Dell Enterprise Acoustics

A Dell Technical White Paper

Chris E. Peterson

Dell Enterprise Acoustical, Structural Vibration, and Thermal Engineering

THIS WHITE PAPER IS FOR INFORMATIONAL PURPOSES ONLY, AND MAY CONTAIN TYPOGRAPHICAL ERRORS AND TECHNICAL INACCURACIES. THE CONTENT IS PROVIDED AS IS, WITHOUT EXPRESS OR IMPLIED WARRANTIES OF ANY KIND.

© 2011 Dell Inc. All rights reserved. Reproduction of this material in any manner whatsoever without the express written permission of Dell Inc. is strictly forbidden. For more information, contact Dell.

Dell, the *DELL* logo, the *DELL* badge, and *PowerEdge* are trademarks of Dell Inc.

April 2011

Contents

Introduction 3
Playing Audio Examples 4
Dell Acoustical Design 5
Expectations for Noise 6
Considerations and Deployment When Acoustics is Important 7
How are the Noises Made? 9
Fans 9
Drives 10
Electrical Components 10
Human Interaction 10
Noise Perception 11
Magnitude 11
Frequency Content 11
Changes with Time 12
Location When the Sound is Distracting 13
Descriptions of Distractions 13
Metrics Used in Descriptions of Product Noise 14
A-Weighted Sound Pressure Level (dBA) 14
A-Weighted Sound Power Level (bels) 15
Loudness (sones) 17
Tones 17
Other Sound Quality metrics 18
Limitations in Using Metrics to Describe Noise 18
Interpretation of Numbers Used to Describe Product Noise 19
Configurations and Operating Conditions 19
How to Interpret Acoustical Data 20
Summary 22
Works Cited 23

Tables

Table 1. Sample Descriptors of Noise 14
Table 2. Real-World Interpretations of Acoustical Values 22

Figures

Figure 1. Varied Server Components Contributing Directly and Indirectly to Noise 6
Figure 2. Spreading in Progressive Sound Waves 8
Figure 3. The Barrier Effect on Progressive Sound Waves 8
Figure 4. How Noise is Generated in a Server 9
Figure 5. Two Mechanisms of Fan Airborne Noise 10
Figure 6. Two Sounds With the Same Frequency Content and Different Magnitudes 12
Figure 7. Changes in Sound With Time 13
Figure 8. Sound Power Measurement of a Tower Server 17
Figure 9. Familiar Sources of Tones 18
Figure 10. Sample Acoustical Report For a Dell Server 21

Introduction

You have probably become accustomed to the different noises from technology in your everyday life. The laundry machine spins up to speed, sloshes the clothes back and forth, and then gives off a series of beeps when it is done. The blender whirrs and chatters as it blends food. The air conditioner makes static-like noise as it moves cool air toward you. When things are running right in your car, you hear the purring of the engine and ascent in pitch when you accelerate. When things are not running right, you hear chopping noises (and feel wobbling) from the brakes, rattles from the pistons, or scraping of the wipers on the windshield.

Technological developments have allowed products like those in the examples cited above to enter everyday life and operate in close proximity to you and your ears. Increased expectations for the sounds and noises have accompanied the new proximities of the products. You have told us over the past several years that the noises from your computer affect your concentration, satisfaction, and ultimately buying decisions.

Dell has combined your feedback with data from product noise literature and its own studies on customer response to noise in order to develop products better aligned with evolving expectations. Acoustical performance must be properly understood by a company during product design, and it can be helpful for you to understand when considering a purchase. In this paper, we explore the mechanisms of, people's reactions to, language of, and Dell's work to control noise from Enterprise products.

Playing Audio Examples

This paper includes embedded audio examples to help illustrate specific points. The following steps describe how to play an embedded audio file:

1. Click the play icon:

   Some icons are displayed within figures and some are displayed within text.

2. Adobe Acrobat may ask permission to enable the audio. Choose one of the permissions options to continue. You may need to click the play icon again to play the audio file.

3. The audio will begin to play in the embedded player.

The playback levels will depend on the volume settings on your computer. The embedded audio examples are intended to give you an idea of the types of sounds described in this paper and do not provide actual reference levels.

Dell Acoustical Design

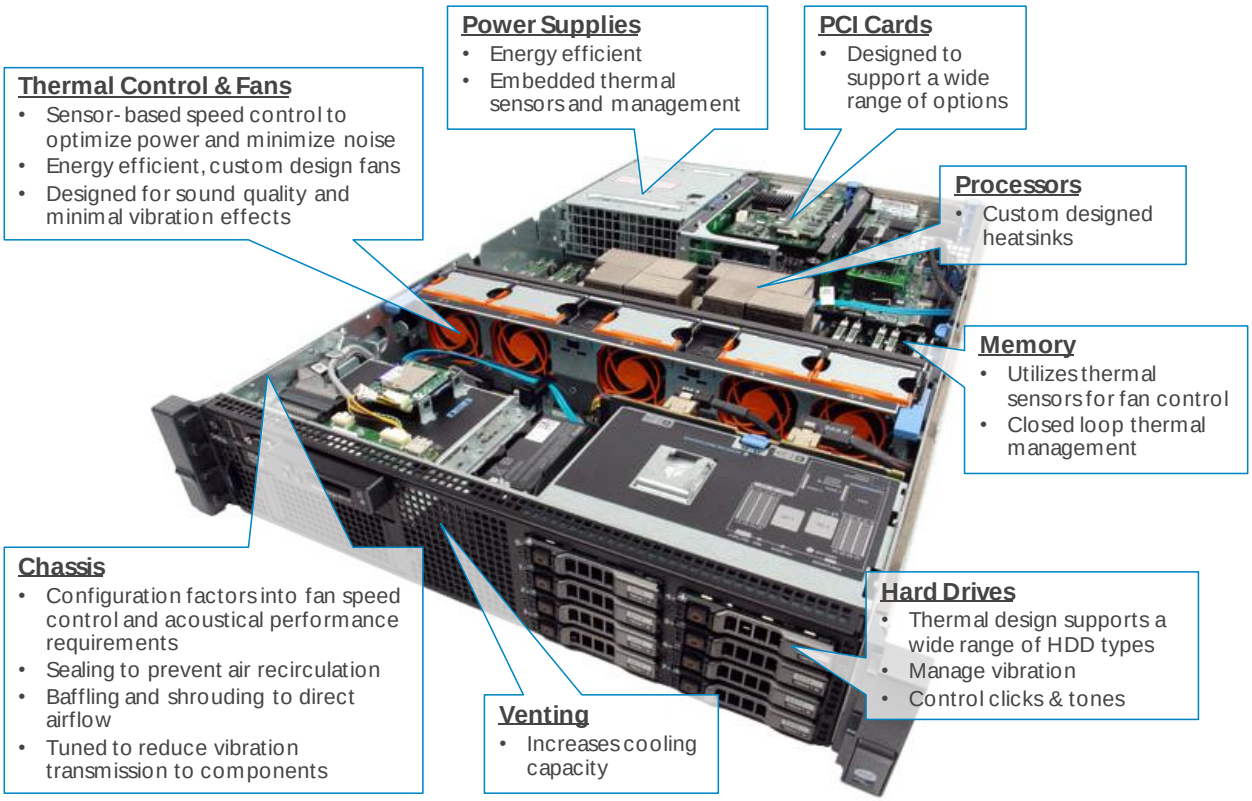
Dell acoustical design focuses on the noise that most affects you. The sources of these noises are varied, from fans to electrical components, from hard drives to shaking of panels, and others. Some of these are portrayed in Figure 1. Several teams cooperate in order to change, reduce, or remove the causes of noise.

Some functions critical to acoustical design reside in Thermal, Acoustical, and Structural Vibration Engineering. Thermal Engineering is the area dedicated to manage heat to ensure safe and reliable temperatures. Most of the components of a computer generate heat as a byproduct of their conversion of electrical power input to processing power, or, in the case of hard drives, also as mechanical power. The heat must be removed from the components in order to prevent thermally induced failures. Because devices like fans generally make noise in the process of moving heat from one area to another, efficient thermal management is vital to noise minimization (Lovicott n.d.) (Coxe n.d.). Acoustical and Structural Vibration Engineering is the area dedicated to understanding customer response to noise and managing noise and vibration to ensure reliable performance and positive customer experience. Some of the areas of concern include Sound Quality, vibration control to reduce fan impact on hard drives, and component requirements and selection to eliminate rattles, hums, and buzzes. Note that the term *noise* is used in this paper to refer to acoustical noise, as opposed to electrical noise.

The following are some of the ways that Dell approaches acoustical design.

- Dell acoustical performance requirements reflect studies of customer response to controlled applications of noise features. The requirements focus on Sound Quality, Sound Power, and transient behaviors, for a range of operating states and configurations.
- Dell engages with its parts suppliers and provides component requirements that correlate with performance required when the parts are installed in the server.
- Dell design teams work closely together to understand performance tradeoff and optimization areas. For example, acoustical engineers interface with thermal, industrial design, mechanical, power, reliability, and other teams to ensure that targets are achieved.
- Dell acoustical design begins early in product development, and strategy is applied consistently across the product portfolio.

Figure 1. Varied Server Components Contributing Directly and Indirectly to Noise



Expectations for Noise

People tend to expect certain noise behaviors. Some common examples are the expectation for the sound for acceleration of a sports car, the sound of a refrigerator when its compressor is working, the sound (and feel) when brakes are wearing thin on a car, etc. This also holds for expectations of noises from Enterprise products—we expect noises when the computer is booting and calibrating itself and we expect a change to accompany increase in computational intensity. However, we also expect these behaviors not to go on indefinitely.

Expectations tend also to depend on the environment where products are set up. Enterprise products are deployed in a wide variety of environments, and people's acoustical expectations vary in kind. Customers of Enterprise products appear to fall into three groups with regard to acoustics:

- Quiet: Those who put computers right next to them (on the desk or at their feet) tend to be sensitive to every tick and whirr. They are affected not only by noise but are generally discerning and vocal when they don't like the sound from the server.
- Performance: Those who put their servers in data centers or other rooms with which they interface only during servicing or only when aided with hearing protection devices tend not to care about what the servers sound like, so long as the servers are providing the desired computational and transactional performance they want.
- Out of Sight/Out of Mind: A third group consists of those who don't generally think about server noise until they must be near the noise and it interferes in some way with their activities or until they are asked about noise.

To understand more about how and in what circumstances Dell customers react to noise, Dell has conducted studies in which customer response has been documented while levels of different features have been varied. In the studies, the noise level of the environment, proximity to the product, operation, and other expectations for noise are documented and correlated with response. Thresholds for acceptable levels have been determined and incorporated into Dell performance requirements.

Considerations and Deployment When Acoustics is Important

Acoustics is one of many performance attributes that you may seek when you go to purchase a computer. You may consider it in concert with, or possibly as a trade-off against other performance areas, like processing, virtual and storage capabilities, as well as many other criteria. If noise is not important to you, then you may focus on other areas of importance besides acoustics.

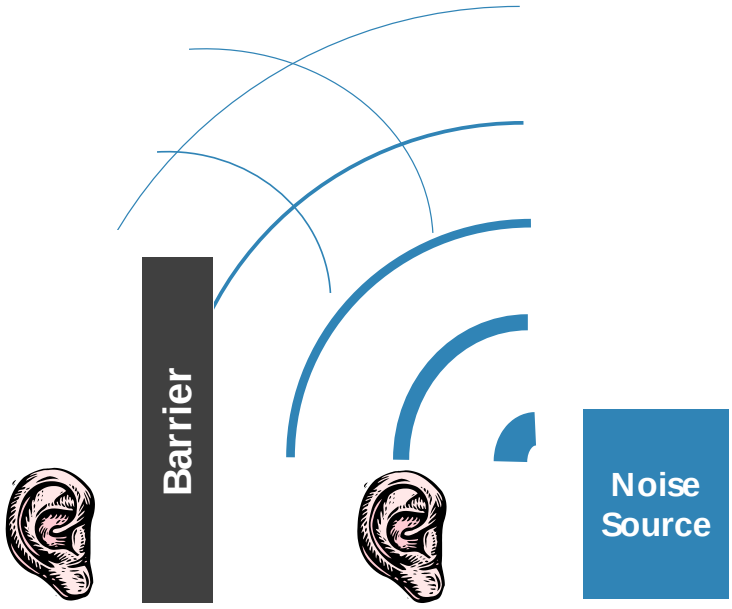
In the following section considerations are presented to help you make decisions to keep acoustical noise at a minimum. Later in this paper commonly used noise metrics and ways to interpret acoustical data to help you understand impacts of your decisions will be discussed.

- Higher-powered parts generally require additional cooling and hence run more loudly.
- Hard Disk Drives (HDDs):
    - The spindle speed (e.g., 7,200 rpm vs. 15,000 rpm) is a dominant factor in HDD noise. As spindle speed decreases, the noise also decreases.
    - If HDDs dominate the noise, then reducing the number of HDDs decreases noise levels. A reduction in HDDs by half will reduce the loudness perceived by approximately 30%.
- Redundancy:
    - Redundancy of components does not generally have an intuitive impact on noise.
    - Although increasing the number of noisemakers generally increases noise, often the additional parts provide some other capability.
    - In the case of fans, this additional capability may be lower fan speed and hence net lower noise.
    - When power supply units (PSU) share loads, each PSU has a lower load and requires less cooling, so fans can generally run slower and more quietly.
- Ambient temperature:
    - Most acoustical data are provided for products when they are operating in temperatures at 23+/-2 deg C per International Standards.
    - If your ambient is higher than this, then you may already have large air movers whose noise usurps that of the product you wish to deploy.
    - An increase in ambient temperature generally results in an increase in fan speeds and hence an increase in noise level.
- Location of the product:
    - You may have something that makes more noise than you like. It may be a server, an air-conditioner, a refrigerator, or a person. And though the following tips may seem obvious to some, they are stated here for completeness.
    - Moving the noise source further away (or moving yourself from the noise source) will generally decrease the noise level (see Figure 2). Cases in which this is not true include echoic rooms (reflective walls and few chairs, sofas, or carpets).
    - Placing an obstruction in the path of the noise will also decrease the noise. The obstruction generally needs to have some mass to it, for example, metal or wood. It also needs to be fairly expansive in order to block and diffuse as much of the noise as possible (see Figure 3). On the extreme end, think of noise barriers along a highway.

- Noise reduction is usually incremental. Outside of the tips above, this means that one must combine many different forms of noise treatment in order to make much difference. For example, a carpet or sofa will help to absorb sound but only to a small degree and generally only for higher frequencies. You need to add several such pieces of furniture in order to notice an appreciable difference.

Figure 2. Spreading in Progressive Sound Waves

Figure 3. The Barrier Effect on Progressive Sound Waves



How Are the Noises Made?

When you plug in and start up a computer, you begin a continuous series of events. For the focus of this paper, one of these events is the conversion of electrical energy into acoustical energy. In other words, noise is one of several byproducts of power utilization in a computer, along with heat, vibration, electromagnetic radiation, etc. Some sources of noise include the following:

- Fans
- Drives, such as Hard Disk Drives (HDDs), optical disk drives (ODDs), tape drives, etc.
- Electrical components, such as capacitors, transformers, etc.
- Human interaction, such as closing the front bezel

Figure 4. How Noise is Generated in a Server

Fans

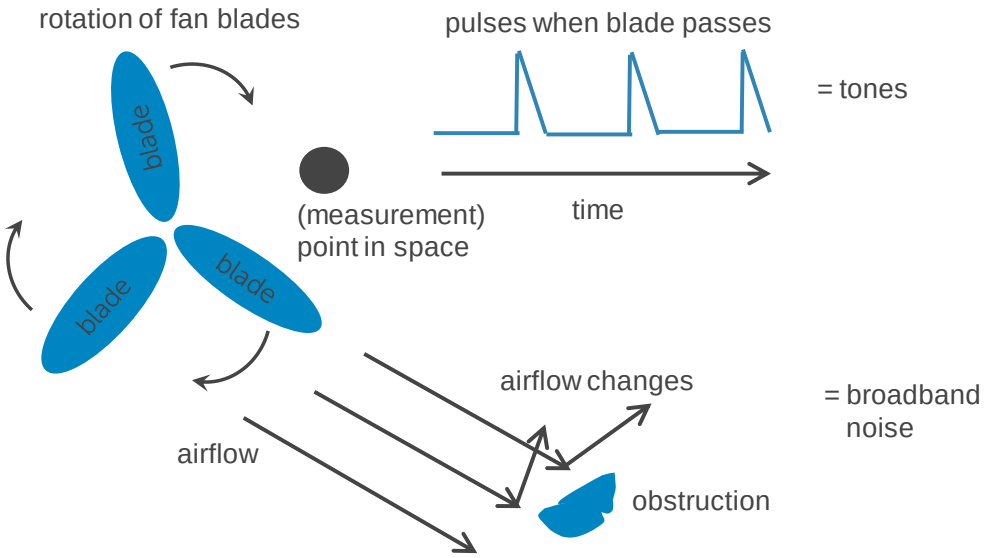
Fans are the main tools used in computers for cooling. Fans are also generally the dominant source of noise in a server.

The primary component of fan noise is airborne and is composed of pressure pulses as fan blades slice the air and push air molecules to induce air flow. The air molecules in the flow pick up and exhaust heat from various components such as the Central Processing Unit (CPU), memory and other electrical parts that heat up as they are used in the server. The whooshing noise you hear from a fan results from impact of airflow on obstructions in its path; it is described also as broadband or white noise. The whistles or sirens you hear from a fan generally result from the blades' passing a single point in space at a constant rate; they are described as tones and their level of distraction is often referred to as prominence. The second component of fan noise is the shaking of parts that are attached to the fan as

the fan vibrates (unbalance, pole-pass, etc.) in response to its rotational motion. Descriptions of this component of noise include hums and rattles.

Both components of fan noise take many forms that depend on how the fan is used to move the air, for example, rotational speed of the fan, number of blades, type of motor, obstructions in the air flow, method of mounting/attachment of the fan to the chassis, etc.

Figure 5. Two Mechanisms of Fan Airborne Noise



Drives

Drives generate noise through the motion of their internal components. For example, HDDs translate electrical power into rotation of platters and motions of other internal parts that are used to write data to or read data from the platters. The components of HDD noise are analogous to those of fan noise: the moving parts of the HDD generate pressure pulses in air and also cause shaking in anything connected to the HDD. The former generally evokes descriptions of constant white noise, some ticking and ringing; and the latter of a low-pitched hum or buzz.

Electrical Components

Capacitors, transformers, and other electrical components swell and contract in time with the applied alternating current. Although not generally visible to the naked eye, these fluctuations in mechanical size and structure cause tapping and popping sounds much as if you were tapping on them yourself.

Human Interaction

Other noises result simply through the interaction of a person with the server and are therefore generally transient, i.e., short-lived. Some examples include the sounds of latching a cover and sliding a server on rails.

Noise Perception

The mere fact that the word *noise* is used means that someone hears and responds to something. In Enterprise product acoustical design, the focus is on features that would distract you from your job. Noise can be characterized in many different ways, but to have meaning terms must be relevant to the amount of distraction you experience. In many cases, your auditory system perceives cues in sound, even if you cannot find words to describe them.

From a scientific standpoint, the following three elements are fundamental in characterization of noise:

- Magnitude
- Frequency content
- Changes with time

From a perceptual standpoint, the following elements are important in characterization:

- Listening location when you find the sound distracting
- Words that best describe the sound

Magnitude

Magnitude or amplitude describes the amount of sound. Scientists and engineers use a variety of metrics for sound and therefore may refer to different magnitudes for sound intensity, sound pressure, sound power, etc. In perceptual terms however, the term for magnitude which may be most familiar is volume (how loud or quiet something sounds). As discussed below, the human auditory system experiences sound logarithmically. This characteristic of hearing causes considerable confusion for many people when they try to relate acoustical metrics to perception.

Generally it is a combination of sounds that affect our perception of magnitude. For example, several distracting but quiet events can be drowned out with sufficient magnitude of a masking noise. However, high magnitudes can overwhelm or mask sounds that we desire to hear, causing distraction and stress, and at the extreme end, hearing damage. In most environments, magnitude of sound decreases as you walk away from the source of sound. This happens because the energy in the sound wave “spreads” over increasing surface areas as it propagates outward (See Figure 2 and “Considerations and Deployment When Acoustics is Important”).

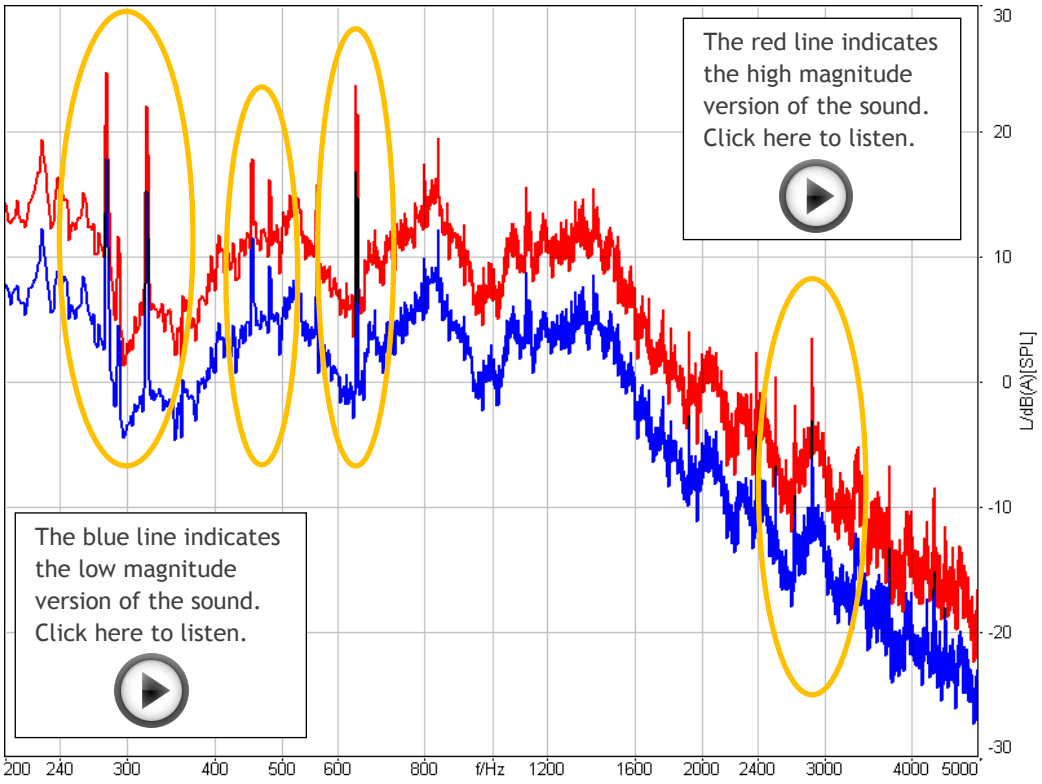
Frequency Content

Frequency is the number of cycles per second. In perceptual terms, frequency refers to the pitch of a sound, like bass or treble. Most sounds are a complex myriad of multiple frequencies of different magnitudes. For example, think of a chord played on a piano or guitar — several notes are played at once. Figure 6 provides a visual representation of frequency content and magnitude. In the figure, two sounds are portrayed with the same frequency content but different magnitudes using Fourier Transform representation, in which the x-axis represents frequency in Hz and the y-axis represents the A-weighted sound pressure level, here SPL(A), in dBA. Tones are indicated in orange ovals. HEAD Acoustics® GmbH ArtemiS-F v9 was used to generate the plot.

Although the human auditory system can hear sounds from 20 Hz up to 20,000 Hz, it responds to each frequency differently. Middle frequencies ~2,000-4,000 Hz stand out, and very low or very high frequencies must have high magnitudes to be heard. For example, if the blade-pass tone of a fan is ~2,400 Hz, it will be more distracting than if it were ~800 Hz and the same magnitude.

An interesting phenomenon known as beating can cause distraction. It occurs when two tones are close to each other but are not the same frequency. Your auditory system perceives the average of the two frequencies and senses it changing at a rate equal to the difference between the two frequencies. It is the perceived change with time that you find distracting.

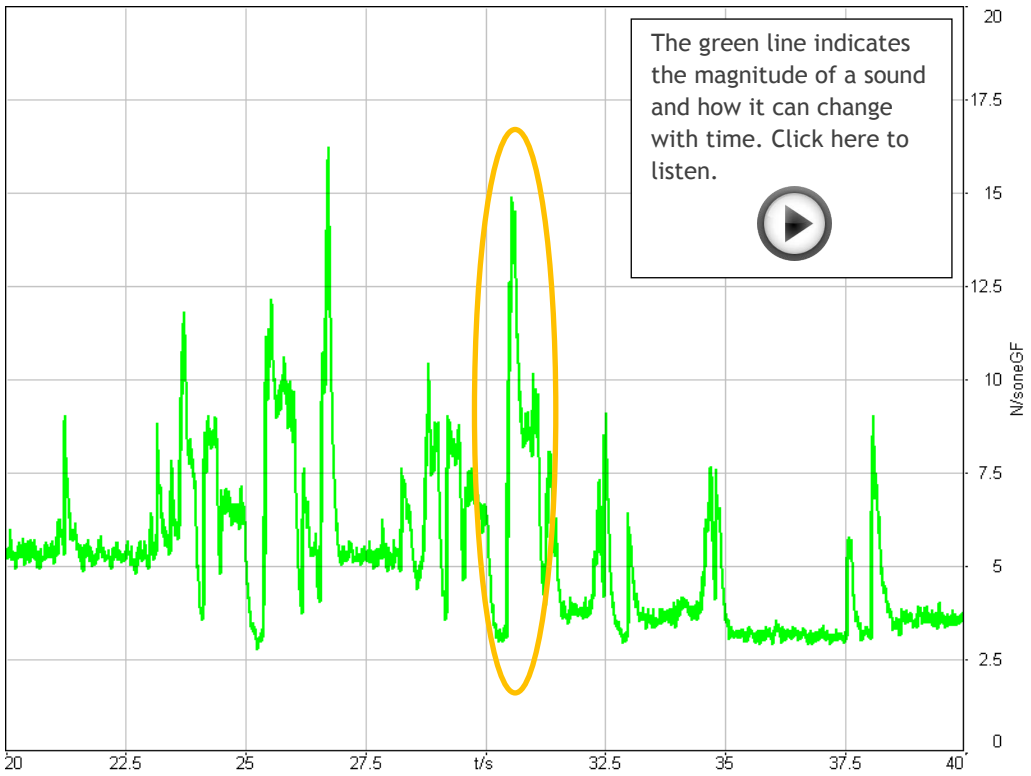
Figure 6. Two Sounds With the Same Frequency Content and Different Magnitudes



Changes with Time

People tend to notice events that change in relatively short time spans. These may represent transient events or continuous events, such as frequency modulation and amplitude modulation. Frequency modulation is what is used on sirens of many emergency vehicles. Note how the periodic change in frequency stands out to you the next time you hear a siren. Amplitude modulation sounds like a pulsing. The noise comes and goes, and you wish it would either just stay or go away. Figure 7 provides a visual representation of changes with time, in white the x-axis represents time in seconds and the y-axis represents loudness in sones. The orange oval indicates a sudden five-fold change from ~3 sones up to ~15 sones. HEAD Acoustics® GmbH ArtemiS-F v9 was used to generate the plot.

Figure 7. Changes in Sound With Time



Location When the Sound is Distracting

Noisemakers are in many different parts of a computer, so when you stand at the front of the computer you will hear something different than when you stand at the rear or to the side. Also, someone near the computer will experience it as louder than someone far away, because sound amplitude generally decreases with distance. If the level of sound of the computer where you stand is below that of the background noise and its frequency content has no radical anomalies, then you will not hear the sound. Finally, you may notice a noise only when you walk nearer to it when servicing or working with the system.

Descriptions of Distractions

In order for Dell to improve the acoustical experience, we must understand what distracts you. Often, people do not have terminology or measuring equipment to provide sufficient details, even if they have experienced the sound numerous times previously. It is therefore important that any and all vocabulary pertinent to sounds be tried when describing the sound. Some words helpful in this exercise might include those in Table 1.

Table 1. Sample Descriptors of Noise

beeping	boomy	buzzing	chirping	even	grinding
harmonious	hissing	humming	knocking	louder	melodious
modulating	pulsating	quieter	raspy	rattling	ringing
rushing	scraping	screeching	smooth	soft	squelching
tapping	ticking	tinny	whiny	whistling	windy

Noise may be characterized in many different ways. Magnitude, frequency, and changes in time are some of the objective measures. Location, masking effects, and a person's experience with a specific sound play important roles in the perception of the noise. Because perception is unique to each person, accurate portrayals and appropriate fixes require as clear descriptions as possible for correlation to the objective measurements.

Metrics Used in Descriptions of Product Noise

Sound can be described in many different ways. In Enterprise product acoustical design, the focus is on reducing the effect of features that would distract someone from his or her job. The purpose of noise metrics is to provide engineers with a way to objectively describe distraction from noise so that improvements may be quantified. This helps in the following ways:

- Comparison points to other products' sounds
- Prediction of customer preference with change in acoustics

International standards have evolved over the years to provide methods for measuring and reporting values for some of the metrics. However, many metrics that are useful in correlation to human response are either specialized to specific areas of industry or have not gained wide (international) consensus regarding the means to calculate their values. Some of the more widely used metrics are discussed below and include the following:

- A-Weighted Sound Pressure Level
- A-Weighted Sound Power Level
- Loudness
- Tones

A-Weighted Sound Pressure Level (dBA)

A-weighted Sound Pressure Level is probably the most recognized metric for acoustical noise. Based on studies of human response to sound dating back to the 1930s, A-weighted sound pressure level was developed as a metric to help reflect how the human auditory system integrates different frequencies in noise. It remains a mainstay of comparison of all sorts of noises, even though its range of validity is actually limited to low-magnitude sounds. The following concepts are critical to an understanding of this metric.

Sound Pressure Level (SPL and Lp are common abbreviations), without the modifier *A-weighted*, is a purely scientific metric that reflects the magnitude of sound as a ratio to a reference value at a point in space regardless of who is listening. It is a logarithmic calculation and is given by the formula Lp = 20*log10(p_rms/p_ref), with units of decibels (dB). Logarithms can seem complex for those unfamiliar with their use. They are used when the range of numbers is very large and result in a compressed interpretation of the range. Any standard calculus text will provide a review of logarithms. One common misconception about product noise involves the addition of noise sources. Addition of a

measurement of *x* dB and a measurement of *y* dB does not result in *x* + *y* dB! Moreover, when something sounds twice as loud, the sound pressure level is **not** twice as high; indeed it is approximately 10 dB higher.

Sound pressure level is location dependent (Figure 3), which means that a change in measurement location results in change in reading. The proper way to document Sound Pressure Level is with the reference value, for example, Lp = 56 dB, re: 20 microPascals, and the measurement location. When the reference value is given, then the intended metric and the value associated with the medium through which sound is propagating is unambiguous.

A-weighting refers to a way of processing the magnitudes of different frequencies in a sound in an effort to reflect the way the human auditory system responds to those different frequencies. For example, levels in low and high frequency bands are biased downward, since humans are not as sensitive to these frequency ranges. The biases were not arbitrarily determined; they are based on empirical studies of human response. Because of the applied weighting scheme, the *A-weighted* sound pressure level of a sound will usually be quite different from its non-weighted sound pressure level. A-weighted Sound Pressure Level (LpA) is also a logarithmic representation of sound magnitudes, but its units are A-weighted decibels (dBA).

The International Standard ISO7779 (ISO 7779, 3rd ed., *Acoustics - Measurement of airborne noise emitted by information technology and telecommunications equipment* 2010) describes measurement and reporting of A-weighted sound pressure level in depth, as it relates to product acoustical noise. Because A-weighted sound pressure level is location-dependent, its reading must be augmented with the location of measurement and should ideally also include the sound environment, location of the item under test, and operating state of the computer, in order for someone to make a meaningful comparison. For example:

Measured with a microphone at 120-cm from the floor and 50-cm from the front plane of the server sitting on the floor of a hemi-anechoic room, the idle A-weighted sound pressure level, LpA, is 43 dBA, re: 20 µPa.

A-weighted sound pressure level has limitations and is often misused as a metric. Sound level meters, which may be affordably purchased at many electronics stores, allow for quick measurements by just about anyone. Unfortunately, the considerations of location dependence, ambient environments, weighting schemes, and logarithmic functions do not necessarily accompany their use.

To further confuse matters, A-weighting is only one of several schemes to weight sound pressure level in an effort to reflect the way the human ear perceives magnitudes of sound. B-weighting and C-weighting as well as other weighting proposals are used but are less common in the sound field. They reflect behavior of the auditory system that flattens out sensitivity of sounds as the magnitude increases. That is, as things get louder, it matters less if the sound is low or high frequency.

A-Weighted Sound Power Level (bels)

Sound generally travels in many directions. In order to describe the total amount of sound from a noise source, one must take measurements at many locations around it (see Figure 8). Sound Power Level gives a measure of acoustic power radiating from a sound source by integrating sound pressure level measurements on the surface of an area that surrounds the sound source. It is often abbreviated as Lw and given in bels. A-weighted sound power level, however, refers to integration of A-weighted sound pressure levels around a noise source and is generally abbreviated as LwA. As with sound pressure

level, sound power level is calculated logarithmically. It should be noted that power and pressure are distinctly different properties and cannot generally be trivially translated between each other.

A benefit of the integration of and distinction to *sound pressure level*, in terms of reporting, is that sound power level is **not** location-dependent. This means that any two products' sound power levels may be contrasted without concern for the location of measurement devices. This benefit of ease of comparison of sound power level is at the same time a disadvantage for meaningful comparisons for a human listener who can feasibly only stand at one location, experience the sound only at that location, and hence has little use for the sound power level that relays sound at all locations. That is, the sound power level is the same regardless of whether the person is in front, at the side, or at the rear of the computer.

As with A-weighted sound pressure level, means for measurement and reporting of A-weighted sound power level are fully documented in the International Standard ISO7779 and others (ISO 7779, 3rd ed., *Acoustics - Measurement of airborne noise emitted by information technology and telecommunications equipment* 2010). When companies report the sound power level of a product, they generally report a value that is higher than the measured LwA. This is done to account for variation in product noise and to ensure that the level experienced by the user is lower than the reported value. The international standard ISO9296 (ISO 9296:1988 (E) *Acoustics - Declared noise emission values of computer and business equipment* 1988) specifies the calculation process to produce the upper limit value. LwAd is the upper limit value resulting when the measurement and calculation have taken place in an accredited lab in which the process specified in the ISO standard has been followed. LwAUL represents the upper-limit value resulting when the measurement and calculation have taken place in which an engineering-grade process has been followed.

Although usage of the term *bels* is generally unique to sound power level, proper form should include its reference value. In air, this is 1 picoWatt. An example of documentation for A-weighted sound power level might be the following: *The idle upper limit A-weighted sound power level of the server, LwAUL, is 5.4 bels, re: 1 pW.*

For completeness, it should be noted that measurement of sound power is not limited to the hemispherical array of microphones shown in Figure 8. Measurements in reverberation chambers and also in different array shapes and rooms are also valid. See, for example ISO 3744 (ISO 3744:2010 *Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane* 2010).

Figure 8. Sound Power Measurement of a Tower Server

Loudness (sones)

Loudness as a metric was proposed in the 1930s and describes how loud something is. Like A-weighting, it is based on responses of humans to different magnitudes and frequencies of sound (ISO 532:1975 *Acoustics - Method for calculating loudness level* 1975). In contrast to A-weighted sound pressure level, however, loudness is a linear measure. That is, when something sounds twice as loud, the value of the loudness metric is also twice as high.

Two benefits of loudness as a metric are that it is easy to understand and that it requires no reference value (for example, 20 µPa for sound pressure level). But, as with A-weighted sound pressure level, loudness is location-dependent. Proper usage of loudness as a metric requires that the product designer know where the person is situated relative to the product. An example of a loudness description might be the following: *Measured with a microphone at 120-cm from the floor and 50-cm from the front plane of the server sitting on the floor of a hemi-anechoic room, the loudness is 1.4 sones.*

Tones

Tones are the whistles, hums, and, in general, specific frequencies or groups of frequencies that stand out from the general noise (See Figure 5 and Figure 6). An example of an intentionally annoying tone is the whistle of a tea pot. When the water boils and steam builds up, it exerts force on the small hole in the spout and creates the desired alarm that the water is hot and ready to pour. But in products like computers, a whistle like this is rarely desired. Just like the tea pot whistle sends us an alarm, a whistle from a computer sends us an alarm. Some familiar sources of tones are shown in Figure 9.

Figure 9. Familiar Sources of Tones

The magnitude of the whistle can be scientifically measured as the amount of energy in specific frequency bands relative to the energy in surrounding frequency bands, but several theories exist in literature to try to account for the amount of energy that is necessary to cause a listener an annoyance. Clearly the energy in the frequency of the whistle of a tea pot is sufficient to cause alarm, but as the tone becomes less intense, the extent of alarm also decreases until a certain threshold at which you don't notice the tone unless you try to listen to it. Various tone magnitudes are portrayed in Figure 6.

Click here to listen to an example of a prominent tone from a fan:

Two theories are presented in the international standard ECMA-74 (ECMA-74, 11th ed., *Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment* 2010). Dell uses the prominence ratio method to determine the presence and extent of annoyance of a tone and to limit the tone to an acceptable level during acoustical design.

Other Sound Quality metrics

Sound Quality refers generally to the absence of distraction and to the sense that a product is doing its job correctly because the sound is the "expected" sound. A wide variety of different sound quality metrics exist in industry and many are specific to certain fields of industry. For example, the automobile industry may be sensitive to sound quality features that accompany wind noise. Some better known sound quality metrics include modulation, tonality, rattles, squeaks, oscillations, sharpness, roughness, etc. The studies referenced earlier have included sound quality metrics and valuation, in determining to what Dell customers respond to acoustically, and respective thresholds.

Limitations in Using Metrics to Describe Noise

Metrics are vital in objective assessment of sound, but they must be used carefully. Each metric individually inherently only describes one dimension of the sound. That is to say, the metrics are not of equal importance in all cases of design for customer satisfaction to noise. For some applications, specific frequency content may be most important; in others, the change with time is critical. In others, some combination of the metrics may be considered together. It is important that the acoustical designer understands the relevant metrics and the appropriate thresholds for the customers. And, as with most things, competing theories and methods exist for similar features of sound.

An unfortunately ubiquitous example of misuse of a metric in the product noise world is the reference to all noise as *decibels* and the equivalent misuse of the unit *dBA*.

- The "decibel" is a unit that refers to a variety of metrics and is not limited to acoustical noise. For example, a decibel can represent the ratio of measured voltage to reference voltage.
- Several different acoustical variables use "decibels" as their units, including sound pressure level, sound power level, intensity level, prominence ratio, etc. Without more information, the usage of "decibel" could refer to any of these.
- When used in reference to sound pressure level, "decibel" is misleading without further information, because, as is described previously, sound pressure level depends on a specific measurement location. For example, if I take a measurement at 1m from a server I will get a different (generally higher) reading than if I take the measurement at 3m.
- Use of these terms implies a logarithmic function and means that the values cannot be simply added, subtracted, etc.
- Regardless of which specific metric the "decibel" is being used to refer, that metric only represents one way to describe the sound.

Interpretation of Numbers Used to Describe Product Noise

From the previous sections, you can see that there are many different ways to describe noise. One of the reasons for using metrics is to allow you to get an idea of the sound and make quantitative tradeoffs to other performance areas before you actually hear the sound itself. In order to use the metrics, you must have a sense of what the values for them mean. How loud is too loud? At what prominence ratio is a tone distracting? Although the answers to these questions are specific to your environment and usage conditions, the following sections provide some insight.

Configurations and Operating Conditions

The noise from a server depends on the noise of the things inside it and also upon what is being done with the things inside it. Reports for values on noise are essentially meaningless if the configuration (parts inside the server) and operating conditions (what is being done) are not provided.

Noisemakers were discussed earlier in this paper. As the number of noisemakers goes up, one can generally expect the noise levels to increase. A-weighted sound pressure level, A-weighted sound power level, and loudness follow some general rules of thumb, but sound quality is not generally intuitive. For example, if fan noise dominates a server, then doubling the number of fans will generally increase A-weighted sound power level ~0.3 bel, and, depending on where you are listening, increase A-weighted sound pressure level ~3 dBA and loudness ~30%. The additional fans may also result in an amplified tone at blade-pass or may beat.

Not all noisemakers are created equally. For example, a certain fan may output very little high frequency energy and another fan may output significant high frequency energy. When they are put in the same product together, they may help to mask each other's acoustical deficits or they may enhance each other's problems. As another example, as discussed, HDD speed is a key variable in vibration and acoustical output, so when a higher-speed HDD is put in the same chassis as a lower-speed HDD, the higher-speed HDD will generally dominate the noise. Different technologies involved in HDDs or fans will result in different noise signatures.

When a server utilizes its CPUs (or memory, etc.), electrical power is converted into signals and logic with a byproduct of heat, and as we discussed before, the heat must be removed. The same generally occurs when the ambient (i.e., surrounding) temperature increases. Fans respond to the request to remove heat by spinning faster and moving more air. The fan noise therefore increases when these

parts are being utilized. When HDDs are activated, their heads begin to move back and forth to read and write; the HDD noise therefore increases when HDDs are utilized. Moreover, between the steady states of idle and active, transient noise occurs. For example, as the fan spins up, it may pass through fan speeds that generate tones (because of structural resonance), or when an HDD activates, a motor may spin up that temporarily introduces clicking as it engages components.

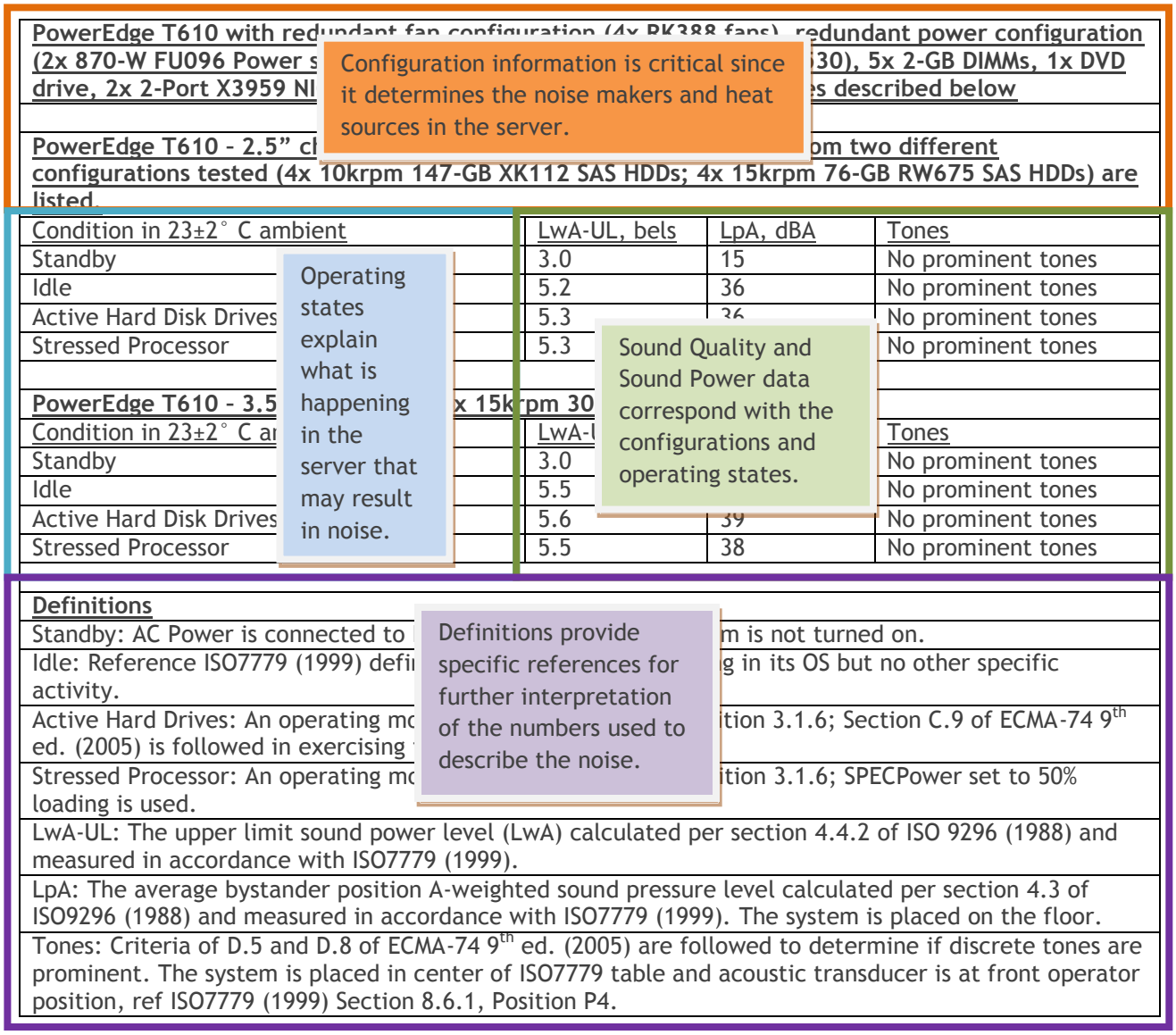
Many other examples could be given with the point that acoustical noise is strongly dependent on configuration and operating conditions of the server. These configurations and operating conditions must be carefully documented in order for the reported acoustical data to have relevance to the person reviewing the data.

Is a lower value always better? No. Acoustics is one of many performance areas of a server. Although fans can be run at their lowest speeds (hence lowest noise levels when fans dominate the noise source) for some configurations and operating states, a variety of operating states must be considered in combination with the electrical power, heat management, and noise involved with transients among states. Moreover, sound quality issues may be masked when magnitudes of certain sounds are higher. This is the idea when you turn on a noise generator in your bedroom before you go to bed—it drowns out the various noises in your house as you sleep.

How to Interpret Acoustical Data

Noise can be described with a variety of metrics—not one of which singularly suffices. Noise also depends on configuration and operating conditions. These data must be represented for the description of the sound to mean anything to the acoustical designer, marketing, and the customer. Figure 10 gives an sample presentation of these data.

Figure 10. Sample Acoustical Report For a Dell Server



PowerEdge T610 with redundant fan configuration (4x PK388 fans), redundant power configuration (2x 870-W FU096 Power s…30), 5x 2-GB DIMMs, 1x DVD drive, 2x 2-Port X3959 NI… described below

PowerEdge T610 – 2.5" ch…om two different configurations tested (4x 10krpm 147-GB XK112 SAS HDDs; 4x 15krpm 76-GB RW675 SAS HDDs) are listed.

Condition in 23±2° C ambient	LwA-UL, bels	LpA, dBA	Tones
Standby	3.0	15	No prominent tones
Idle	5.2	36	No prominent tones
Active Hard Disk Drives	5.3	36	No prominent tones
Stressed Processor	5.3		No prominent tones

PowerEdge T610 – 3.5…x 15krpm 30…

Condition in 23±2° C a…	LwA-…		Tones
Standby	3.0		No prominent tones
Idle	5.5		No prominent tones
Active Hard Disk Drives	5.6	39	No prominent tones
Stressed Processor	5.5	38	No prominent tones

Definitions

Standby: AC Power is connected to …m is not turned on.

Idle: Reference ISO7779 (1999) defi…g in its OS but no other specific activity.

Active Hard Drives: An operating mo…ition 3.1.6; Section C.9 of ECMA-74 9th ed. (2005) is followed in exercising …

Stressed Processor: An operating mo…ition 3.1.6; SPECPower set to 50% loading is used.

LwA-UL: The upper limit sound power level (LwA) calculated per section 4.4.2 of ISO 9296 (1988) and measured in accordance with ISO7779 (1999).

LpA: The average bystander position A-weighted sound pressure level calculated per section 4.3 of ISO9296 (1988) and measured in accordance with ISO7779 (1999). The system is placed on the floor.

Tones: Criteria of D.5 and D.8 of ECMA-74 9th ed. (2005) are followed to determine if discrete tones are prominent. The system is placed in center of ISO7779 table and acoustic transducer is at front operator position, ref ISO7779 (1999) Section 8.6.1, Position P4.

As mentioned in the previous section, a lower value for an acoustical metric is not necessarily better, and moreover, it may not even be relevant. A recording studio might have an ambient noise level LpA of 20 dBA, re: 20 µPa; very quiet office areas might get to an ambient noise level LpA of 30 dBA, re: 20 µPa; but many office environments hover around an ambient level LpA of 40-50 dBA, re: 20 µPa. If the device you wish to put in one of these spaces has a measured LpA at some relevant measurement position that is substantially lower (6 dBA or more) than the ambient LpA (and if the device has no prominent sound quality issues and no intermittent noises), then you are not likely to hear it. There is even less of a need to achieve a noise level this low if the LpA at the relevant measurement position is even lower than that, relative to the ambient LpA.

In Table 2, various product noise scenarios are provided with some simple descriptions of how you might perceive the noise described. The descriptions include values for the metrics that have been

discussed in this paper so that you can gain some context for what the values mean. Prominent tones or other sound quality issues will alter the interpretations of this data. A-weighted sound pressure level (LpA, dBA), declared A-weighted sound power level (LwAd, bels), and loudness (sones) are given in the table for simplicity.

Table 2. Real-World Interpretations of Acoustical Values

Value measured at your ears		Equivalent noise experience[1]	Masked noise, LwAd, bels, re 1 pW[2]
LpA, dBA, re 20 µPa	Loudness (sones)		
~20	~0	Recording studio	~2.5
~35	~2	Quiet office	~4.5
~45	~4	Whispering	~5.5
~60	~10	Conversation levels	~7.0
~75	~30	Data center, vacuum cleaner (must elevate voice to be heard)	~8.5
~90	~80	Loud concert	At this point, either there are several very loud noise sources or one very large one.

[1] Without any prominent tones, other sound quality issues, or intermittent noises

[2] The noise described in the leftmost column would likely mask, or overwhelm, the noise with a sound power level in the rightmost column. This is measured when standing 1m from the noise source in the rightmost column and without prominent tones or other sound quality issues present.

Summary

Noise in the workplace is a concern that may influence your product choices. Expectations for noise vary between different user groups and depend on the environment and intent for use. Fans and HDDs are the primary sources of noise in servers. They generate hums, rattles, whistles, and broadband, static-like noise.

Some of the metrics used to provide objective descriptions have been discussed. It can be helpful for you to become familiar with the benefits and disadvantages of the metrics as well as the configuration and operating conditions in order to have a meaningful dialog on issues and what can be done to improve noisy situations. Not one single metric suffices to describe a noise—values for several metrics are usually necessary. Tones, modulation, and sharpness are some sound quality metrics that are important complements to magnitude metrics such as loudness, A-weighted sound pressure level, and A-weighted sound power level.

Acoustics is a part of the solution that Dell delivers to its customers. Dell prioritizes acoustical design of products for customers in office and general (non-data-center) spaces and works closely across teams for optimization of meeting teams' targets. Configurations and operating conditions are key variables in noise, and Dell is listening to customer concerns to provide and communicate configuration options for reduced noise.

Works Cited

Coxe, KC. "Thermal Design of the the Dell (TM) PowerEdge (TM) M-Series." n.d. http://www.dell.com/downloads/global/products/pedge/en/pedge_mseries_thermal_design.pdf (accessed January 2011).

ECMA-74, 11th ed., Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment. Geneva: ECMA International, 2010.

ISO 3744:2010 Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane. Geneva: International Organization for Standardization, 2010.

ISO 532:1975 Acoustics - Method for calculating loudness level. Geneva: International Organization for Standardization, 1975.

ISO 7779, 3rd ed., Acoustics - Measurement of airborne noise emitted by information technology and telecommunications equipment. Geneva: International Organization for Standardization, 2010.

ISO 9296:1988 (E) Acoustics - Declared noise emission values of computer and business equipment. Geneva: International Organization for Standardization, 1988.

Lovicott, Dominick. "Thermal Design of the Dell (TM) Power Edge (TM) T610 (TM), R610 (TM), and R710 (TM) Servers." n.d. http://www.dell.com/downloads/global/products/pedge/en/server-poweredge-11g-thermal-design-en.pdf (accessed January 2011).