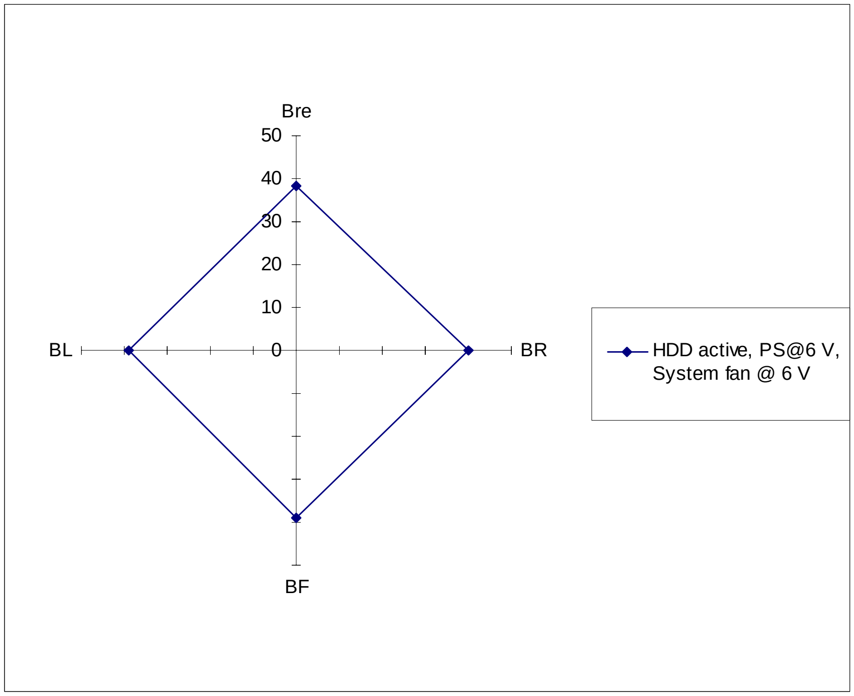


Figure 39. Directivity Plots With Sound Pressure Data on Bystander Positions for Floor Standing Setup

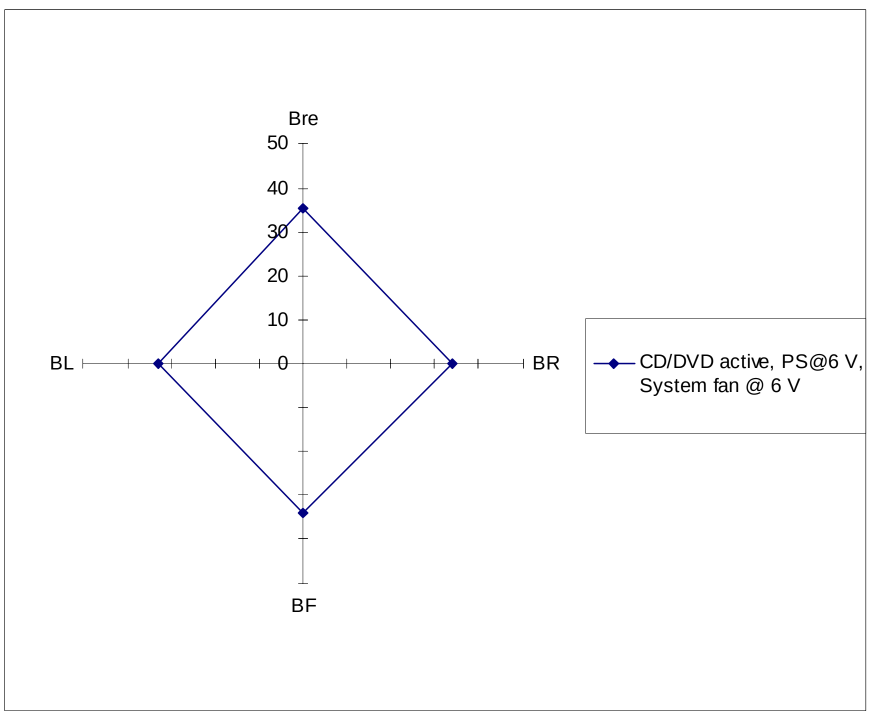


Figure 40. Directivity Plots With Sound Pressure Data on Bystander Positions for Floor Standing Setup

6.7 Frequency Spectra

6.7.1 Power Supply Fan

In the sound power experiments, the frequency spectra are A-weighted and the energy in the frequency bands is summed. Because of this, sound power numbers do not give any information regarding the spectral composition of the signals. For all experiments, listed in Tables 4, 5, 6, 7, and 8, spectral information was collected. The spectra, presented in this section, represent the total emitted sound power in each subsequent 1/3-octave band. Thus, the results presented are already integrated over the 10 microphone locations. The emission of the power supply fan, the main fan and the hard drives as measured in these 1/3-octave bands will now be analyzed. Measurements are performed according to ISO 7779 standards. The results for the power supply fan outside of the chassis for voltages of 6, 7, 8, 9, 10, 11, and 12 V are given in Figure 41.

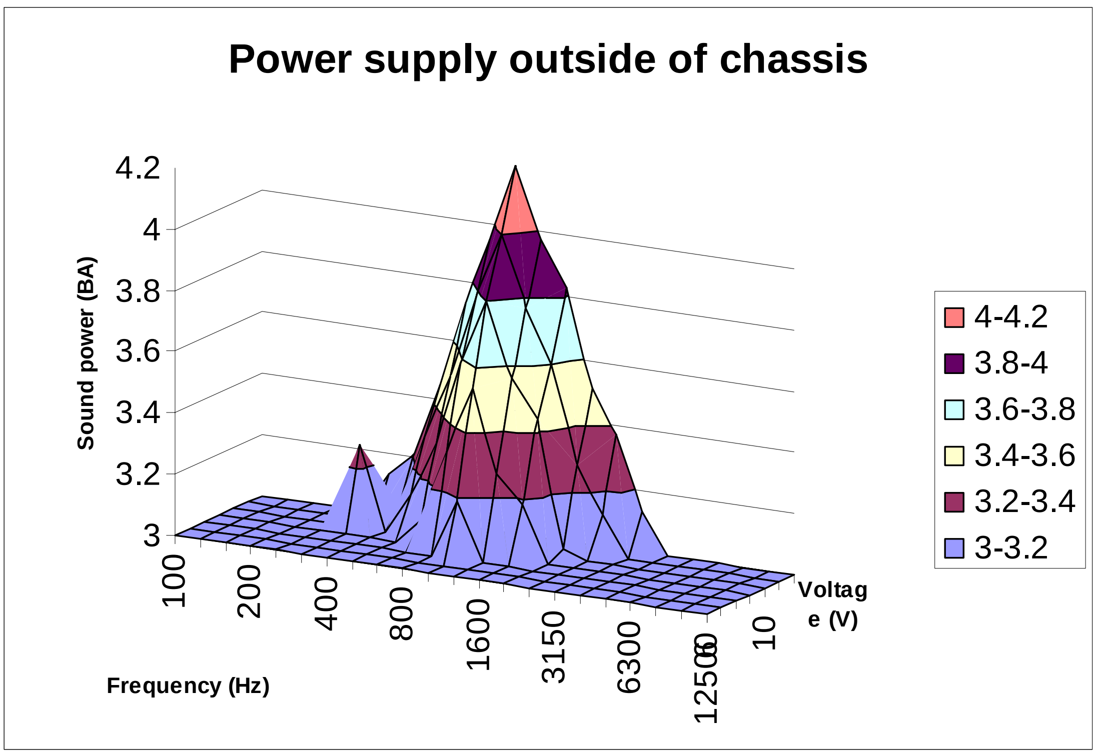


Figure 41. 1/3-Octave Spectra of Power Supply Outside of Chassis at Different Voltages

Figure 41 shows that the main emission of the power supply fan is in the 1/3-octave band with a center frequency of 1000 Hz. Because of the A-weighting that was applied, low and high frequencies are attenuated significantly. Therefore the 1/3-octave bands in the 400 Hz to 2500 Hz range are very prominent. The peaks in the spectrum can be attributed to the fan blade pass frequency and its higher harmonics. However, because of the integration in 1/3-octave bands, the resolution is low. A narrow band analysis was conducted and the peaks could be directly correlated to the fundamental blade pass frequency and its higher harmonics. No other peaks in the spectrum, due to resonance, were present. The results for the power supply fan inside of the chassis for voltages of 6, 7, 8, 9, 10, 11, and 12 V are given in Figure 42.

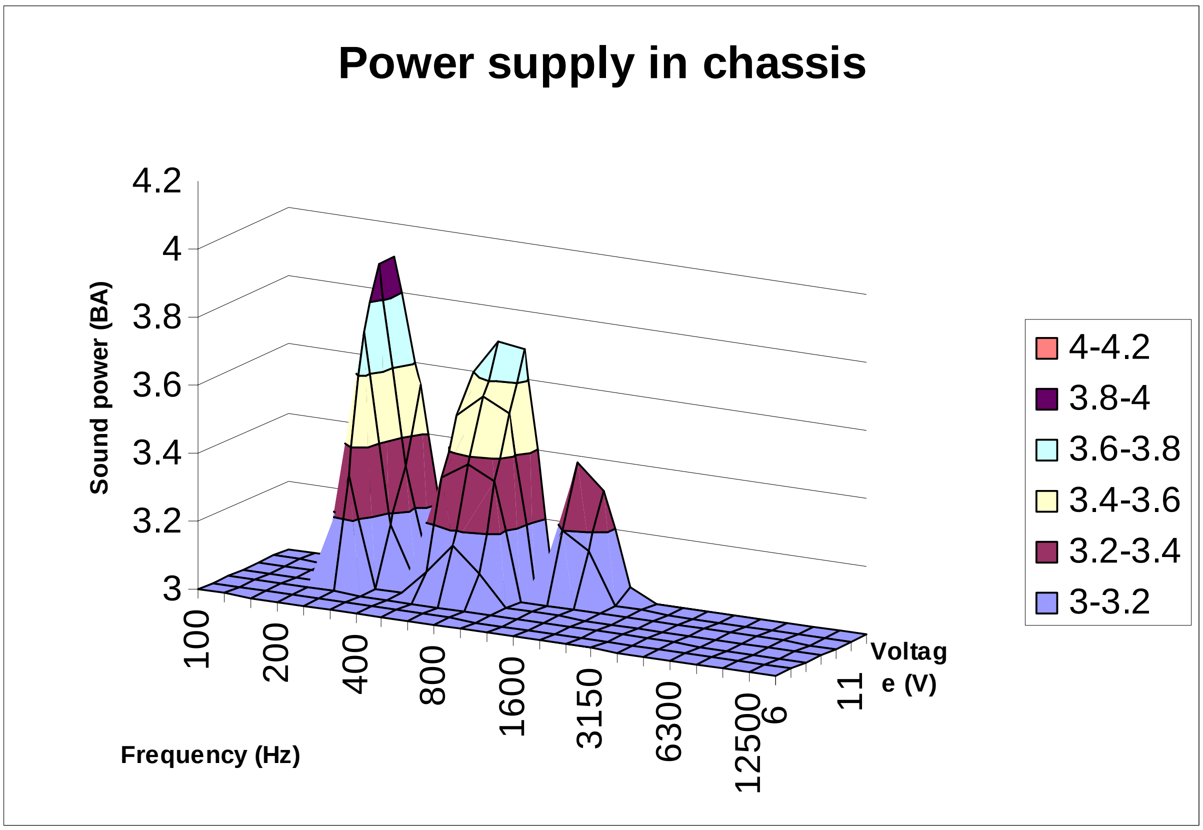


Figure 42. 1/3-Octave Spectra of Power Supply Inside of Chassis at Different Voltages

Figure 42 shows the spectrum when the fan is places inside the chassis. The spectrum changes due to installation in the chassis. The harmonic nature of the emission is visible in the figure. As was demonstrated earlier, the RPM of the fan decreases when the fan is places inside the chassis.

6.7.2 System Fan

The 1/3-octave band spectra for the system fan outside of the chassis are given in Figure 43.

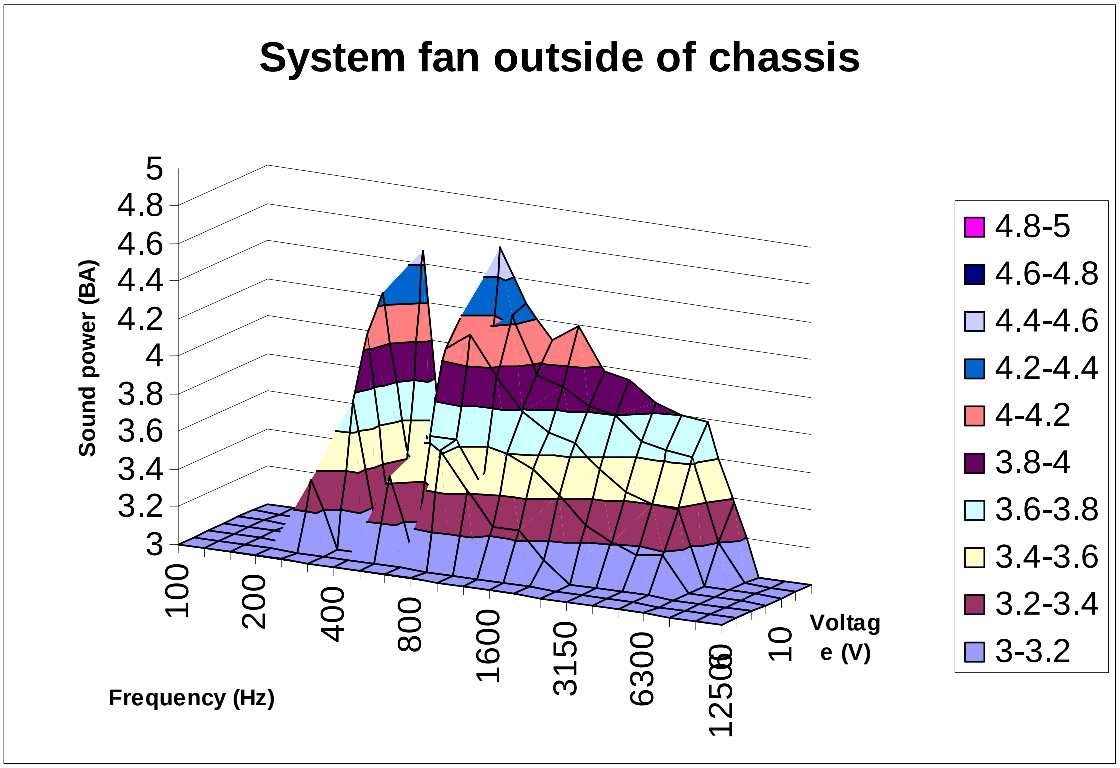


Figure 43. 1/3-Octave Spectra of System Fan Outside of Chassis at Different Voltages

Again, the A-weighting results in a prominent contribution in the 400 Hz to 2500 Hz range. The peaks in the spectrum are caused by the blade pass frequency of the fan and its higher harmonics. Peaks in the spectrum can be directly correlated to the fundamental blade pass frequency and its higher harmonics. The 1/3-octave band spectra for the system fan inside of the chassis in the fan holder with the mounts are given Figure 44. It shows a similar spectrum as Figure 43. Due to the representation in 1/3-octave bands, the resolution is not very high.

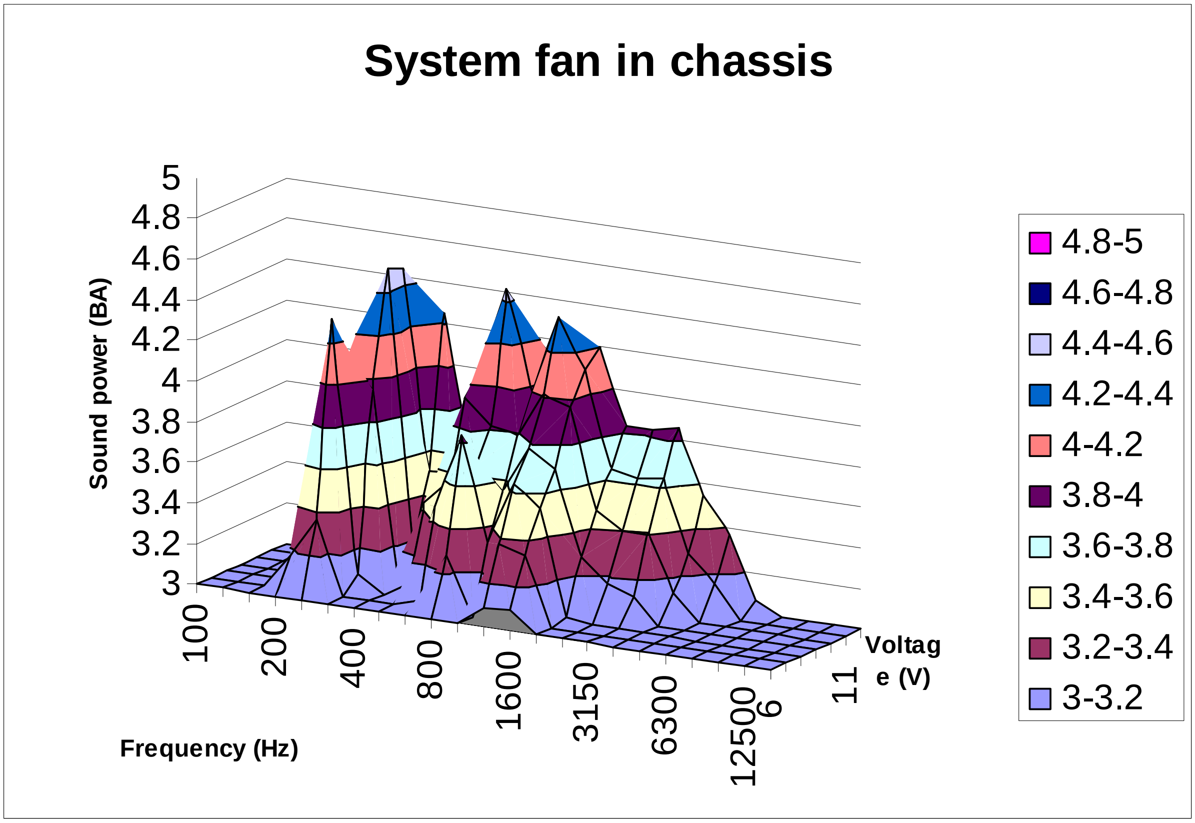


Figure 44. 1/3-Octave Spectra of System Fan Inside of Chassis at Different Voltages

6.7.3 Hard Drive

The spectrum for the emission of the hard drive in the idle mode is given in Figure 45. Note that in this case the drive was in idle mode, and no other noise sources were present.

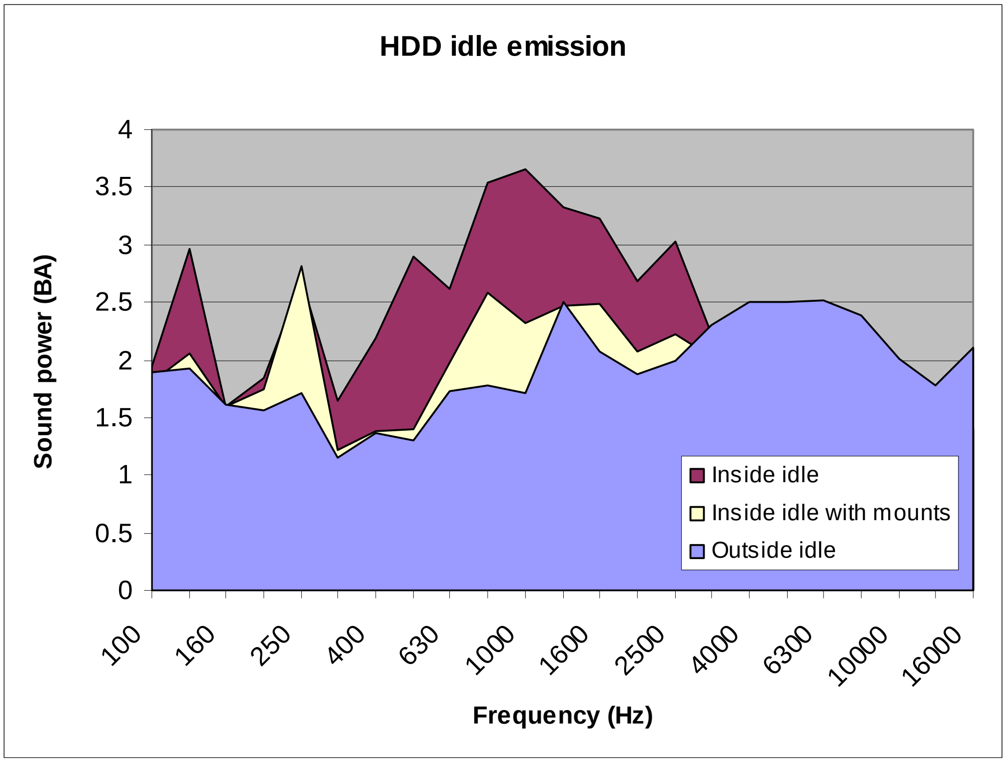


Figure 45. 1/3-Octave Spectra of Hard Drive in Idle Mode

There is a sharp peak in the spectrum for the 1/3-octave band with a center frequency of 125 Hz. This will be discussed in more detail. An analysis of the raw test data learns that the measurement in this case is also affected by the background noise. The emitted sound power in the idle mode for the drives is very low and the background noise level in the chamber is relatively high. Therefore the condition that the background ambient noise is 0.6 BA above the background level is not satisfied for the low 1/3-octave bands. Note however that the noise emission of the hard drives, when compared to the emission of the fans, has a spectrum with predominantly higher frequencies. There is significant emission in the 1000 Hz to 4000 Hz range, a sensitive part of the spectrum for the human ear. Analyzing the frequency content of signals is important in localizing and characterizing noise sources and developing noise control strategies.

The spectrum for hard drive in the active mode is given in Figure 46.

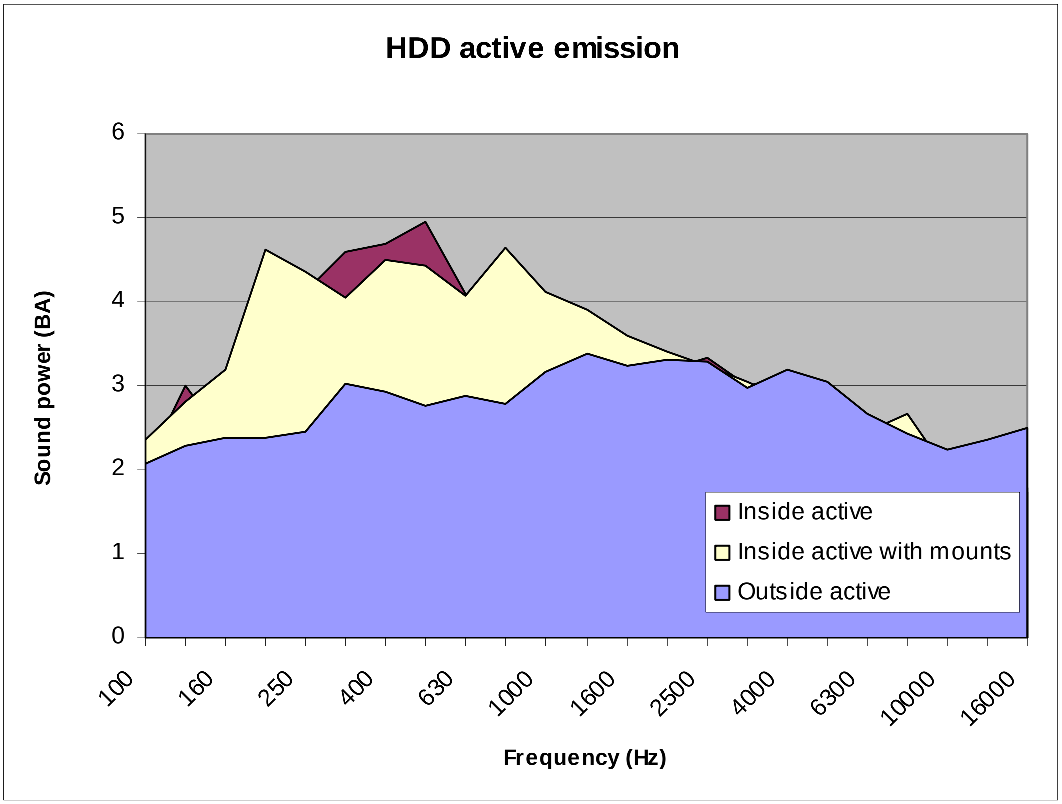


Figure 46. 1/3-Octave Spectra of Hard Drive in Active Mode

Figure 46 shows that the noise emission of this drive in the active mode is, in contrast to the emission in idle mode, predominantly of a low frequency nature. Most of the energy is contained in the 125 Hz to 1000 Hz frequency bands.

In order to get a more detailed spectral analysis, a narrow band analysis was conducted using one of the microphones in the setup. The sound pressure level of this microphone was measured in 1/24-octave bands for the idle and active mode. In addition, the background sound pressure level was determined. The results are given in Figure 47. It shows that there are sharp peaks in the spectrum in the 120 Hz and 250 Hz frequency bands. This corresponds to the first and second harmonic of the rotational frequency of the drive: 7200 RPM = 120 Hz. Note that the sound pressure level in the 120 Hz frequency band is the same in the idle and the active mode. Figure 47 also shows that in the active mode there are high-pressure levels in the frequency bands between 200 Hz and 600 Hz. This “narrow band” analysis is useful for correlating for instance peaks in noise emission spectra to rotational frequencies of fans and hard drives.

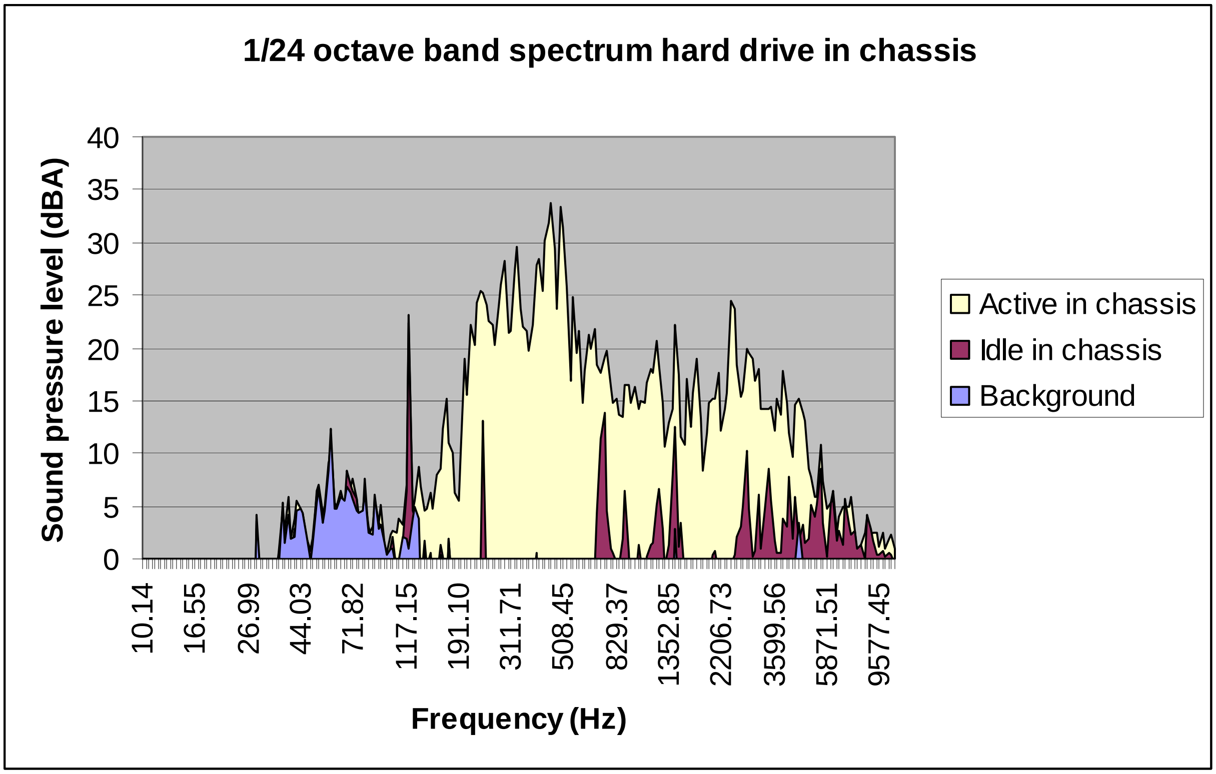


Figure 47. 1/24-Octave Spectra of Hard Drive Emissions

6.7.4 System

The spectra for the system in idle mode are given in Figure 48. The voltage to the system fan was varied between 6 V and 12 V, the voltage to the power supply was 6 V and the drive was in idle mode.

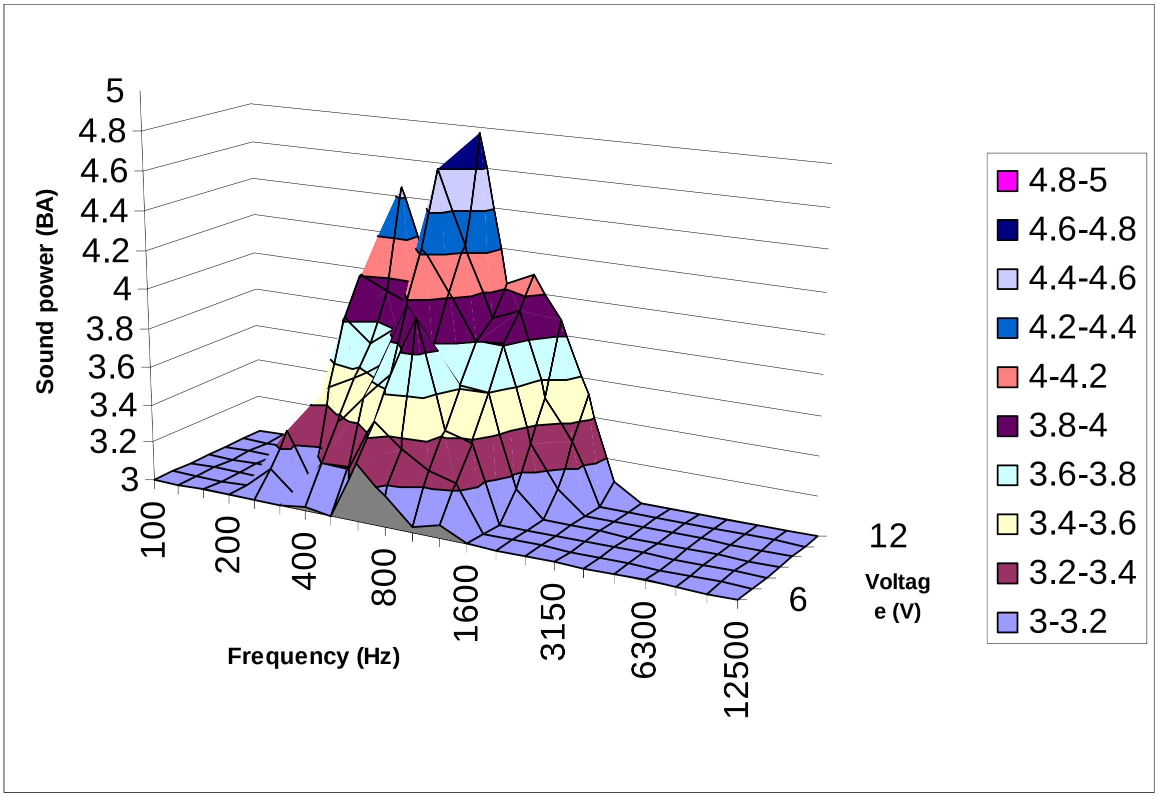


Figure 48. 1/3-Octave Spectra of System in Idle Mode

Figure 48 shows that the system fan is the most important noise source in the system in the idle mode. The emission of the system with the hard drive in the active mode is given in Figure 49.

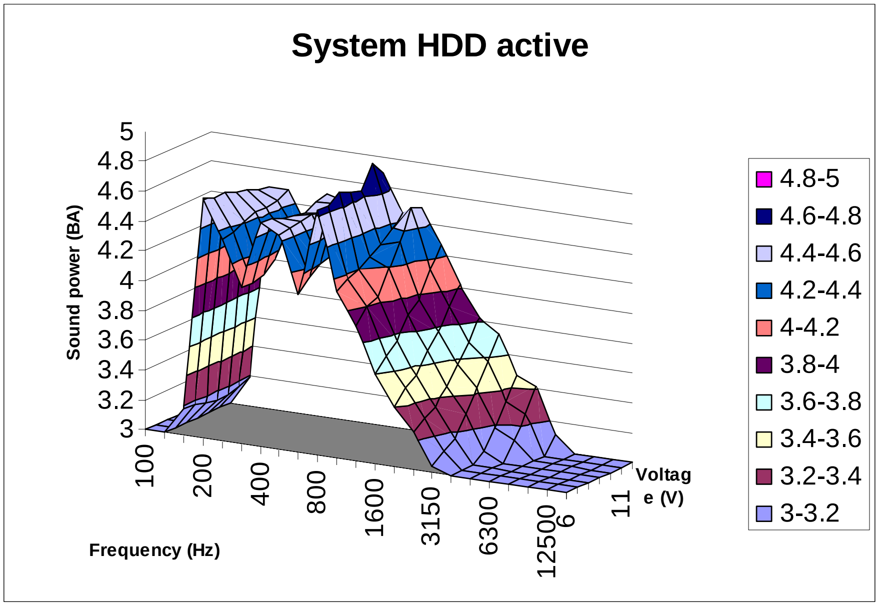


Figure 49. 1/3-Octave Spectra of System Emission with Hard Drive in Active Mode

Figure 49 shows that the hard drive is the most important noise source in the system in the active mode. The fan emission is not a large contributor, and therefore the spectrum does not change significantly with voltage. The emission of the system with the DVD drive in the active mode is given in Figure 50. It shows that the emission of the DVD drive is predominantly in the 1 kHz to 2 kHz range.

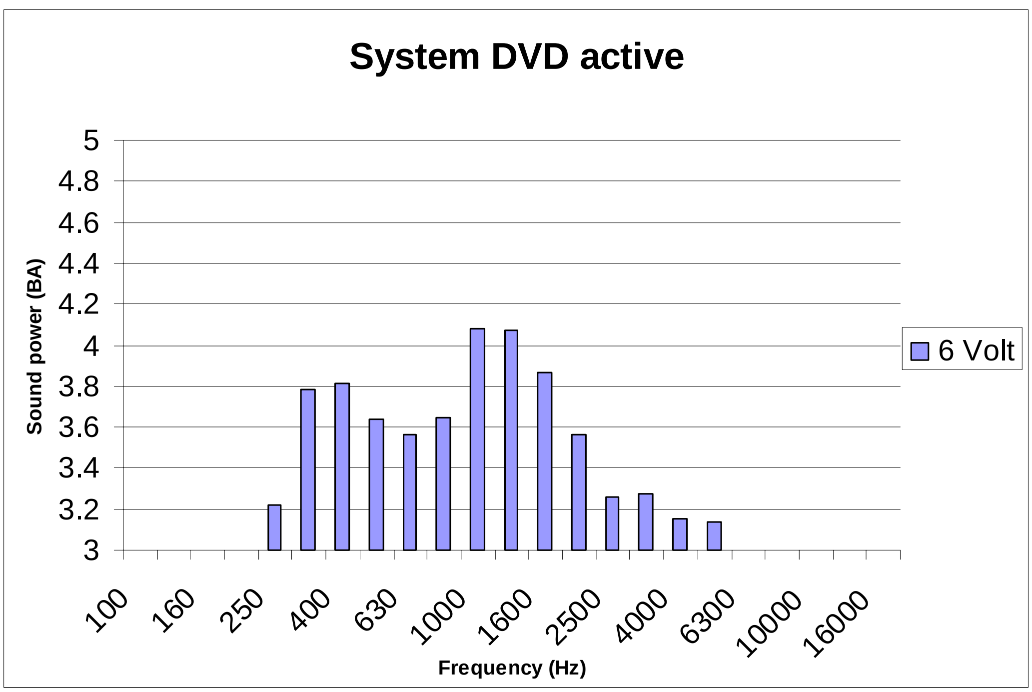


Figure 50. 1/3-Octave Spectra of System Emission with DVD in Active Mode

6.8 Conclusions

The conclusions to be drawn from the present investigation are:

- The measured sound power level of the example ATX chassis is 3.8 BA in the idle mode at 6 V system fan voltage. This corresponds to an external ambient temperature of 23 °C and meets the goal.
- The measured sound power level of the example ATX chassis is 5.1 BA in the idle state at 12 V fan voltage. This corresponds to an external ambient temperature of 35 °C.
- The measured sound power level of the example ATX chassis is 5.3 BA in the hard drive active mode at 6 V fan voltage.
- The measured sound power level of the example ATX chassis is 4.8 BA in the hard drive active mode at 6 V fan voltage.

7. Design Example 2: Mini-Tower with Front to Back Airflow

Now that the system components were chosen and a prototype was built, experiments can be carried out. Experiments are necessary to identify installation issues and to experimentally determine the emission levels. The analysis starts with an analysis of the individual noise sources. This enables comparison between predicted values and emission under installed conditions on the component level. Next, system level sound power emission is determined. In order to investigate sound levels at specific positions, sound pressure experiments were carried out at operator and bystander positions. Sound pressure and sound power alone do not necessarily give a correct impression of the sound quality, experienced by the user. Frequency spectra were collected to visualize the spectra emitted by the noise sources.

7.1 Power Supply Noise Emission

The acoustic emission of the power supply unit was determined for different fan voltages in order to investigate the effect of fan speed control[3]. The results are given in Figure 51.

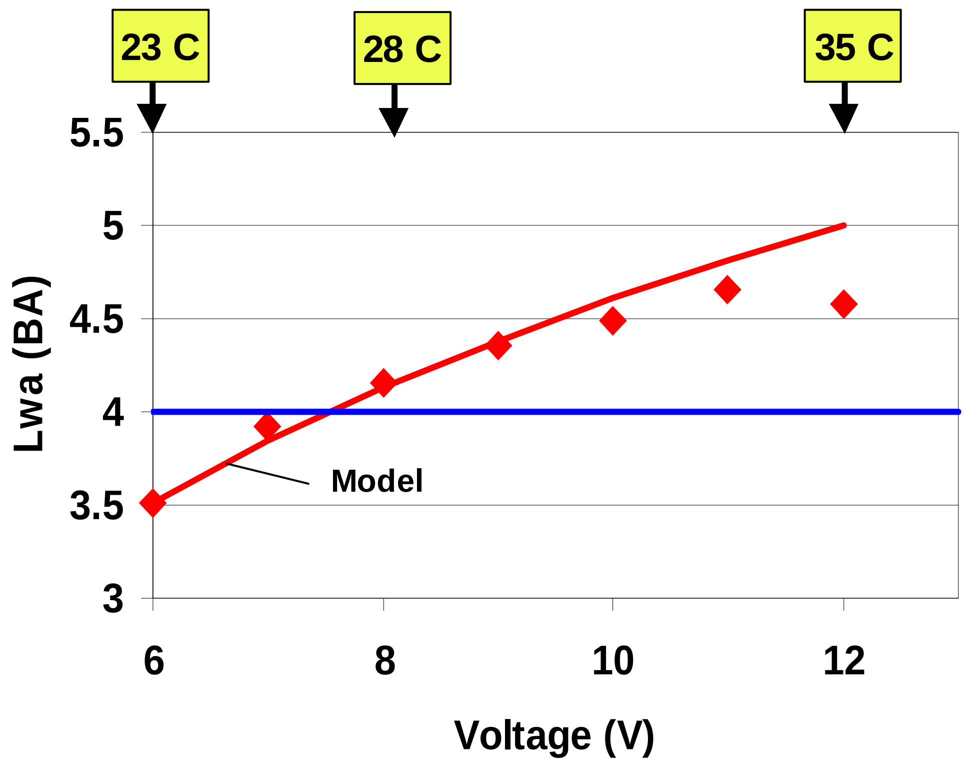


Figure 51. Power Supply Noise Emission

Figure 51 shows that the acoustic emission of the power supply is significant. The sound power emission at 12 V is about 5.0 BA. The sound power emission at 6 V, corresponding to an external ambient temperature of 23 °C, is about 3.5 BA.

[3] In addition to the fan voltage, the fan rotational frequency (RPM) should be determined with for instance a tachometer with an optic sensor. This assists in correlating acoustic frequencies to rotational frequencies of the fan. Fan emission spectra have peaks that typically correspond to the fan blade pass frequency and its higher harmonics.

There is a relationship between the emitted sound power **level** (in BA) of the fan and the logarithm of the fan voltage. An analysis for the power supply gives:

Equation 1

$$L_{waPS} = 4.20 * LOG10(V) + 0.32$$

The manufacturer data for an 80 mm x 25-mm fan gives the following relation between the emitted sound power level and the airflow through the fan[4]:

Equation 2

$$L_{waPSman} = 4.96 * LOG10(CFM) - 2.67$$

The airflow through the fan in cubic feet per minute, CFM, is related to the voltage, *V*, according to:

Equation 3

$$CFM = 35 * \left[\frac{V}{12}\right]$$

The fan RPM, the fan CFM and the fan voltage are all directly linearly related. Inserting the expression in equation 3 into equation 2 gives the following manufacturer noise emission level as a function of voltage under laboratory test conditions:

Equation 4

$$L_{waPSman} = 4.96 * LOG10(V) - 0.36$$

Comparing the manufacturer laboratory test data in equation 4 and the measured noise emission levels under installed conditions in equation 1 indicates that the noise level under installed conditions can be estimated to a reasonable degree of accuracy with the manufacturer data. The model estimation is also given in Figure 51.

[4] This model is a first order estimate, because it does not include the effect of backpressure on the acoustic emissions. Emitted sound power is based on fan emissions at zero backpressure using manufacturer sound power data. This method was validated for a number of desktop, workstation and server systems. The results were in reasonable agreement with measurements and thus allows a first order estimate.

7.2 System Fan Noise Emission

The acoustic emission of the main fan with the bezel was determined for different voltages in order to simulate the effect of fan speed control. The results are given in Figure 52.

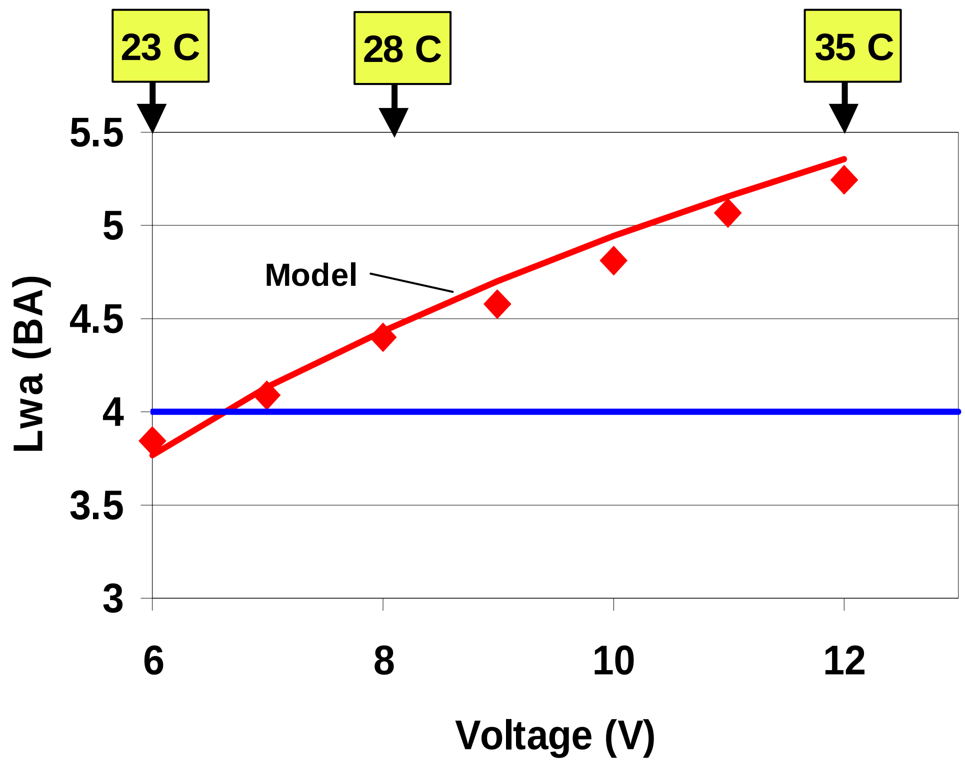


Figure 52. System Fan Noise Emission

Figure 52 shows that the acoustic emission of the system fan at 12 V is about 5.2 BA. The sound power emission at 6 V, corresponding to an external ambient temperature of 23 °C, is about 3.8 BA. Fan acoustic emissions, in terms of emitted sound power **levels**, typically are linearly related to the logarithm, base 10, of the fan voltage or RPM. An analysis for the data, presented in Figure 52, for the system fan with the bezel gives:

Equation 5

$$L_{waFAN} = 4.71 * LOG10(V) + 0.13$$

The manufacturer data for this 92 mm x 25-mm fan gives the following relation between the emitted sound power level and the fan voltage (using the same approach as for the power supply fan):

Equation 6

$$L_{waFANman} = 5.28 * LOG10(V) - 0.33$$

Figure 52 shows that there is good agreement between the model and the experimental results.

7.3 Noise Emission of Hard Drives in Idle Mode

To test the emission of hard drives, the power supply fan and the system fan are turned off and the emitted sound power of the drives is measured in seek mode and idle mode. The results are summarized in Figure 53.

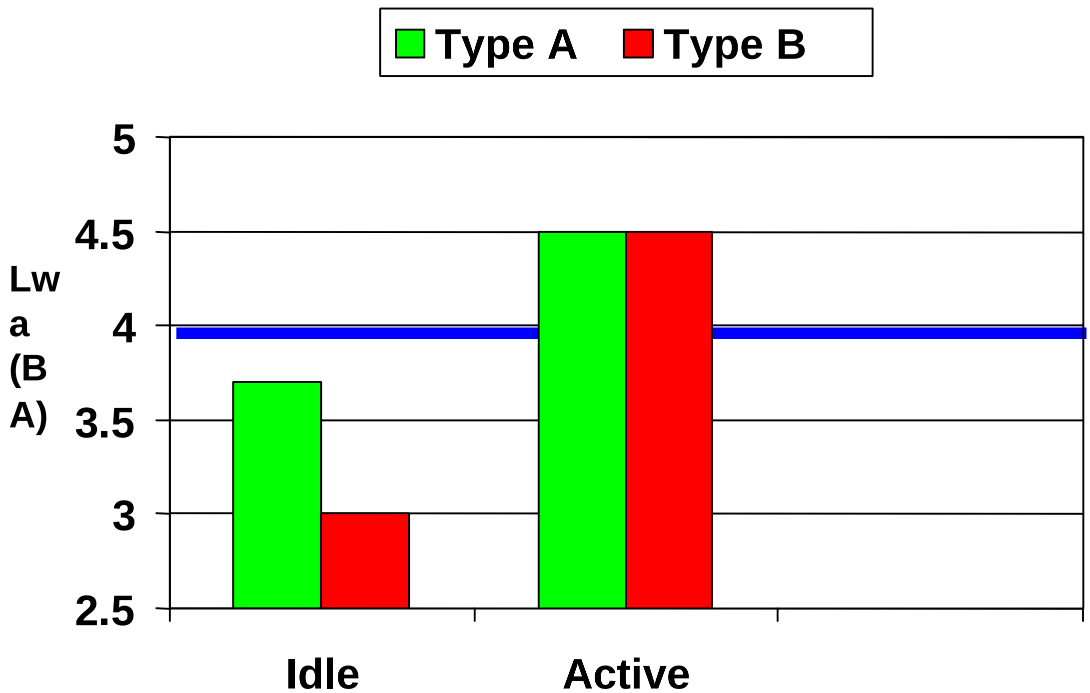


Figure 53. Noise Emission of Soft-mounted Hard Drive in Idle and Seek Mode

The manufacturer specification for the drive emissions is a typical A-weighted sound power emission of 4.1 BA in the idle state for the type A drive, and 3.2 BA for the type B drive. For the type A drive, the emission in the idle and active states was measured in a previous series of experiments. Soft mountings of the drives resulted in a significant reduction of the emitted sound power in the idle and seek modes. An attenuation of 0.2 BA in the idle state and 0.8 BA in the active state was measured. Taking into account the attenuation provided by the mounts, the combined sound power level for the two drives in the idle mode is 3.9 BA. The chassis thus provides an additional 0.2 BA of attenuation. The absorbing materials are especially efficient for higher frequencies, which are typically emitted by hard drives.

For design studies, one can use these formulas to estimate the emitted sound power under installed conditions:

Equation 7

$$L_{waHDD} = L_{waHDDman} - 0.4 \quad \textbf{(idle mode)}$$

Equation 8

$$L_{waHDD} = L_{waHDDman} - 0.8 \quad \textbf{(active mode)}$$

7.4 System Noise Emission

Figure 54 shows the measured system noise emission levels in the idle and active states. It also includes the predicted results using the simple model.

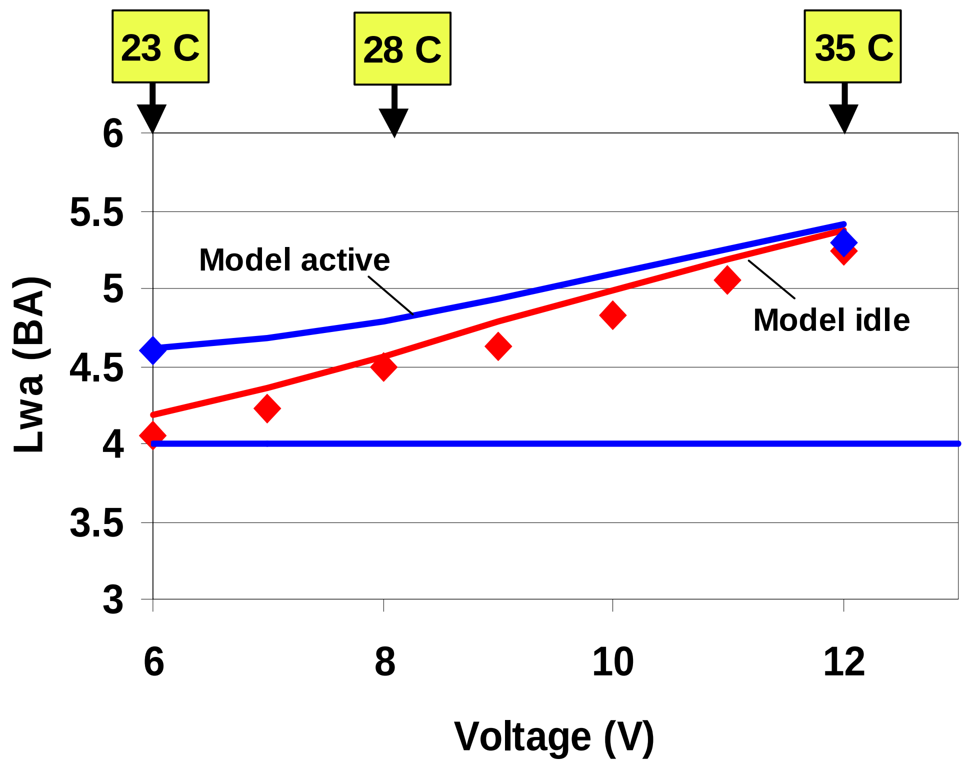


Figure 54. System Noise Emission Levels

Figure 54 shows the total system noise emission level as a function of voltage. The system fan voltage was varied in this case, while the power supply fan voltage was fixed at 6V. The total system noise emission at 6 V is 4.0 BA. At this voltage, the most important contributors to the system noise level are the hard drives and the system fan. As the fan voltages increase, the relative importance of the hard drive emission decreases.

In the previous sections, it was demonstrated that the noise emission levels of the components could be estimated to a reasonable degree of accuracy with manufacturer data. These component level estimates are combined into a system level prediction in Figure 54. It is assumed that the noise sources are incoherent and uncorrelated. This means that the presence of one source does not affect the sound emission of the other source. Because the sources are incoherent and uncorrelated, the energies of the sources can be summed to obtain the total system emitted energy.

In terms of sound power levels this gives:

Equation 9

$$L_{wa} = LOG10(10^{L_{waPS}} + 10^{L_{waFAN}} + 10^{L_{waHDD}})$$

The expressions for L_{waPS}, L_{waFAN} and L_{waHDD} are given in equation 4, equation 6 and equation 7 or 8.

Figure 54 shows that there is good agreement between the measured system noise levels and the predicted noise levels. Thus, the assumption that the sources are incoherent and uncorrelated seems to be justified. Note that the model predictions were validated first on the component level, and that these results are now used in this system level prediction. This offers a model for the designer to conduct a sensitivity analysis. The influence of changes in a component to the overall system noise level can now be predicted to a reasonable degree of accuracy with this simple, straightforward model. The resulting system level noise prediction as a function of voltage is not a linear relationship because of the logarithmic summation described in Equation 9. A linear approximation is reasonable, but at low fan voltages the influence of the hard drive emission is significant.

7.5 Directivity Diagrams

The results of the sound pressure measurements are used to construct a very simple directivity diagram. In the absence of intensity scanning, this approach provides a first insight into the directional characteristics of the sources under consideration. The four bystander positions are located at the same distance from the source, on the front, left, right and rear respectively. The positions are denoted as: BF (Bystander Front), BR (Bystander Right), BL (Bystander Left) and Bre (Bystander Rear).

The results for the sound pressure measurements are given in the polar plots in Figure 55 and Figure 56.

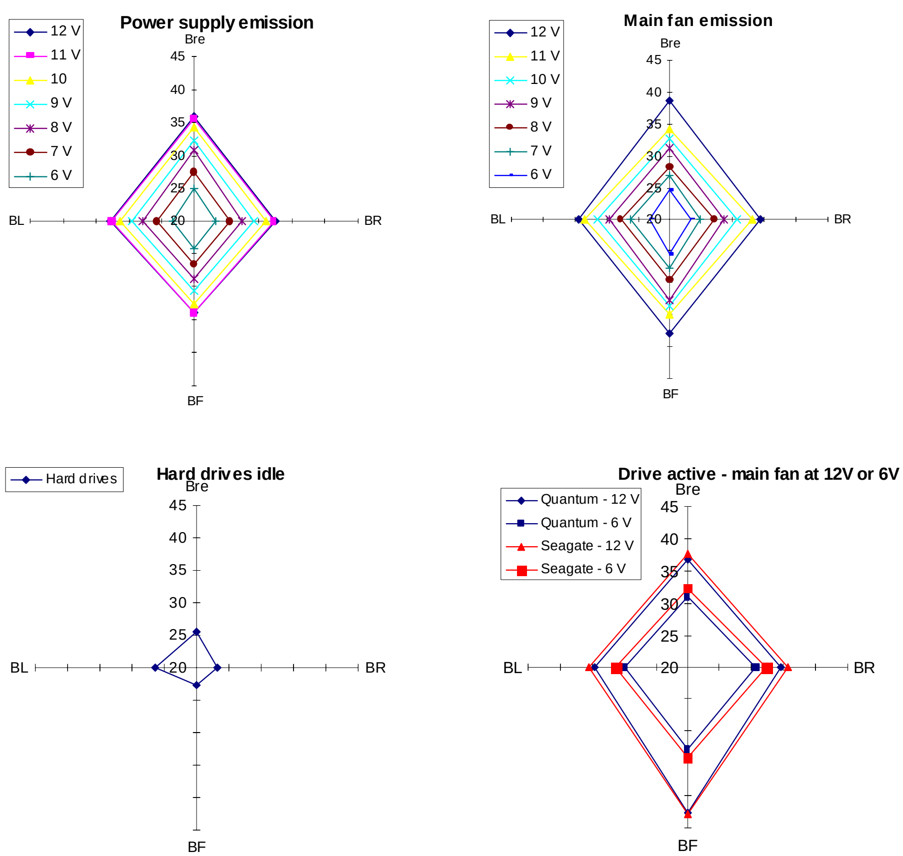


Figure 55. Directivity Plots with Sound Pressure Data on Bystander Positions

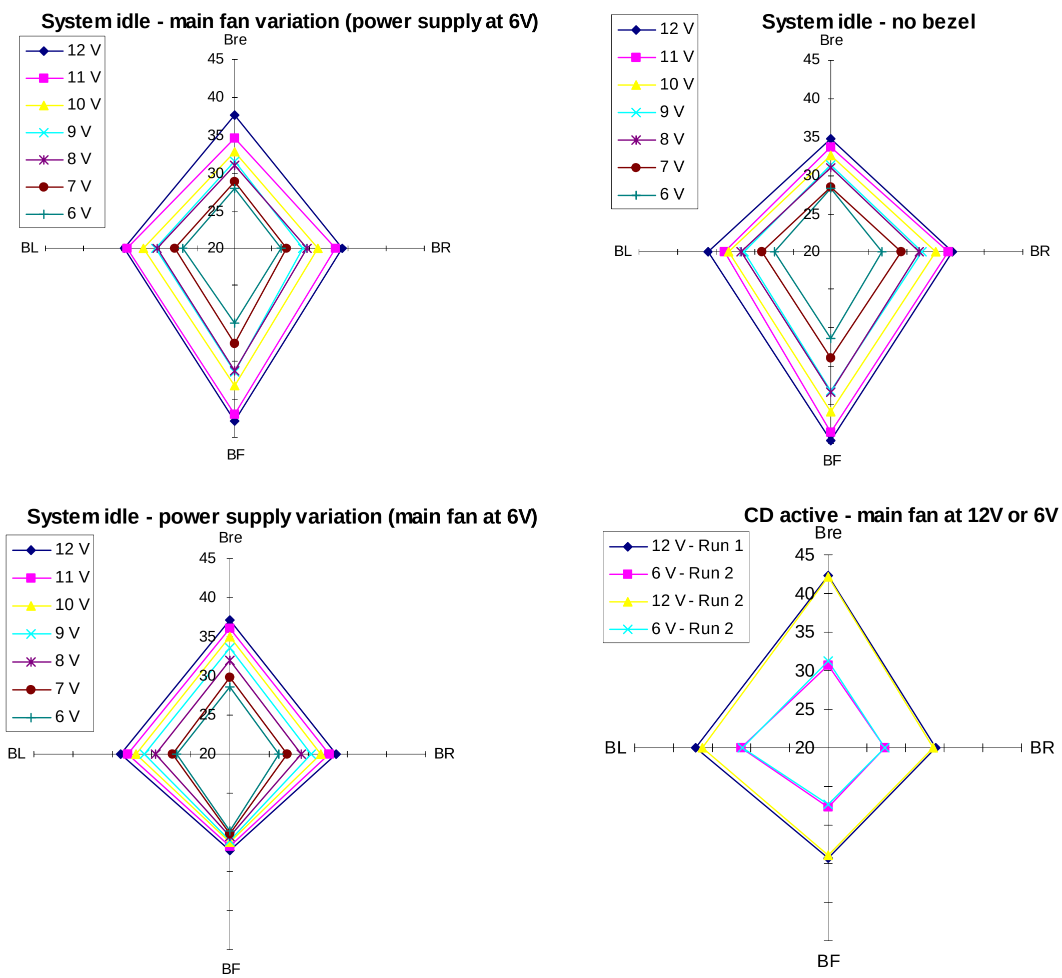


Figure 56. Directivity Plots with Sound Pressure Data on Bystander Positions

Figure 55 shows that the emission of the power supply is directional, with the predominant emission directed towards the rear. Evidently, this is because the power supply fan is located at the rear of the chassis. Figure 55 shows that the emission of the system fan is omni-directional. This is an important observation. The present chassis design incorporates front to back airflow. The air intake is located in the front of the chassis. Because of the presence of the acoustic bezel, there is no direct line-of-sight to the system fan. The directivity towards the front is significantly reduced because of this. This is important, since a high directivity towards the front of the chassis, with the typical operator positions, is undesirable. This is supported by the data in Figure 56, for the system idle with and without the bezel. Without the bezel, the noise radiated to the front of the chassis is about 2 dBA to 3 dBA higher.

7.6 Frequency Spectra

One-Third Octave Bands

In the sound power experiments, the frequency spectra are A-weighted and the energy in the frequency bands is summed. Because of this, sound power numbers do not give any information regarding the spectral composition of the signals. Information regarding the frequency content of the signals is important to identify, for instance, pure tones that could be perceived as annoying by the user. In addition, spectral information is very useful in localizing noise sources by correlating pure tone frequencies to fan or hard drive characteristic rotational frequencies.

For all experiments, spectral information was collected. The spectra, presented in this section, represent the total emitted sound power in each subsequent 1/3-octave band. Thus, the results presented are already integrated over the 10 microphone locations. The emission of the power supply fan, the main fan and the hard drives as measured in these 1/3-octave bands are then analyzed. The measurements are performed according to ISO 7779 standards.

Power Supply Fan

The results for the power supply fan for voltages of 6, 7, 8, 9, 10, 11, and 12 V are given in Figure 57.

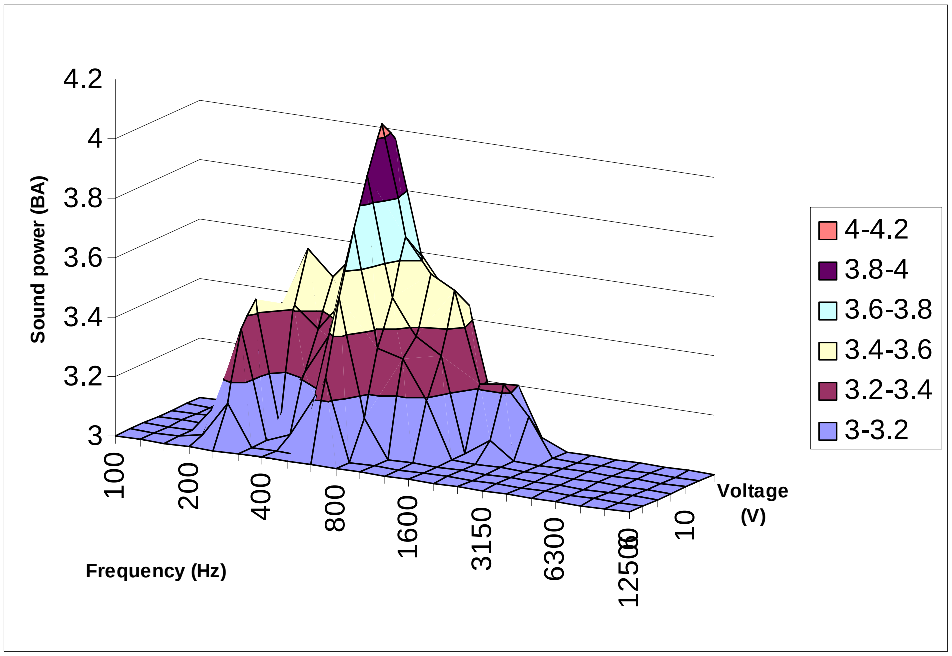


Figure 57. 1/3-Octave Spectra of Power Supply at Different Voltages

Figure 57 shows that the main emission of the power supply fan is in the 1/3- octave band with a center frequency of 630 Hz. Because of the A-weighting that was applied, low and high frequencies are attenuated significantly. Therefore the 1/3-octave bands in the 400 Hz to 2500 Hz range are very prominent. The peaks in the spectrum can be attributed to the fan blade pass frequency and its higher harmonics. However, because of the integration in 1/3-octave bands, the resolution is low. A narrow band analysis was conducted and the peaks could be directly correlated to the fundamental blade pass frequency and its higher harmonics. No other peaks in the spectrum, due to resonance, for instance, were present.

System Fan

The 1/3 octave band spectra for the system fan are given in Figure 58.

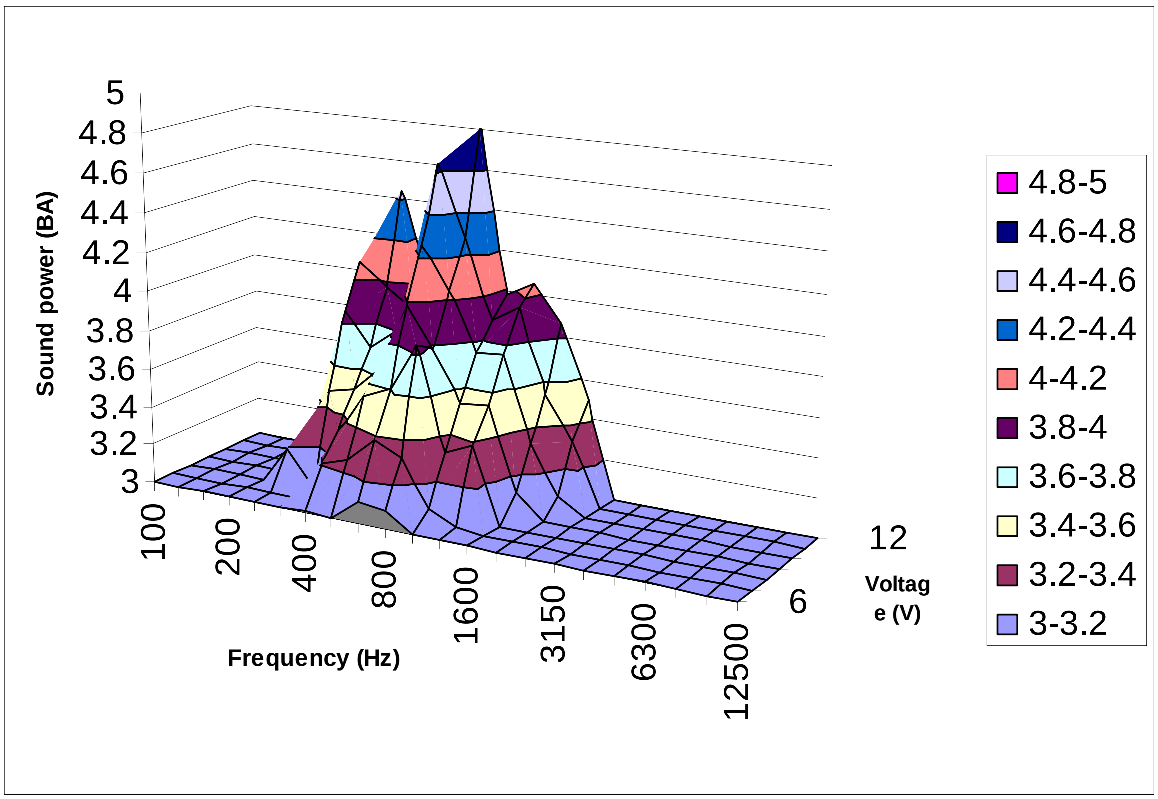


Figure 58. 1/3-Octave Spectra of System Fan at Different Voltages

Again, the A-weighting results in a prominent contribution in the 400 Hz to 2500 Hz range. The peaks in the spectrum are caused by the blade pass frequency of the fan and its higher harmonics. A narrow band analysis was conducted and the peaks could be directly correlated to the fundamental blade pass frequency and its higher harmonics. No other peaks in the spectrum due to duct resonance, for instance, were present. This is an important observation, because resonance has a tonal character and is perceived as annoying. The absorbing material in the duct and soft mounting the fan in the duct prevent excitation of these structural resonance and minimize noise propagation in the duct.

Hard Drives: Idle Mode

The spectrum for the emission of the hard drives in idle mode is given in Figure 59. In this case both drives were in idle mode, and no other noise sources were present.

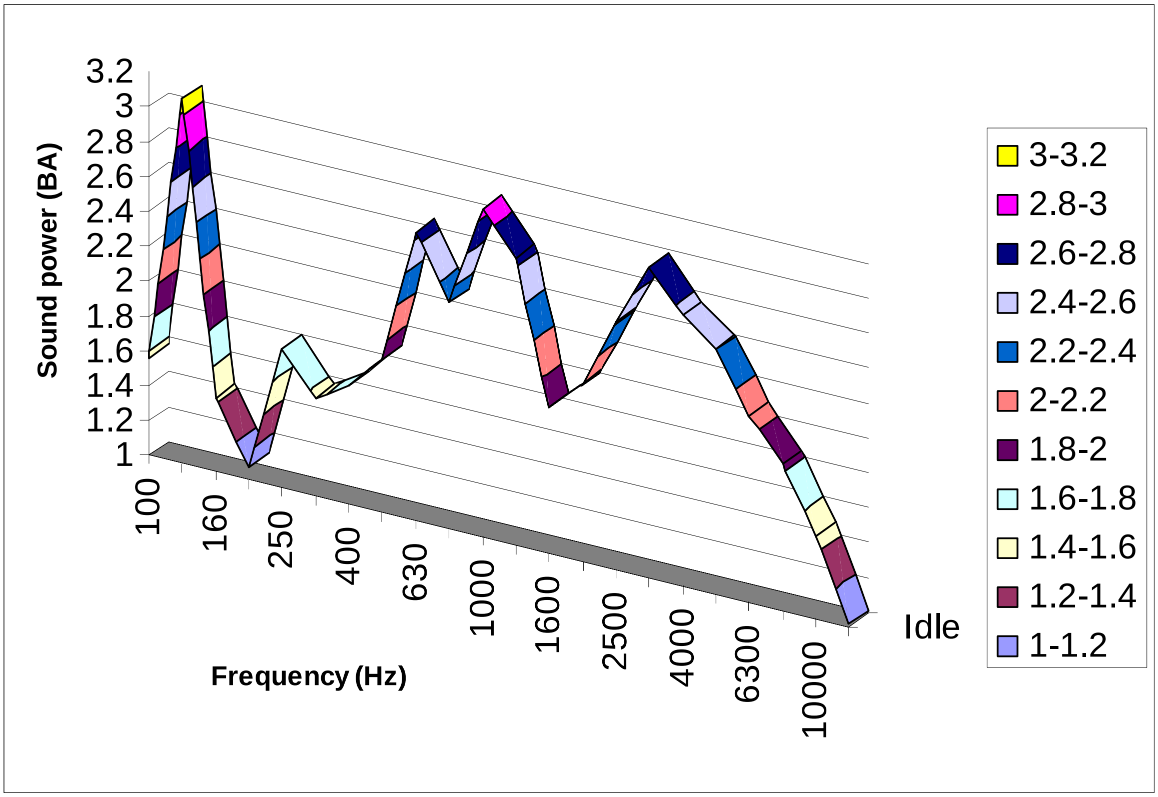


Figure 59. 1/3-Octave Spectrum Hard Drives in Idle Mode

There is a sharp peak in the spectrum for the 1/3-octave band with a center frequency of 125 Hz. An analysis of the raw test data shows that the measurement in this case is affected by the background noise. The emitted sound power in the idle mode for the drives is very low, and the background noise level in the chamber is relatively high. Therefore the condition that the background ambient noise is 0.6 B above the background level is not satisfied for the low 1/3-octave bands. According to ISO 7779 "the EUT did not produce significant noise in specific bands with center frequencies of 100, 125, 160, 200, 8000, 10000, and 12500 Hz, the true noise value for those bands was not determined."

Note, however, that the noise emission of the hard drives, when compared to the emission of the fans, has a higher frequency content. There is significant emission in the 1000 Hz to 4000 Hz range, a sensitive part of the spectrum for the human ear.

Analyzing the frequency content of signals is important in localizing and characterizing noise sources and developing noise control strategies.

Hard Drives: Active Mode

The spectrum for the type A hard drive in active mode is given in Figure 60. The power supply and the system fan ran at the lowest voltage, 6 V, in order to minimize contributions from these noise sources.

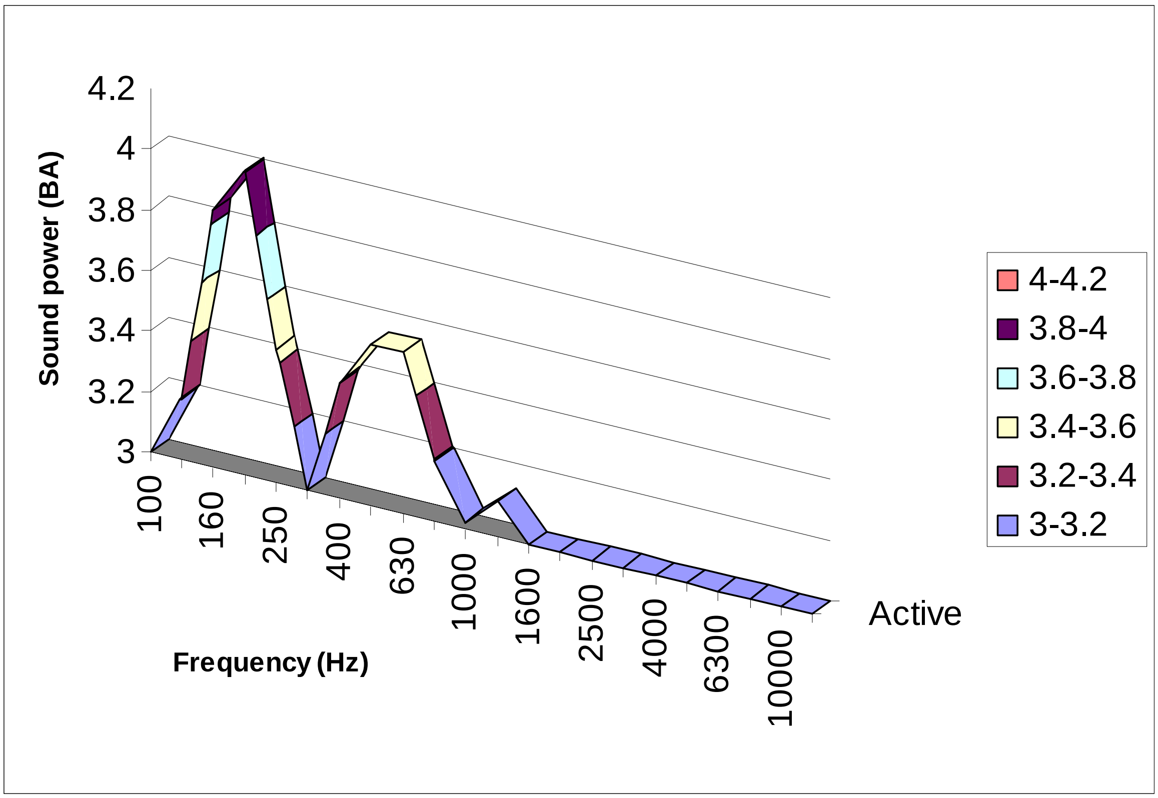


Figure 60. 1/3-Octave Spectrum of Type A Drive in Active Mode, All Fans at 6V

Figure 58 and Figure 59 show that the noise emission of these fans at 6 V is below 3.0 BA in all 1/3-octave bands. Therefore, the noise emission in the low frequency bands, shown in Figure 61, can be attributed to the noise emission of the hard drive. In contrast to the emission in idle mode, the noise emission of this drive in the active mode is predominantly of a low frequency nature.

The noise emission of the type B drive in the active mode is given in Figure 61. In the active mode, the drive also emits also significant low frequency noise that is emitted by the drive. For this specific drive there also is a contribution of some higher frequencies, as can be seen in Figure 61.

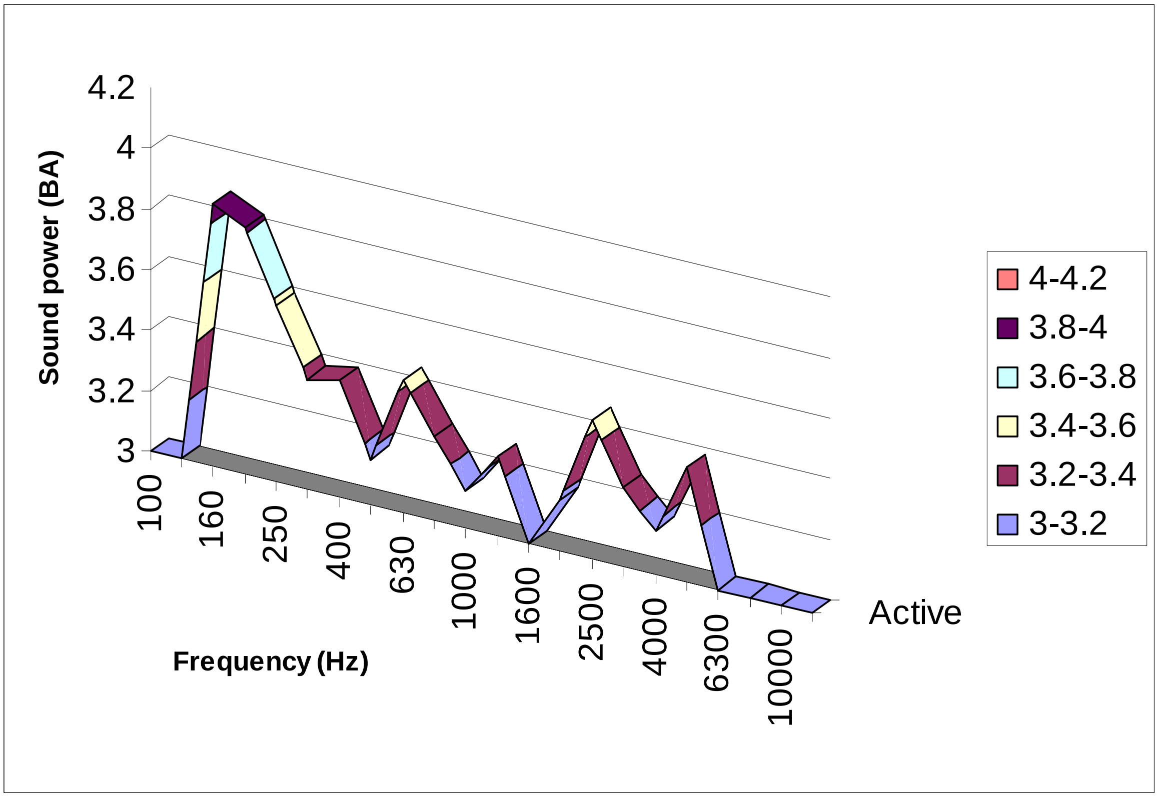


Figure 61. 1/3-Octave Spectrum Type B Drive in Active Mode, All Fans at 6 Volts

System Idle

The spectra for the system in idle mode are given in Figure 62. The voltage to the system fan was varied between 6 V and 12 V, the voltage to the power supply was 6 V, and the drives were in idle mode.

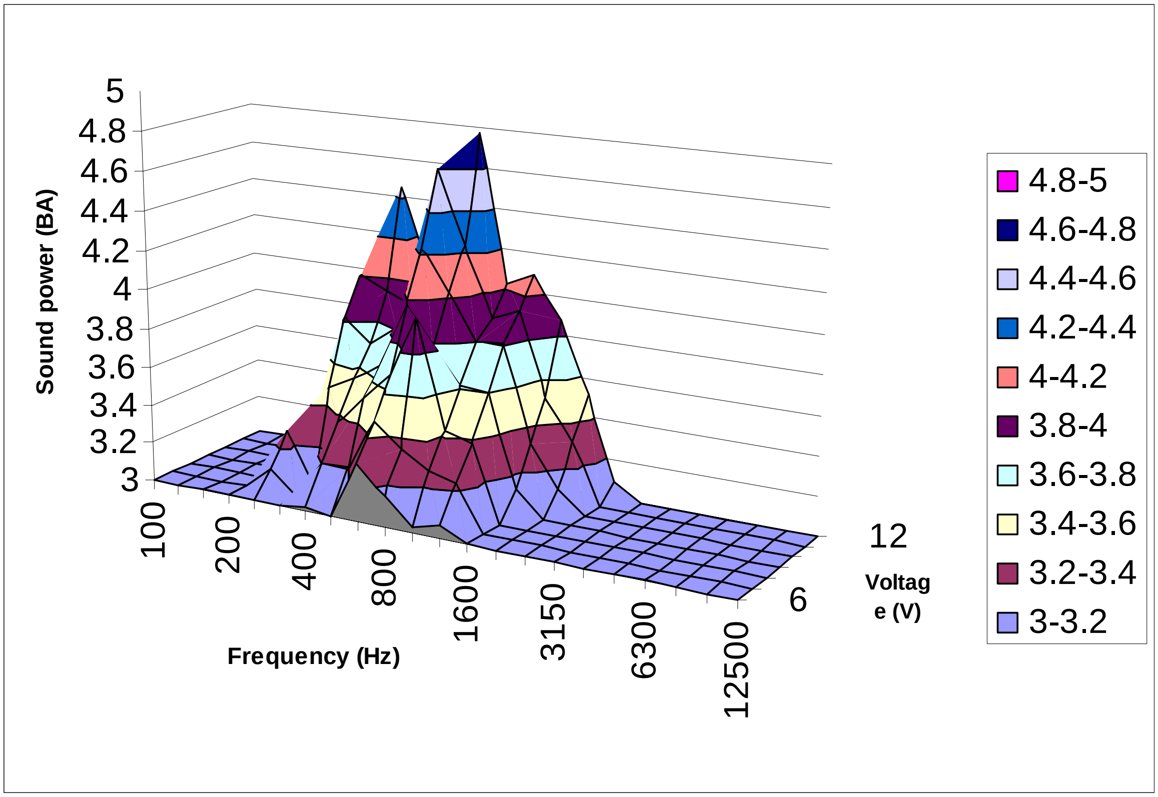


Figure 62. 1/3-Octave Band Spectra of System in Idle Mode

Figure 62 shows that the system fan is the most important noise source in the system. At low voltages, however, the emission of the hard drives becomes significant.

Bezel Attenuation

Experiments were carried out for the system in idle mode with and without the bezel. The attenuation of the bezel was determined from these measurements. Figure 63 shows the attenuation spectrum of the bezel as a function of the system fan voltage.

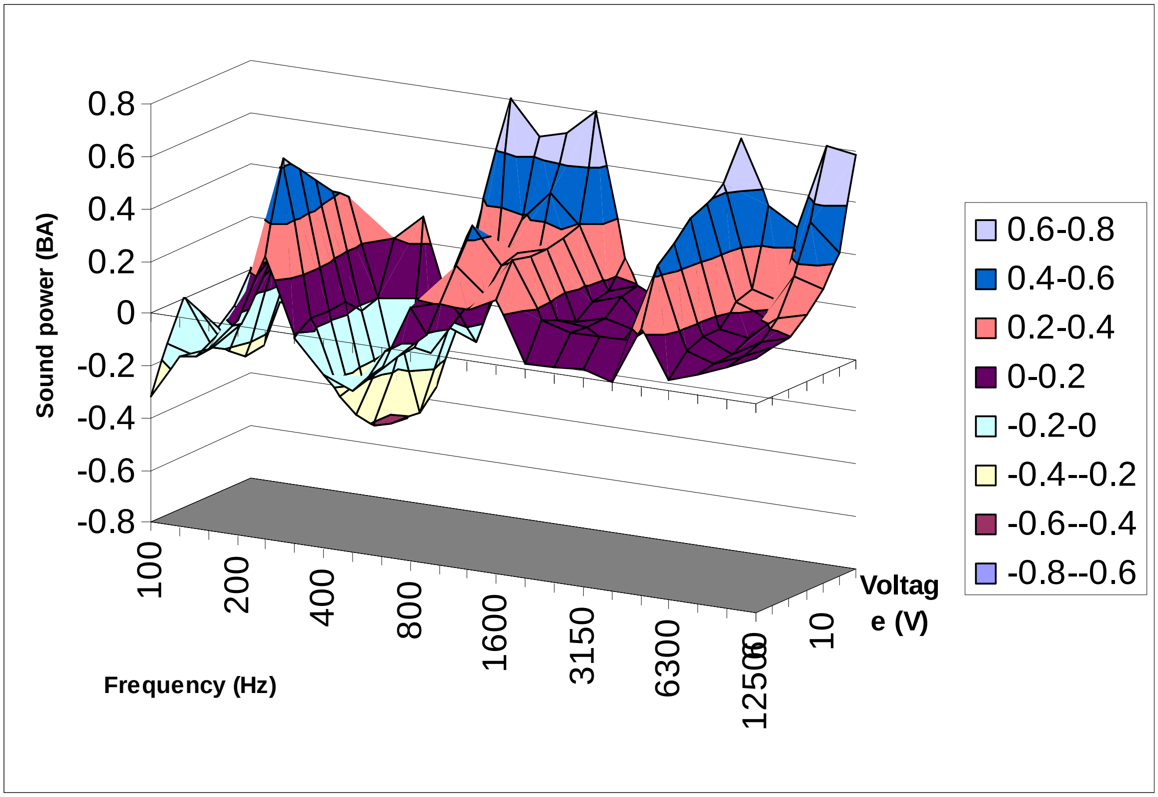


Figure 63. 1/3-Octave Band Spectra of Bezel Attenuation

Figure 63 shows that the attenuation of the bezel occurs mainly at higher frequencies. At lower frequencies the attenuation is in some cases negative. This can be attributed to the shift in the operating point of the system fan when the bezel is removed. The pressure drop, introduced by the bezel, affects the operating point and therefore the noise emission: the emission of a fan is a function of the back pressure. Figure 63 shows that the attenuation is very significant at higher frequencies. Because hard drives emit noise in this part of the spectrum, the bezel is efficient to contain this noise.

7.7 Thermal/Acoustic Trade-Off

The previous sections demonstrate that the system fan is a main source of noise, and fan speed control is efficient. It is already applied in current chassis and power supplies. The amount of noise emitted by the system fan is largely determined by the system fan voltage that is required at a given external ambient temperature to deliver the required cooling. The flow impedance of, for instance, the duct and the bezel configuration affects the required voltage. Some of these parts provide a certain amount of attenuation, but they also introduce airflow restriction that results in an increased system fan voltage. The analysis, presented in this section, gives an example of a front intake system. It demonstrates the thermal/acoustic trade-offs and the indirect influence of pressure drops on acoustic emission levels. Figure 64 shows fan curves at different voltages for the system fan, and system impedance curves for a number of configurations.

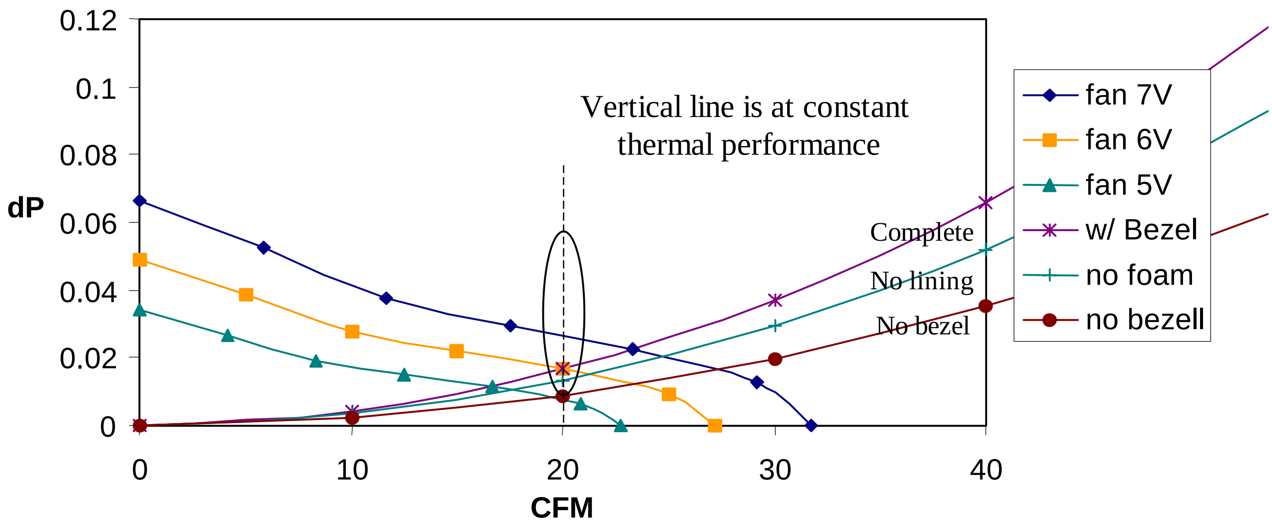


Figure 64. Thermal/Acoustic Trade-Off at 23 °C

In the graph, three fan curves are displayed:

- 92 mm x 25-mm fan running at 7 V
- 92 mm x 25-mm fan running at 6 V
- 92 mm x 25-mm fan running at 5 V

In the same graph, three different system impedance curves are displayed:

- The complete system, including bezel and acoustic foam (absorbing material) in the bezel
- The system, including bezel but no acoustic lining in the bezel
- The system without the bezel

Figure 64 shows the influence of the bezel and the foam on the system impedance curve. It shows that the operating point of the fan shifts due to the pressure drop that is introduced by these components. From a thermal perspective, the target flow rate at 23 °C with the fan running at 6 V is achieved with the bezel and the lining on the system. Figure 64 shows that when the bezel and the lining are removed, the system fan could be run at 5 V. However, running a fan below 6 V is not reliable. The bezel provides about 0.2 BA attenuation at low voltages.

Figure 65 shows fan curves at different voltages for the system fan and system impedance curves for a number of configurations.

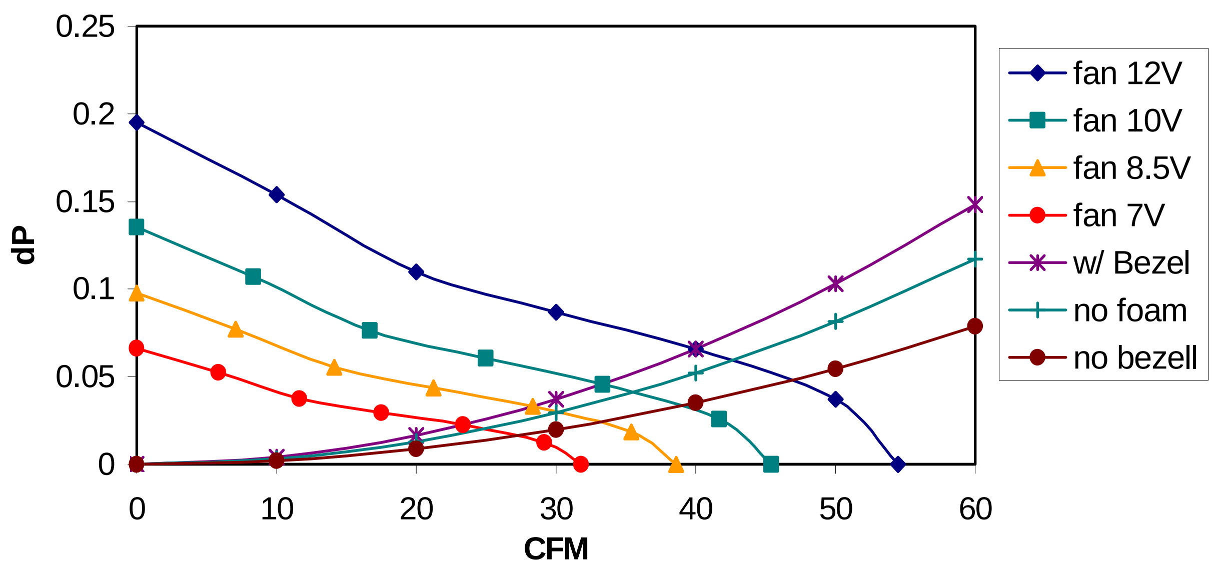


Figure 65. Thermal/Acoustic Trade-Off at 35 °C

Figure 65 shows the thermal/acoustic trade off at 35 °C. In the graph, three fan curves are displayed:

- 92 mm x 25-mm fan running at 12 V
- 92 mm x 25-mm fan running at 10 V
- 92 mm x 25-mm fan running at 8.5 V

In the same graph, three different system impedance curves are displayed:

- The complete system, including bezel and acoustic foam (absorbing material) in the bezel
- The system, including bezel but no acoustic lining in the bezel
- The system without the bezel

Figure 65 shows the influence of the bezel and the foam on the system impedance curve. It shows that the operating point of the fan shifts due to the pressure drop that is introduced by these components. From a thermal perspective, the target airflow rate at 35 °C with the fan running at 12 V is achieved with the bezel and the lining on the system. If the foam is removed, the fan could be run at 11 V. This would give a benefit of 0.2 BA because the fan could be run at a lower voltage. If both the foam and the bezel are removed, the system fan could be run at 10 V, giving a 0.4 BA reduction. However, because there is a direct line-of-sight in this case, the bezel attenuation of 0.2 BA is lost. Thus, the net effect would be a reduction of 0.2 BA at high voltages. However, without the bezel there is an increased sound pressure towards the front of the chassis due to the opening. This is a very undesirable, because the sound is directed towards the user. In addition, the foam provides damping of structural and acoustic resonance in the duct system. This is an important observation, because resonance causes specific frequencies to be excited and are perceived as being annoying.

7.8 Conclusion

The acoustic performance of the prototype was determined and can now be compared to the goal that was defined. As indicated in the previous section, sound pressure levels and the frequency spectra should be used in addition to identify if there are any specific spatial or tonal issues that should be resolved.

8. Appendix A: Related Documents

Acoustic design:	**Author:**	**ISBN:**
Engineering Noise Control: Theory and Practice	Bies & Hansen	0046200215
Handbook of Acoustics	Crocker	047125293X
Noise and Vibration Control Engineering: Principles and Applications	Beranek	0471617512
Acoustics	Beranek	088318494X
Korperschall : Physikalische Grundlagen Und Technische Anwendungen (in German)	Cremer & Heckl	3540546316
Shock and Vibration Handbook	Harris	0070269203
Theoretical acoustics:	**Author:**	**ISBN:**
The Theory of Sound - Volume I	Rayleigh	0486602923
The Theory of Sound - Volume II	Rayleigh	0486602931
Theoretical Acoustics	Morse & Ingard	0691024014
Acoustics : An Introduction to Its Physical Principles and Applications	Pierce	0883186128

Hard Disk Drive Suppliers:	
Fujitsu	http://www.fujitsu.com/
Hitachi	http://www.hitachi.com/
IBM	http://www.ibm.com/
Maxtor	http://www.maxtor.com/Maxtorhome.htm
Quantum	http://www.quantum.com/
Samsung	http://www.samsung.com/
Seagate	http://www.seagate.com/
Western Digital	http://www.westerndigital.com/
Drive Mounting:	
Seagate report	http://www.seagate.com/newsinfo/docs/disc/isolators_for_acoustics_qrk.pdf

9. Appendix B : Standards and Organizations

Standards:	Address:	Documents:	Titles:	Availability:
ANSI	http://www.ansi.org/			
ASTM	http://www.astm.org/	E-1050	Standards test method for impedance and absorption of acoustical materials using a tube, two microphones and a digital frequency analysis system	
		C 384	Standards test method for impedance and absorption of acoustical materials by the impedance tube method	
ECMA	http://www.ecma.ch/	ECMA 74	Measurement of airborne noise emitted by information technology and telecommunications equipment	Free download at ECMA site
		ECMA 108	Measurement of high frequency noise emitted by information technology and telecommunications equipment	Free download at ECMA site
		ECMA 109	Declared noise emission values of information technology and telecommunications equipment	Free download at ECMA site
		ECMA 275	Measurement of structure-born vibrations introduced by small air moving devices	Free download at ECMA site
		ECMA TR/62	Product noise emission of computer and business equipment	Free download at ECMA site
		ECMA TR/70	Product-related environmental attributes	Free download at ECMA site
ETSI	http://www.etsi.org/	ETS 300 753	Equipment engineering (EE): acoustic noise emitted by telecommunications equipment	Posted on web site
ISO	http://www.iso.ch/	ISO 7779	Measurement of airborne noise emitted by information technology and telecommunications equipment	http://www.iso.ch/ or http://global.ihs.com/
		ISO 9295	Measurement of high frequency noise emitted by computer and business equipment	http://www.iso.ch/ or http://global.ihs.com/
		ISO 9296	Declared noise emission values of computer and business equipment	http://www.iso.ch/ or http://global.ihs.com/
		ISO 10302	Method for the measurement of airborne noise emitted by small air moving devices	http://www.iso.ch/ or http://global.ihs.com/

10. Appendix C : Sound Power and Sound Pressure Measurements

10.1 Sound power measurements

10.1.1 Purpose

To demonstrate that product with fans, drives (floppy, hard, and CD-ROM), or other noise producing components do not produce excessive broadband noise. Product must not exceed these noise limits with a maximum configuration and maximum activity.

10.1.2 Quantity

Investigation: 1 system

Validation: 3 systems

10.1.3 Test Objective

1. No measured noise greater than targets.
2. Values are A-weighted in Bels measured between 100 kHz and 16 kHz. Measurements are made in both idle and active modes of all subassemblies. A-weighted means that the measured noise value is corrected to reflect what a healthy human ear hears.
3. Published noise values (the declared sound power level per ISO 9296) shall be 0.3 B higher than the measured values when only one sample of the same system is tested.
4. Published noise values shall be calculated using the following procedure when two or more samples of the same system are tested:

   a. Calculate arithmetic mean of the N samples to get LwAm in BA

   b. Calculate product standard deviation Sp of N samples in BA

   c. Calculate total standard deviation St = Sqrt (Sp2 + 0.152) in BA

   d. Calculate the Declared sound power level using

   $$LwAd = LwAm + 1.5 \times St + k \times (0.2 - St)$$

   where k is acceptance constant, a function of sample size N given in Table B.1

Table B.1 Acceptance constant k for N machines in the sample

N	2	3	4	5	6	7	8	9	10	100
k	0.351	0.564	0.692	0.778	0.842	0.892	0.932	0.966	0.994	1.350

e. The published sound power level shall be the calculated declared sound power level round up to the next 0.1 BA.

5. The published sound power level calculated using this method is in compliance with ISO 9296 and it carries a 95 % statistical confidence that no more than 6.5 % of product exceeds the published sound power level. It can be verified according to ISO 9296 by anyone using three samples.
6. For products using multiple key acoustic components (fan, HDD, etc.), it is recommended that samples be selected such that they cover the variation that product may have. For example, a system (governed by a model number, etc.) with four suppliers of fans, should include samples from all suppliers. This may require testing four or eight systems. The above procedure should then be followed to calculate the declared sound power level.

10.1.4 Test Profile

1. Acoustics Room and Equipment

a. Test Room: Shall provide a free field over a reflecting plane. The background ambient in the acoustics room (with no units operating) should be 0.6 to 1.0 B quieter than the unit under test measured values in each 1/3-octave band between 100 and 16 kHz. This requirement is based on the measured noise emitted from the EUT, not the pass/fail criteria. As computers do not generate significant noise in all 1/3-octave bands, it is often not possible for the test room to meet this criterion. ISO 7779 requires noting in the test report that: "The EUT did not produce significant noise in specific bands (list the bands), the true noise value for those bands was not determined."

b. Temperature: shall be 23 °C +/- 2 °C.

c. Relative Humidity: shall be between 40 % to 70 %.

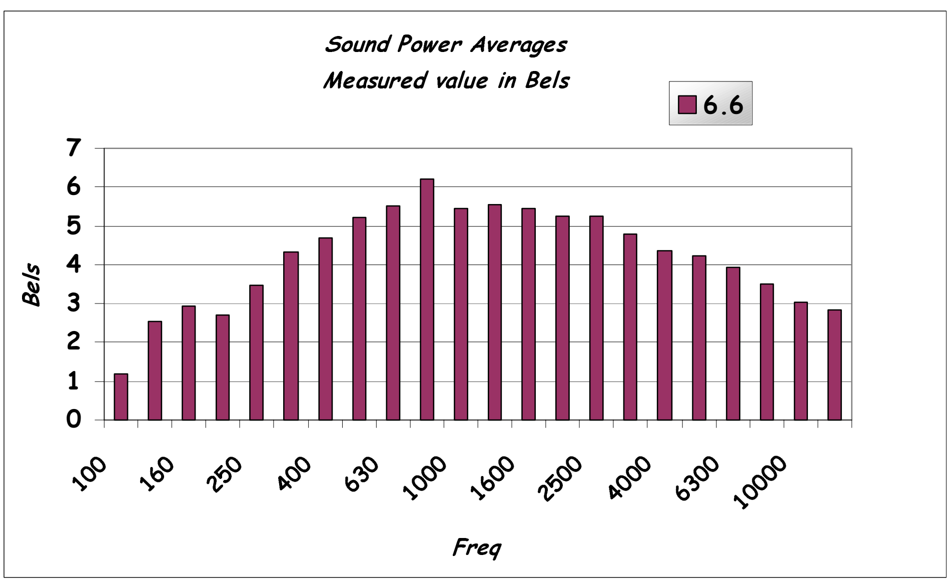
d. Barometric pressure: shall be 86 kPa to 106 kPa.

e. Calibration: before each product test cycle, the measurement system shall be calibrated with an acoustic calibrator with an accuracy of ± 0.03 B.

f. Measurement duration may vary but should be at least 30 seconds and shall be the same for all microphones.

g. The equipment under test shall be operated at its nominal rated voltage and the rated power line frequency.

h. Sound Meter Display: Figure 1 shows a typical sound meter display. Each bar represents a 1/3-octave-measured value. **Figure 1:**



2. Test Unit Setup with microphones (Dome Method):
   a. Hemispherical measurement surfaces require a minimum radius of 1 m. In some cases where sound power levels are relatively low, it may be helpful to select the parallelepiped measurement surface, which permits measurement distances as small as 0.25 m. The measurement radius must be at least two times the characteristic source dimension as measured from the upper corner of the system to the center of the base. Microphones must be at least one m from the chamber walls.
   b. Keyboard and monitor should be located outside the test facility but may be placed beside the unit if remote operation is not possible.
   c. All systems are positioned on the floor in the center of the reflecting plane.
   d. Product may be supported 12 mm off the floor on rubber pads if needed to prevent transmission of noise to the floor.
   e. Rack mounted equipment with more than one end-use enclosure shall be tested and reported as sub-assemblies. Rack mount units shall be supported 0.25 m above the floor by vibration isolating elements. The support shall not interfere with the propagation of airborne sound.
   f. Hand held equipment should be supported 0.1 m above the floor on vibration isolating elements. The support shall not interfere with the propagation of airborne sound.
   g. Microphone positions: Data may be collected using an array of microphones (typically 10) placed in a hemispherical pattern around the EUT.
   h. The EUT should be oriented parallel to the walls of the test room.
   i. The measurement is referenced to the horizontal center of the EUT.
   j. The microphone position shall be selected in such a way that the microphone is not exposed to the air stream from the fan exhaust. Although the front of the EUT is shown in the drawing, the product may be rotated in 90-degree increments to minimize air stream microphone interaction.

k. Microphones will be aimed at the geometric center of the EUT.

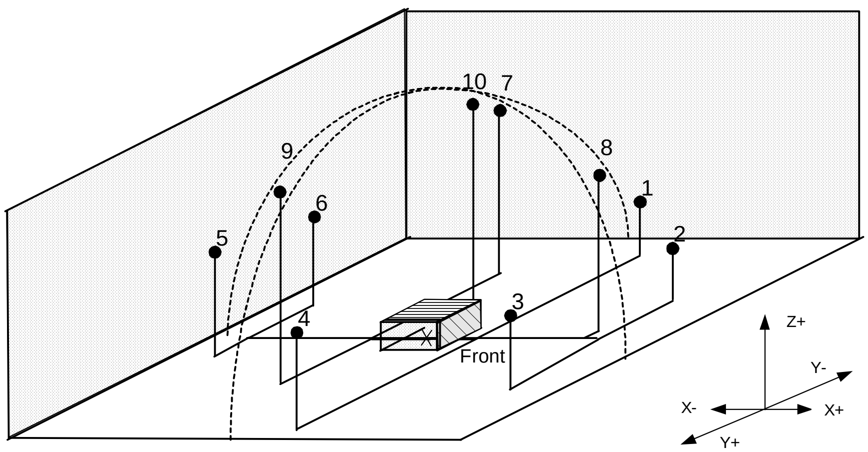


Figure 2

Typical sound power

Microphone positions. **Table 2**

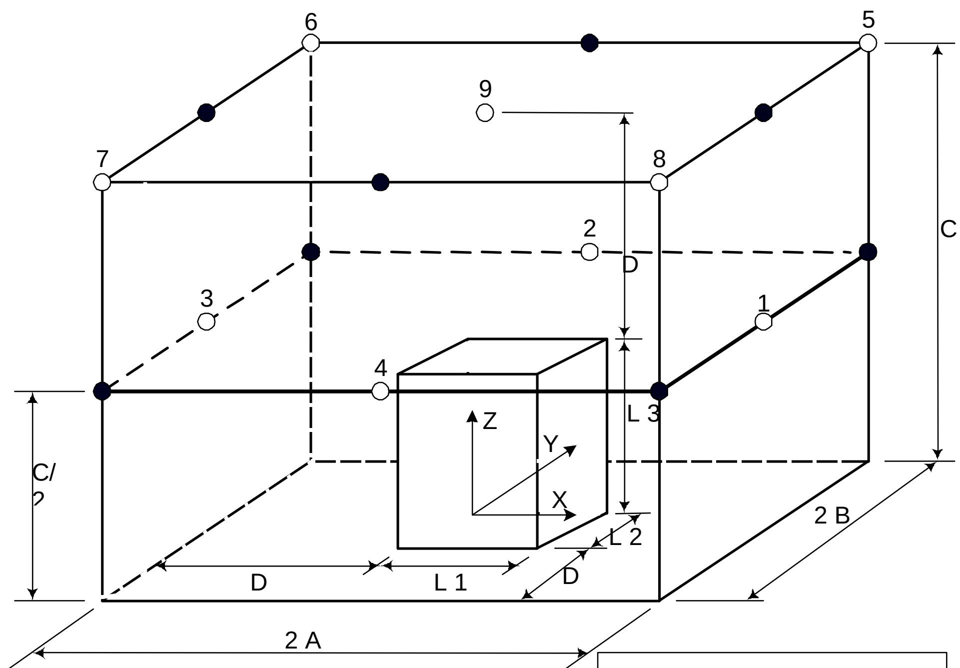
Position	X	Y	Z	Position	X	Y	Z
1	0.16	-0.96	0.22	6	-0.83	-0.40	0.38
2	0.78	-0.60	0.20	7	-0.26	-0.65	0.71
3	0.78	0.55	0.31	8	0.74	-0.07	0.67
4	0.16	0.90	0.41	9	-0.26	0.50	0.83
5	-0.83	0.32	0.45	10	0.10	-0.10	0.99

All dimensions are in radius units, typically 1 but up to 2 m. The origin is at the horizontal center of the reference box surface that is coplanar with the room floor.

3. Test Unit Setup with microphones (Parallelepiped Method):

   a. The surface of the cube is typically 1 m (it may be as close as 0.25 m) from the surface of the product under test, microphones are then positioned at the center of each imaginary plane and at the top two corners. Additionally, one is placed in the top plane directly over the center of the product. Microphones must be at least one m from the chamber walls.

   b. Rack mounted equipment with more than one end-use enclosure shall be tested and reported as sub-assemblies. Rack mount units shall be supported 0.25 m above the floor by vibration isolating elements. The support shall not interfere with the propagation of airborne sound.



○ key microphone positions
● Additional microphone positions, see text.

Surface Area (S)
S = 4 x (AB + BC + CA)
where
A = 0.5 L1 +D
B = 0.5 L2 + D
C = L3 +D
where L1, L2, and L3 are the length,width and height of the unit under test.
D = the measurement distance, (1 meter)

c. The additional microphone positions are required if any one of the following conditions exist:
    - The range of sound pressure values measured at the microphones (in dB) exceeds the number of measurement positions.
    - Any of the dimensions of the reference parallelepiped is larger than 2D.
    - The equipment radiates noise with a high directivity

see ISO 3744 Annex C for further detail.

4. Unit Operational Requirements
    a. Configuration: System to be fully functional, all options that produce noise should be installed and in use during the test.
    b. Warm Up Period: If the fan speed is thermally controlled, then allow at least 30 minutes for the system to warm up.
5. Measurements are made in both the idle and active mode for each subassembly.
    a. Idle Standby: If a power saving mode (sleep mode) is available, such modes may be tested and if tested shall be described in the report
    b. Idle Ready: Disks shall be loaded, power on, unit ready to receive and respond to control link commands, with spindle up to speed and read/write heads in track follow mode.
    c. Active Operating ALL: The drive(s) should be given a command or commands to read or write a random selection of files; the drive algorithm will decide the order in which the commands are executed. It is important that the drives continue to read/write during the complete duration of the noise measurement. All other drives (floppy, CD, tape, etc) shall be in the idle mode, typical of normal use for the system. See ISO-7779 1999, section C.15 and C.9 for more details.
    d. Active Operating Single Drives: For units with a single drive or multiple drives that are independently operable, the drive(s) shall be tested one at a time. Drive operation is specified in c above.
    e. Active Operating Multiple Drives: Units that normally operate multiple drives simultaneously (RAID configurations for example) shall be tested while operating the full number of drives that are normally used. Drive operation is specified in c above.

10.1.5 Expected Failure Mechanisms

Excessive noise from fans, drives (floppy, hard, and CD-ROM), or tape backup.

10.1.6 Pass Criteria

No measured noise greater than specified in targets as applicable.

10.1.7 Basis for Profile

1. The manufacturer specifies targeted noise limits. Test setup and method are based on ISO 7779, “Measurement of airborne noise emitted by information technology and telecommunications equipment.” For questions or issues not addressed in this profile please refer to the ISO 7779:1999.
2. Requirements for report writing are based on ISO 9296 Acoustics, “ Declared Noise Emissions Values of Computer and Business Equipment.”
3. A further area of concern is pure tones, which are prominent, discrete tones that are perceived to be annoying because they are not masked by nearby frequencies. A simplistic indicator of pure tones is to look for amplitude differences between the 1/3- octave band of interest and the two adjacent bands. ISO defines a 0.6 B amplitude difference as significant; any relative difference greater than 1.0 B should be investigated. Refer to ISO 7779:1999, Annex D for more explanation.

10.2 Sound Pressure Measurements

10.2.1 Purpose

To demonstrate that product with fans, drives (floppy, hard and CD-ROM) or other noise producing components do not produce excessive broadband noise. Product must not exceed these noise limits with a maximum configuration and maximum activity.

10.2.2 Quantity

Investigation: 1 system

Validation: 3 systems

10.2.3 Test Objective

1. No measured noise greater than listed in Table 1 or Table 2.
2. Table 1 and Table 2 values are A-weighted measured between 100 kHz and 16 kHz. Measurements are made at both the operator and bystander's positions in both idle and active modes of all subassemblies. A-weighted means that the measured noise value is corrected to reflect what is heard by a healthy human ear.
3. For products using multiple key acoustic components (fan, HDD, etc.), it is recommended that samples be selected such that they cover the variation that product may have. For example, a system (governed by a model number, etc.) with four suppliers of fans, should include samples from at least all suppliers. This may require testing four, eight, or more systems.

10.2.4 Test Profile

1. Acoustics Room and Equipment
   a. Test Room: Shall provide a free field over a reflecting plane. The background ambient in the acoustics room (with no units operating) should be 6 dB to 10 dB quieter than the unit under test measured values in each 1/3-octave band between 100 kHz and 16 kHz. This requirement is based on the measured noise emitted from the EUT, not the pass/fail criteria. As computers do not generate significant noise in all 1/3-octave bands, it is often not possible for the test room to meet this criterion. ISO 7779 requires noting in the test report that: "The EUT did not produce significant noise in specific bands (list the bands), the true noise value for those bands was not determined."
   b. Temperature: shall be 23 °C +/- 2 °C.
   c. Relative Humidity: shall be between 40 % to 70 %.

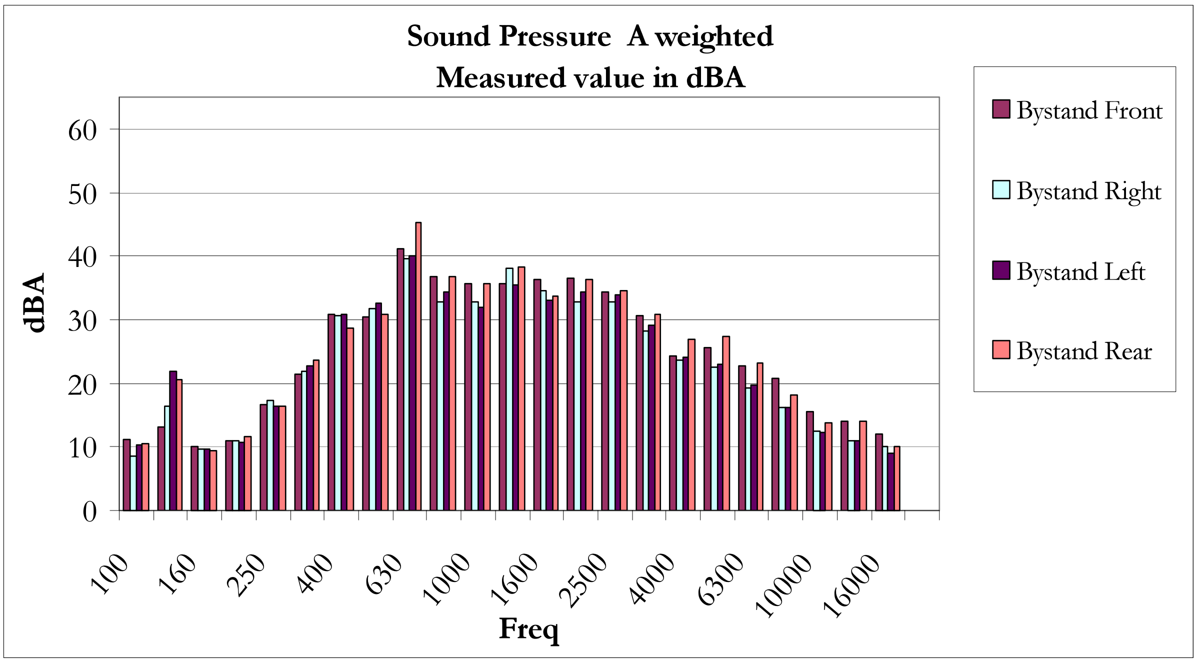
d. Barometric pressure: shall be 86 kPa to 106 kPa.

e. Calibration: before each product test cycle, the measurement system shall be calibrated with an acoustic calibrator with an accuracy of ± 0.3 dB.

f. Measurement duration may vary but should be at least 30 seconds and shall be the same for all microphones.

g. The equipment under test shall be operated at its nominal rated voltage and the rated power line frequency.

h. Sound Meter Display: Figure 1 shows a typical sound meter display. Each bar represents a 1/3-octave measured value. **Figure 1**



2. Test unit setup with microphones:

a. Desktop systems are positioned on a wooden desk at normal table height. Noise is measured at one operator’s position and four bystanders' positions. See Figure 2. See ISO 7779 Annex A for table dimensions and construction.

b. Floor models are tested on the floor. If a unit can be used in both positions (floor and desktop) then the measurement should be taken in the worst case position. Floor model noise is measured at the two operator and four bystander positions. See Figure 2.

c. Rack mounted equipment with more than one end-use enclosure shall be tested and reported as sub-assemblies. Rack mount units shall be supported 0.25 m above the floor by vibration isolating elements. The support shall not interfere with the propagation of airborne sound.

d. Keyboard and monitor should be located outside the test facility but may be placed beside the unit if remote operation is not possible.

e. Product may be supported 12 mm off the floor or desk surface on rubber pads if needed to prevent transmission of noise to the surface.

f. Hand held equipment should be supported 0.1 m above the floor on vibration isolating elements. The support shall not interfere with the propagation of airborne sound.

g. The EUT should be oriented parallel to the walls of the test room.

h. Microphones will be aimed at the geometric center of the EUT

Summary of Microphone Locations

See Figure 2 for details on layout. **Table 3**

	Operator Position	Bystander Position
Desktop	Measurement point 0.5 m away centered in front at 1.2 m. high.	Measurement points 1 m away at 1.5 m high.
Floor Models	Measurement points 0.5 m. from front, 0.4 m. from side and 1.2 m. high.	Measurement points 1 m away at 1.5 m high.

Note: *Operator position for a product with a keyboard attached (laptop for example) is 0.25 m from the front edge of the keyboard. The 0.5 m measurement used here is based the on normal use of the product including a detached keyboard.*

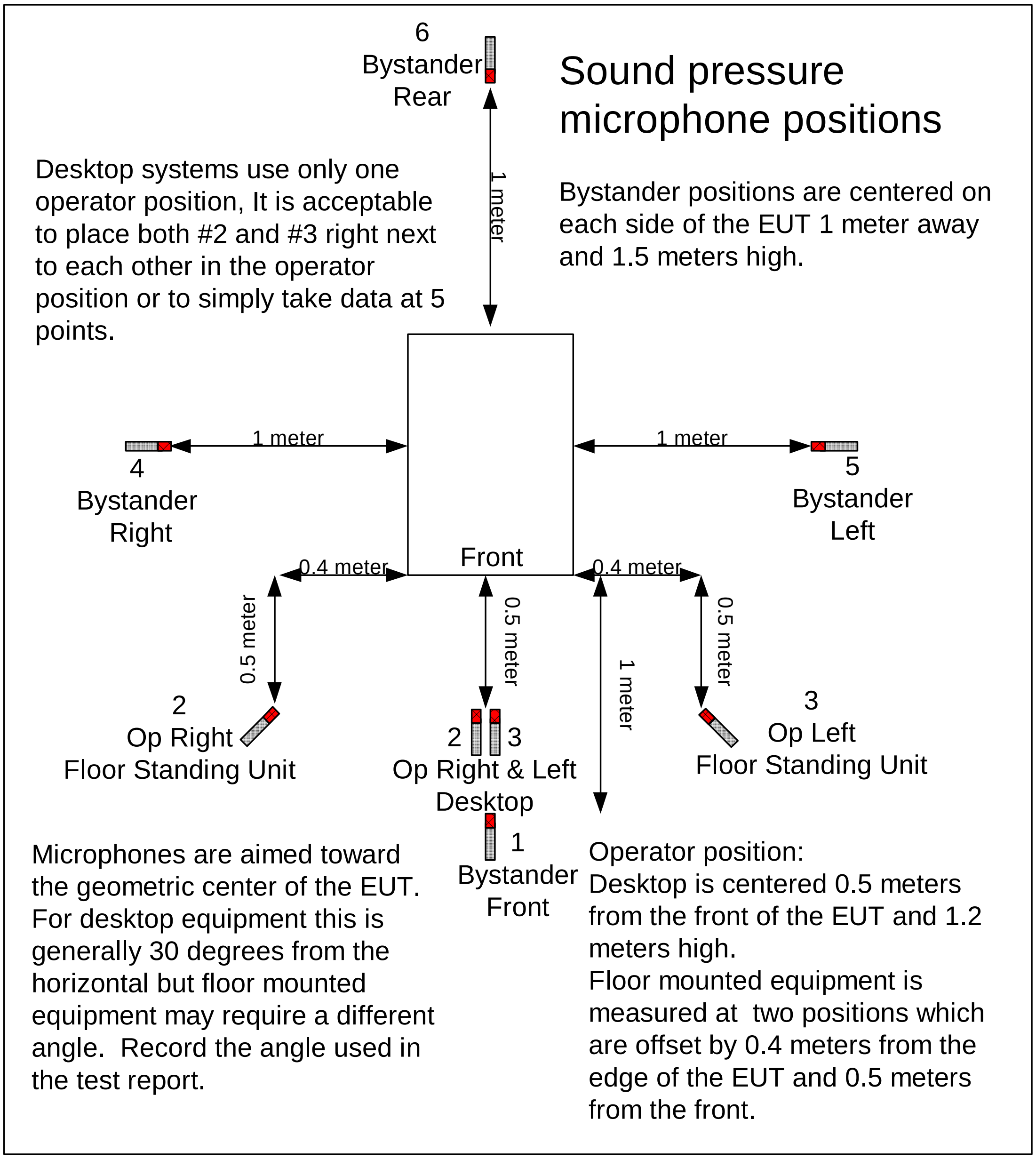


Figure 2 - Sound Pressure Setups Showing Microphone Locations

3. Unit Operational Requirements:

   a. Configuration: system to be fully functional, all options that produce noise should be installed and in use during the test.

   b. Warm Up Period: if the fan speed is thermally controlled, then allow at least 30 minutes for the system to warm up.

4. Measurements are made in both the idle and active mode for each subassembly.
   a. Idle Standby: if a power saving mode (sleep mode) is available, such modes may be tested and if tested, shall be described in the report.
   b. Idle Ready: disks shall be loaded, power on, unit ready to receive and respond to control link commands, with spindle up to speed and read/write heads in track follow mode.
   c. Active Operating ALL: the drive(s) should be given a command or commands to read or write a random selection of files; the drive algorithm will decide the order in which the commands are executed. It is important that the drives continue to read/write during the complete duration of the noise measurement. All other drives (floppy, CD, tape, etc) shall be in the idle mode, typical of normal use for the system. See ISO-7779 1999, section C.15 and C.9 for more details.
   d. Active Operating Single Drives: for units with a single drive or multiple drives that are independently operable, the drive(s) shall be tested one at a time. Drive operation is specified in c above.
   e. Active Operating Multiple Drives: units that normally operate multiple drives simultaneously (RAID configurations for example) shall be tested while operating the full number of drives that are normally used. Drive operation is specified in step c above.

10.2.5 Expected Failure Mechanisms

Excessive noise from fans, drives (floppy, hard, and CD-ROM), and tape backup.

10.2.6 Pass Criteria

No measured noise greater than specified in targets in any of the operator or bystander positions.

10.2.7 Basis for Profile

1. The business units define noise limits. Test setup and method are based on ISO 7779, "Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment." For questions or issues not addressed in this profile please refer to the ISO 7779:1999
2. Requirements for report writing are based on ISO 9296 Acoustics, " Declared Noise Emissions Values of Computer and Business Equipment."
3. A further area of concern is pure tones, which are prominent, discrete tones that are perceived to be annoying because they are not masked by nearby frequencies. A simplistic indicator of pure tones is to look for amplitude differences between the 1/3-octave band of interest and the two adjacent bands. ISO defines a 6 dB amplitude difference as significant; any relative difference greater than 10 dB should be investigated. Refer to ISO 7779 Annex D for more explanation.
4. The ability to resolve and measure noise varies from lab to lab. ISO 7779 states that the expected standard deviation due only to lab setup and equipment and not including EUT variations, is about 1.5 dB. While it is appropriate to report noise values observed using this profile "as measured," it is not appropriate to state that the product will not exceed those measured values. Approximately 90 % of the time, the same units tested in another lab will measure within ± 3 dB of the same value.