Balanced Technology Extended (BTX) Entertainment PC Case Study

Version 1.0

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Version 1.0, 2 February 2005

Revision History

Version	**Description**	**Date**
1.0	Public Release	February 2, 2005

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1. Introduction

Several BTX Entertainment PC system profiles have been designed and analyzed to determine BTX applicability to this relatively new digital home system profile. Each of the different system profiles was designed to be stacked with other standard Audio-Video (A/V) equipment and optimized to meet stringent acoustic targets. The first Entertainment PC system profile illustrated was also prototyped and its performance measured to correlate the thermal and acoustic predictive models. All system profiles are based on a microBTX board, are fully compliant with the *BTX Interface Specification*, and use standard components except where noted.

Figure 1: Balanced Technology Extended Entertainment PC

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2. System Design Overview

The mechanical and thermal design of an Entertainment PC system will influence the appearance and ability to integrate desirable Entertainment PC characteristics, including but not limited to:

- Consumer Electronics aspect ratio (system thickness vs. width)
- System width compliant with standard Audio / Video equipment
- Attractive front panel design
- Easy access to optical storage media player
- Easy access to diverse Audio / Video connections for portable equipment connection
- Quiet operation
- System airflow and power delivery that allows all components to operate within their temperature specifications

Intel has elected to use the *BTX Interface Specification* to demonstrate that such a product can be designed with interchangeable industry standard components. Standards-based system design and integration is critical to cost and availability, but it is important to also demonstrate that there is sufficient latitude for product differentiation.

Many Entertainment PC system designs are possible; however, the content in this case study illustrates systems with similar component placement characteristics. Of particular interest, all the systems illustrated share the following size and placement attributes (directions are provided from a front-of-the-system vantage point):

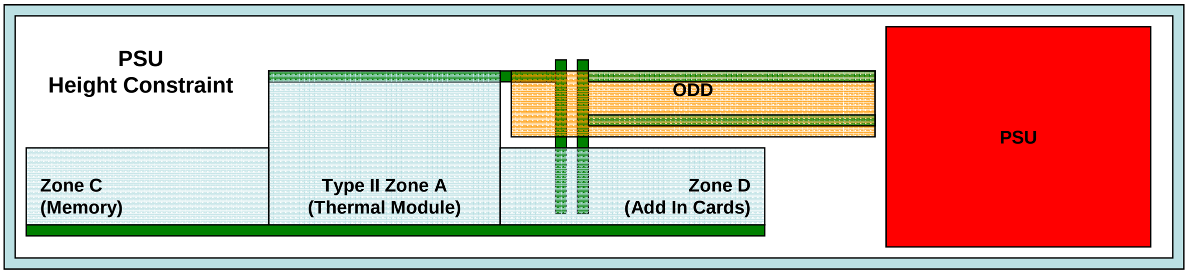
- The system is 432 mm (17”) wide and up to 394 mm (15 ½”) deep – designed to be stacked with other standard A/V equipment.
- The system power supply is located to the right of the motherboard.
- The motherboard is left-justified against the left side of the sheet metal case.
- Two Hard Disc Drive (HDD) units are included and are placed to the right of the motherboard.
- The Optical Disc Drive (ODD) is placed to the immediate right of the Thermal Module Assembly (TMA).

2.1 System Thickness

The minimum system thickness of an Entertainment PC is influenced by the feature loading, industrial design, and acoustic performance targets.

The type and quantity of features in an Entertainment PC will dictate the total power required from the power supply. The cost of a power supply typically increases as the total power increases, but each power supply form factor has a power limit beyond which it becomes cost prohibitive. Generally, smaller power supplies have lower total power capability. A system designer may find that the minimum thickness is limited by the physical size of the power supply, as illustrated in Figure 2.

Figure 2: PSU Limited System Thickness



Front panel symmetry can be an industrial design requirement that limits the minimum system thickness. A centered Optical Disc Drive (ODD) installed in a system whose width is constrained by standard A/V equipment width of 432 mm (17”) will need to fit above the thermal module, which will increase the system thickness
(Figure 3. In this illustration, a Slim or Mobile ODD in place of a Standard ODD would minimize the system thickness. Compare Figure 3 with a centered ODD to Figure 4 with an ODD slightly off-center.

Figure 3: Centered ODD (not to scale)

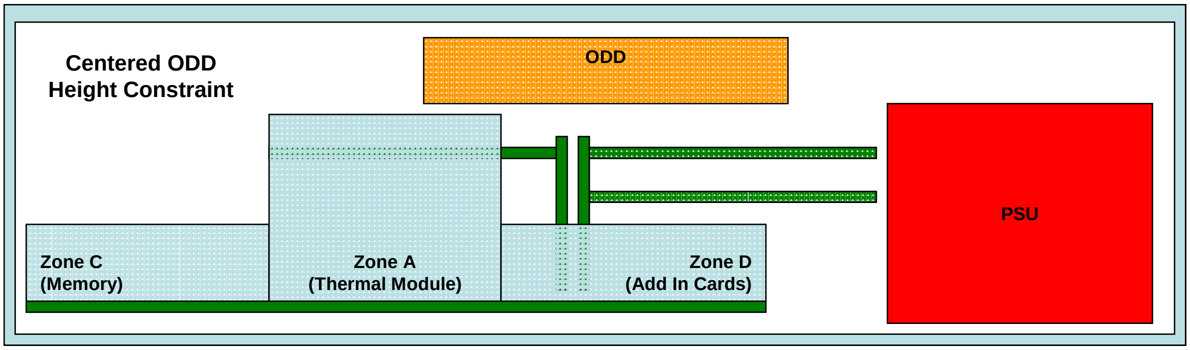
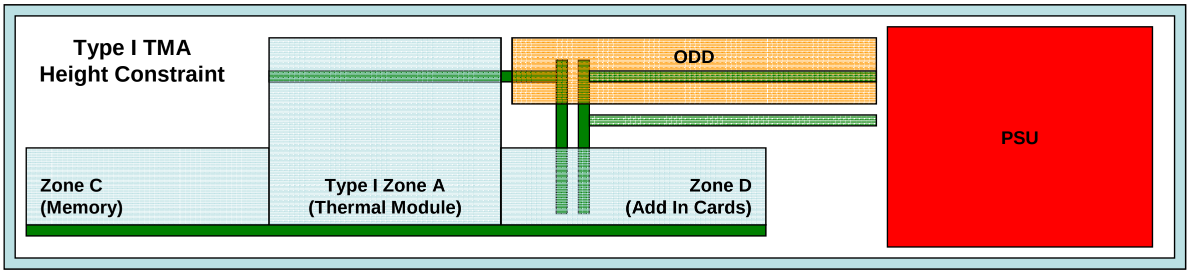
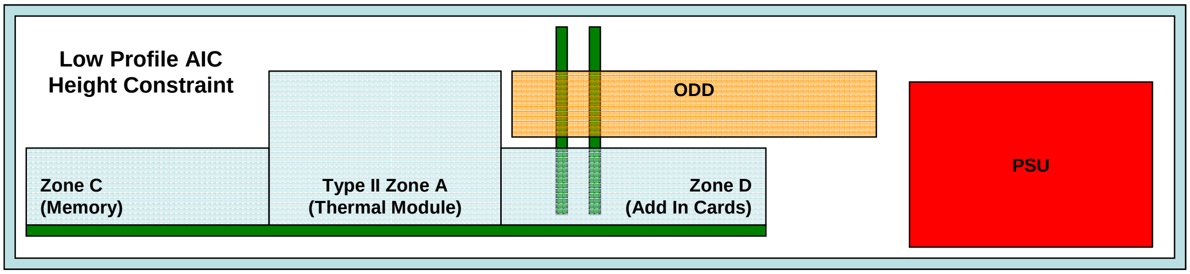


Figure 4: Off-Center ODD (not to scale)



The add-in card profile can influence the system thickness. Low profile add-in cards will increase the system thickness in systems with a Type II TMA and an LFX12V PSU installed (Figure 5). Given the generous 432 mm (17”) width of an Entertainment PC, most of the fit-up illustrations showcase full height add-in cards on a riser. System designers will typically find a broader array of add-in card products available in the full height vs. low profile form factor.

Figure 5: Low Profile Add-In Card (not to scale)



Finally, the acoustic target can also influence the system thickness. Generally, larger fans can spin at lower speed than smaller fans for the same heat dissipation requirement, and lower rpm allows better acoustic performance. A Type I TMA with a 90-mm fan will typically generate less noise than a Type II TMA with a 70-mm fan, but will require greater system thickness (Figure 4).

2.2 Industrial Design

The industrial design of an Entertainment PC will likely more closely resemble that of a consumer electronics device than a typical Personal Computer. A sleek profile requires attention to the factors that significantly change the aspect ratio, but it is also important that the front panel design be attractive and elegant. The following illustrations clearly demonstrate that this important characteristic can be satisfied with a BTX standards-based system.

Figure 6: BTX Entertainment PC Industrial Design

Many BTX desktop PC systems have ventilation on the front face and sides of the front bezel to minimize the inlet airflow impedance to the Thermal Module. Fortunately, the aspect ratio of an Entertainment PC introduces options for ventilation that allow a continuous front bezel unencumbered by ventilation openings. Careful inspection of the illustrations in Figure 6 shows that front bezel ventilation is not required. Refer to Section 2.5.1 for a description of inlet ventilation design recommendations.

2.3 Acoustic Performance Factors

The acoustic performance of any Personal Computer system is most influenced by the amount of noise generated by the installed components. Noise is generated by moving components – e.g., rotating fan blades and bearings or spindles are typical contributors to PC noise.

A general model of system noise based on the noise from its constituents is provided in . Therefore, the system noise can be predicted if the individual component noise sources are available from vendor specifications or previous testing.

Equation 1: System Sound Power From Constituent Sound Power

$$\text{System Sound Power (BA)} = \log_{10}(10^{\text{source 1 BA}} + 10^{\text{source 2 BA}} + \ldots + 10^{\text{source n BA}})$$

As applied to an RAID compliant BTX Entertainment PC with two HDD units, the system noise could be represented as:

Equation 2: RAID Compliant BTX Entertainment PC Sound Power From Constituent Power

$$\text{Entertainment PC (BA)} = \log_{10}(10^{\text{HDD 1 BA}} + 10^{\text{HDD 2 BA}} + 10^{\text{TMA BA}} + 10^{\text{PSU BA}})$$

In an Idle use condition (e.g., Windows Media Center Edition idle), the HDD units are in Idle not Active mode and both the Thermal Module Assembly (TMA) and Power Supply Unit (PSU) fans will be at their minimum operating speed. The Entertainment PC system noise could be forecast based on the HDD Idle sound power and the minimum noise of the TMA and PSU fans.

Equation 3: Idle Entertainment PC Sound Power Model

$$\text{Entertainment PC (BA)} = \log_{10}(10^{\text{HDD Idle BA}} + 10^{\text{HDD Idle BA}} + 10^{\text{TMA Min RPM BA}} + 10^{\text{PSU Min RPM BA}})$$

2.4 Disc Drive Contribution

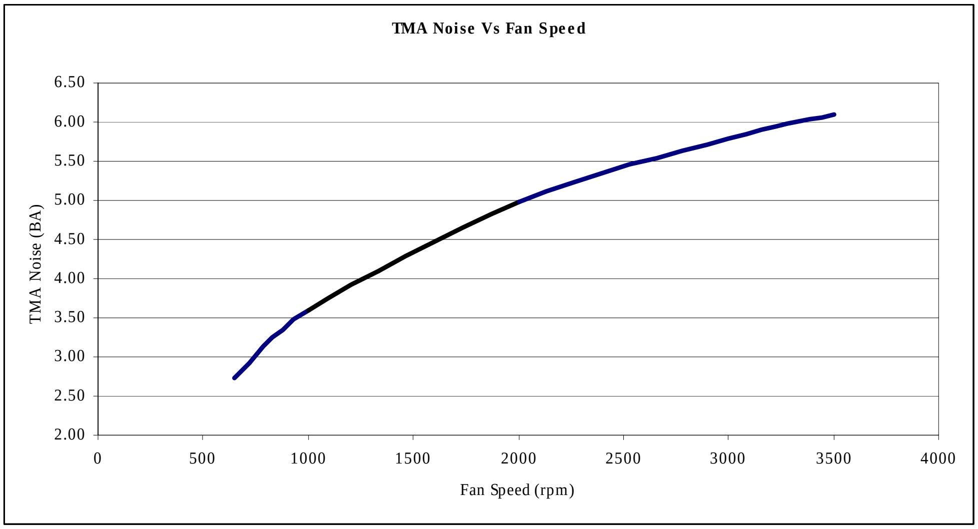
Rotating storage media (Hard Disc and Optical Disc Drives) bearings or spindles will generate noise that can be transmitted through the system structure, in addition to being transmitted through the air. Bearing or spindle noise is typically reduced through the selection of bearing technology – fluid bearings generate the least noise and are broadly available. Quiet high performance drives are offered by most HDD vendors.

Structural transmission can actually amplify the HDD noise through structural resonance. If the disc drive is rigidly mounted to a very rigid structure, structural resonance will be minimized; however, this is not always possible in a system design because large spans of sheet metal casing are not very stiff. Damping materials placed between the drive and its holding bracket are often effective in reducing the transmission and amplification of drive noise.

2.5 Fan Contribution

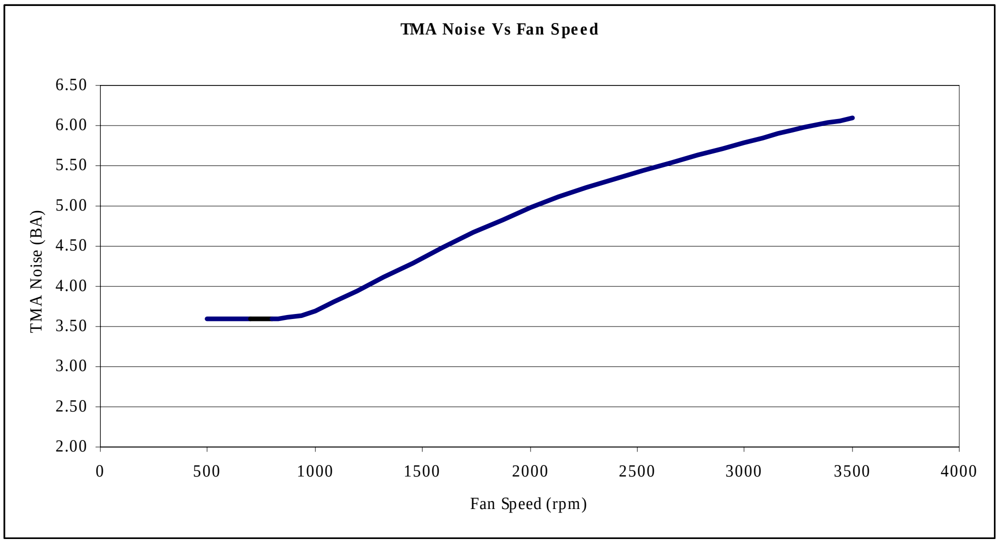
Fan blades generate airborne noise whose source is related to either separation or blade pass. Separation occurs when the airflow that passes over a fan blade leaves the blade surface or when the airflow stream itself separates through shear. In each case the transition from laminar to turbulent flow generates noise, which is then transmitted by airborne vibrations. Blade Pass occurs as a rotating blade of a fan passes by a strut at the fan’s inlet or exit (struts are used to hold the fan motor in place and span the distance from the motor to the outer fan housing). The high pressure at the narrow blade-strut interface creates separation and turbulence that create noise. The amount of noise generated is typically proportional to the fan’s rotational speed (Figure 7). It is, therefore, important to engineer opportunities to reduce fan speeds when designing an Entertainment PC.

Figure 7: TMA Noise vs. Fan Speed



Fans also have other potential sources of noise. The motor assembly includes bearings that may generate noise. The electrical circuit that controls the fan speed may also generate noise. Pulse Width Modulation (PWM) provides the current to the motor windings at a fixed frequency. This control scheme allows significantly lower minimum speeds than fans that are regulated by lowering the motor supply voltage. Most PWM fans will use a control frequency that is well out of human hearing range to eliminate the control frequency as a potential detectable noise source. However, at a low PWM duty cycle (the duration of the current pulse to the windings) corresponding to a low fan speed, the large electrical current pulse that is imparted through the motor windings to the impeller magnets can create a cogging noise. Figure 8 illustrates how fan noise might be dominated by this noise source at low fan speeds.

Figure 8: Cogging Current Noise at Low Fan Speeds



2.5.1 System Design – Impact on Fan Speed

BTX is a system architecture that is exceptionally well-suited for fan speed reduction. As noted in the *BTX System Design Guide*, BTX systems lower fan speed through a substantial reduction in air temperature and airflow impedance.

As noted in Section 2.2, an elegant front panel is an important design characteristic for an Entertainment PC. A front bezel unencumbered by ventilation openings is an important design characteristic that is enabled by appropriate side, bottom, and top panel ventilation near the Thermal Module inlet. The case studies illustrate ventilation options that do not compromise the front bezel industrial design and minimize inlet impedance that would otherwise impact the Thermal Module fan speed and system acoustic performance.

The temperate and heat dissipation requirements of internal components are an important factor in component placement. Higher power components should be placed in the primary airflow stream generated by the Thermal Module. For instance, high performance PCI Express† x16 add-in cards (e.g. a DVI card) should be placed immediately behind the Thermal Module so that a passive heatsink can be used. If a high power card is placed in a lower velocity or higher temperature return airflow stream, it may require an active heatsink whose fan would contribute adversely to the system noise.

Appropriate side, top, or bottom panel ventilation will improve air temperature in most regions. This may be especially important for low power add-in cards, ODD, and HDD units. Poor ventilation will create stagnant flow in certain areas and increase the air temperature. Achieving temperature compliance in a poorly ventilated design would require an undesirable increase in fan speed.

Power supply orientation and placement will impact the system airflow. A power supply can pull air from within the system (as illustrated in the case studies) or from external ambient. If the power supply pulls air from within the system, the impact to the system airflow should be favorably engineered. For instance, a power supply that that prevents sufficient airflow to low power add-in cards or drive bays will impact the system performance in the same way as poor ventilation noted above. A power supply that pulls in lower temperature air from external ambient may allow a substantial reduction in the power supply fan speed. This configuration may, however, have an adverse impact on other component temperatures which might, in turn, require an increase in the Thermal Module fan speed. Evaluations of this configuration will be evaluated and the case study results will be included in future revisions of this document.

2.5.2 Thermal Module Assembly Design – Impact on Fan Speed

The performance of thermal solutions can also have an impact on the noise generated by a system. The more effective any particular heatsink design is conducting and convecting heat, the less airflow is required for any given power dissipation requirement. Selecting more conductive heatsink material, minimizing interface contact losses, and analyzing the trade-offs between heatsink surface area and airflow will reduce the airflow that the fan must generate, which will reduce the required fan speed.

2.5.3 Power Supply Design – Impact on Fan Speed

An efficient power supply will typically generate less heat, thus reducing the airflow required to dissipate that heat. Concurrent thermal and electrical engineering can reduce power supply airflow impedance and ensure that critical components are placed in the airflow stream. Selection of a power supply engineered for efficiency, impedance, and effective heat transfer will allow lower fan speed.

Most power supply fans are, unfortunately, voltage regulated. As noted in Section 2.4, a PWM fan has a greater speed range. Appropriate power supply thermal engineering may allow very low fan speeds in many use conditions, so it is appropriate for power supply vendors and system integrators to consider the additional expense of a PWM fan.

The orientation and placement of the power supply in the system was discussed in Section 2.5.1.

3. Use Condition Definitions

Intel suggests that there are specific use conditions in which the performance of an Entertainment PC are particularly important.

Most computer manufacturers publish acoustic performance values for products in an Idle Operating State. In this state, the system's operating system is in Idle mode, as are the HDD unit(s), and the system is in a temperature controlled room (e.g. an air-conditioned room). PC systems with Fan Speed Control are typically designed so that all their fans are operating at their lowest speed in this state.

An Entertainment PC should also be reasonably quiet during most entertainment use conditions. Simultaneous execution of several digital content applications would be one such likely use condition. An Entertainment PC stacked with other A/V equipment may also be subject to an ambient temperature higher than the rest of the room in which it's installed.

The Maximum use condition is one that is unlikely but it is important to ensure that the system design is capable of maintaining safe and reliable component operating temperatures when all components are at their maximum design power and the system is in a hot climate without temperature control.

Table 1 shows the external system ambient and application load for these three use conditions.

Table 1: Use Condition Descriptions

Use Condition	Description	Target /Requirement
Idle (23 °C)	Microsoft Windows MCE Idle	3.0 BA / 3.3 BA
Typical (28 °C)	Simultaneous: Microsoft[†] Windows[†] MCE TV Record Microsoft Windows MCE Video Play Play@TV remote SD Stream	3.5 BA / 3.8 BA
Maximum (35 °C)	Worst case	NA

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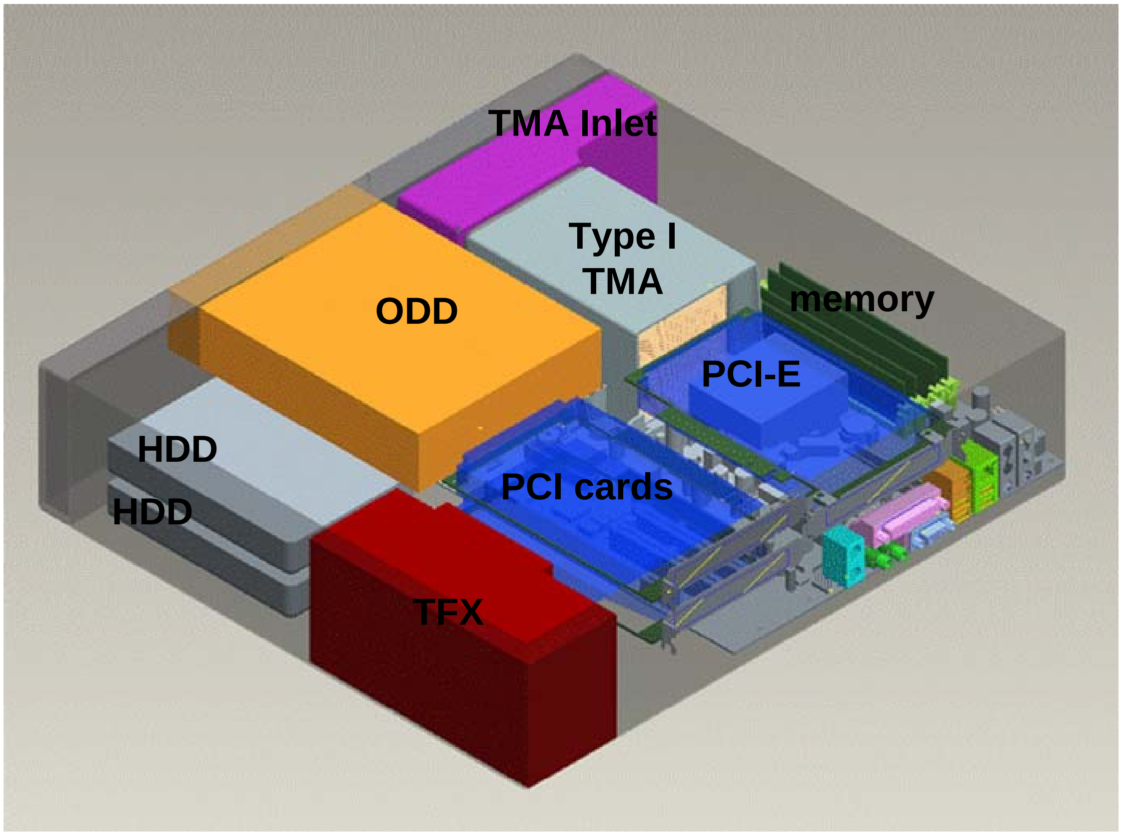
4. Case Study 1: 4” System Thickness

This profile is one that uses standard components while targeting optimal acoustic performance and feature loading. Figure 9 outlines the feature loading for this 4” x 17” x 15.5” (thickness x width x depth) configuration. Note the inclusion of two standard Hard Disc Drive (HDD) components, a desirable characteristic for a PC designed to store digital entertainment content.

Figure 9: Entertainment PC - 4" System Thickness



4.1 Use Condition Power

Before describing the system layout, features, and performance, it is important to understand the component power loads expected for this particular system configuration. Table 2 describes the expected power loads in each use condition, along with the component temperature requirement. For some components, the temperature requirement has been simplified as an approach ambient temperature requirement. The ambient requirement in these cases was derived from either detailed CFD numerical modeling or empirical testing that established a relationship between the component and ambient temperature.

Table 2: Component Temperature Requirements and Use Condition Power Loads

Component	Temperature Requirement	Idle Power (W)	Typical Power (W)	Maximum Power (W)
Processor	67.7 °C Case	54	68	95
Voltage Regulation		27	33	38
MCH	47 °C Ambient	6.9	17.7	17.7
ICH	50 °C Ambient	2	2	4
PSU	50 °C Inlet	138	200	275
Memory	50 °C Ambient	7	12	14
PCI-E x16	55 °C Ambient	10	20	40
PCI	55 °C Ambient	3	5	10
HDD	55 °C Ambient	5	10	10
ODD	50 °C Ambient	5	5	10

4.2 Component Placement

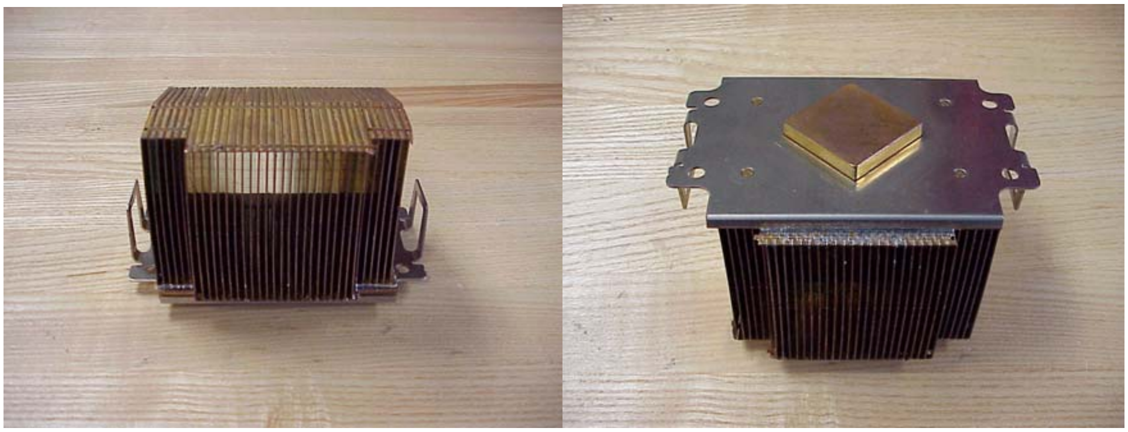
The power supply position is on the right side – opposite the typical placement in BTX. There is not a fixed PSU position defined in the *BTX Interface Specification* or the *BTX System Design Guide* but all the design guide illustrations show the PSU on the left (memory – Zone C) edge of the board. In this system profile, placement of the PSU on the right (add-in card – Zone D) edge of the board allows the ODD to be placed nearer the center of the front panel. Figure 6 illustrates the attractive industrial design options available with a slightly off-center ODD and a thin system profile.

The standard components in this system profile include a microBTX motherboard, memory, Type I TMA, TFX12V PSU, standard Desktop ODD, standard Desktop HDD (2), and full height add-in cards. The full height ½ length PCI Express x16 DVI card is placed on a riser immediately behind the TMA to ensure that this high power component is in the best possible airflow position. Note that the low power PCI cards are also on a riser; however, these cards are not limited to ½ length. The length of cards in these positions will be constrained by the design of their riser card, the placement of the ODD, and the design of the ODD bracket. Both HDD units are placed to in front of the PSU and below the ODD.

4.3 Thermal Module Acoustic Optimization

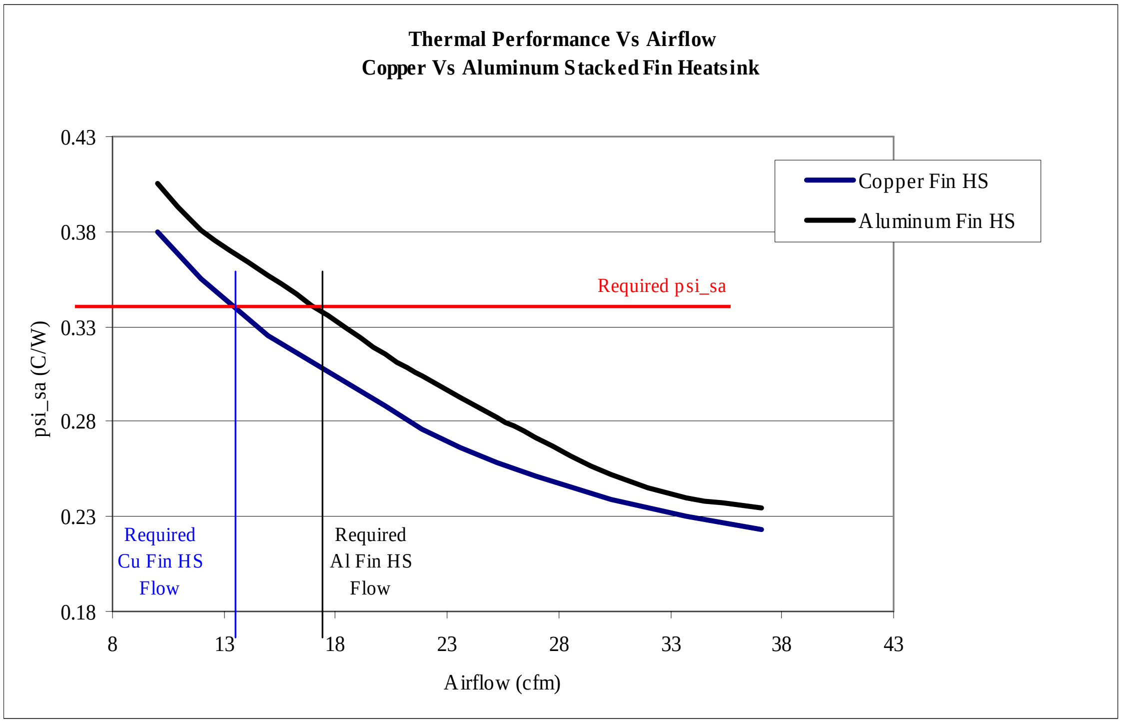
Acoustic optimization of a Type I thermal module targeted fan speed reduction through an improvement in the convective performance of the heatsink. With better convection, the required processor case temperature can be achieved with lower airflow and lower fan speed. By replacing the aluminum fins on a 2004 Performance TMA stacked (soldered) fin heatsink with copper fins (Figure 10), the convective performance of the heatsink improved and considerably lower minimum and maximum fan speeds were possible. This acoustically optimized TMA was used on a 2005 Mainstream (95 watt) processor.

Figure 10: Copper Base Copper Stacked Fin Heatsink



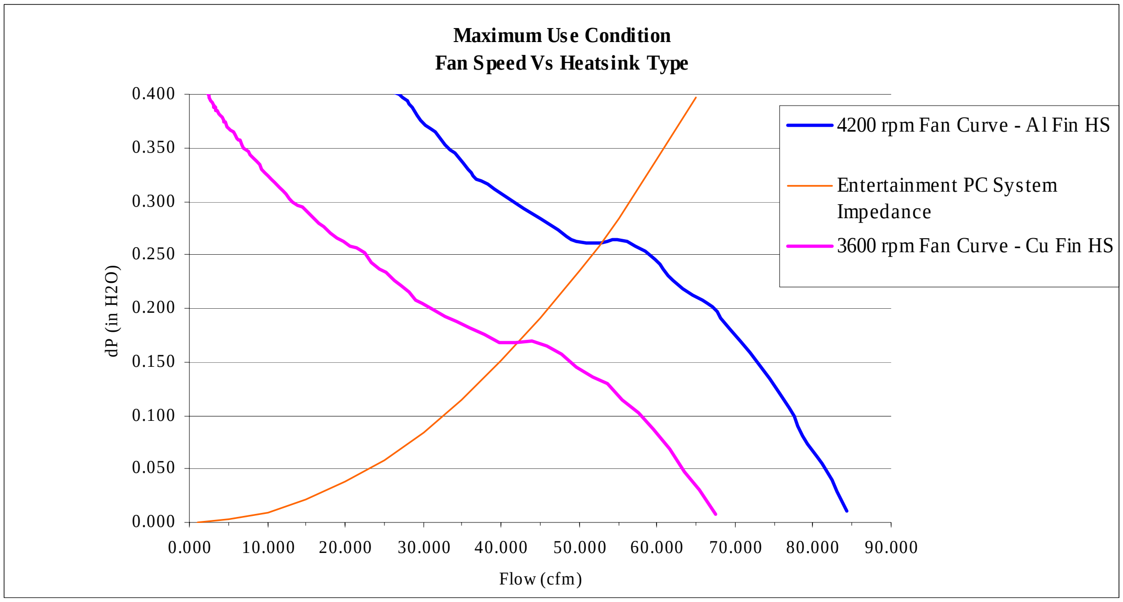
The fan speed reduction allowed can be predicted by first predicting the heatsink airflow required to meet the 2005 Mainstream FMB thermal requirement. The graph in Figure 11 shows how the heatsink's thermal performance (ψ_{sa}) improves as the airflow provided to it increases..

Figure 11: Copper and Aluminum Fin Heatsink Thermal Performance vs. Airflow



The predicted TMA fan curve required to provide the heatsink airflow for each heatsink type is illustrated in Figure 12. Notice the considerable reduction in fan speed for the acoustically optimized TMA in both the Maximum and Idle use conditions.

Figure 12: Fan Speed Vs Heatsink Fin Type



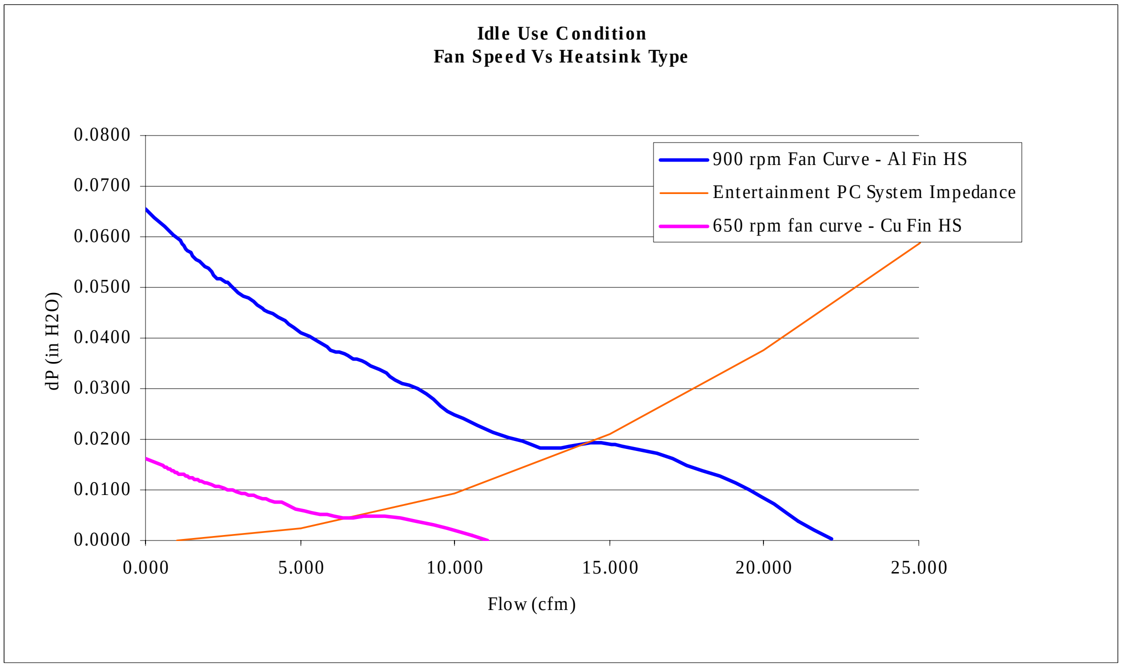


Table 3 shows the predicted TMA fan speeds at each use condition for the Aluminum and Copper stacked fin heatsink TMA designs. Equation 4 was determined by characterization of the TMA fan in an acoustic chamber. The equation was used to predict the TMA noise presented in Table 1. The additional expense of an acoustically optimized TMA can be evaluated against the substantial improvement in the system's acoustic performance.

Equation 4: Thermal Module Noise Vs Fan Speed

TMA Sound Power (BA) = $0.1017 \bullet \text{rpm}^{0.5052}$

Table 3: Use Condition Predicted TMA Fan Speed and Sound Power

Use Condition	TMA Heatsink Fin Type	Fan Speed (rpm)	TMA Sound Power (BA)
Idle	Aluminum Fin	900	3.2
	Copper Fin	600	2.7
Typical	Aluminum Fin	1600	4.2
	Copper Fin	1200	3.7
Maximum	Aluminum Fin	4200	
	Copper Fin	3500	

Note: Measured system acoustic performance data from a prototype build is presented in Section 4.7.

4.4 Power Supply Acoustic Optimization

Optimization of the PSU fan speed was limited to replacement of a voltage-regulated fan with a Pulse Width Modulated (PWM) regulated fan. Typical voltage-regulated fans can achieve a minimum speed that is approximately 50% of the maximum speed; whereas PWM fans can be as low as 20% of the maximum speed. Thermal analysis and empirical testing of a TFX12V power supply retrofit with a PWM fan was conducted to verify that PSU internal component temperatures were compliant with their specifications at Idle power load and 20% of the fan's maximum speed at a PSU inlet air temperature of 50 °C.

The 275W TFX12V with a PWM fan allows an operating range of 1000 to 4000 rpm. In the Idle and Typical conditions, the minimum fan speed provides sufficient airflow to cool the PSU components. At 1000 rpm, the TFX12V was confirmed to operate at 3.1 BA when it was independently tested in an acoustic chamber.

4.5 HDD Acoustic Optimization

High performance 120-GB HDD units were selected for the Entertainment PC prototype. The particular model selected comes with fluid bearings to minimize the source noise. Isolation mounts were inserted between the HDD and its retaining bracket to minimize potential noise contribution from structural resonance.

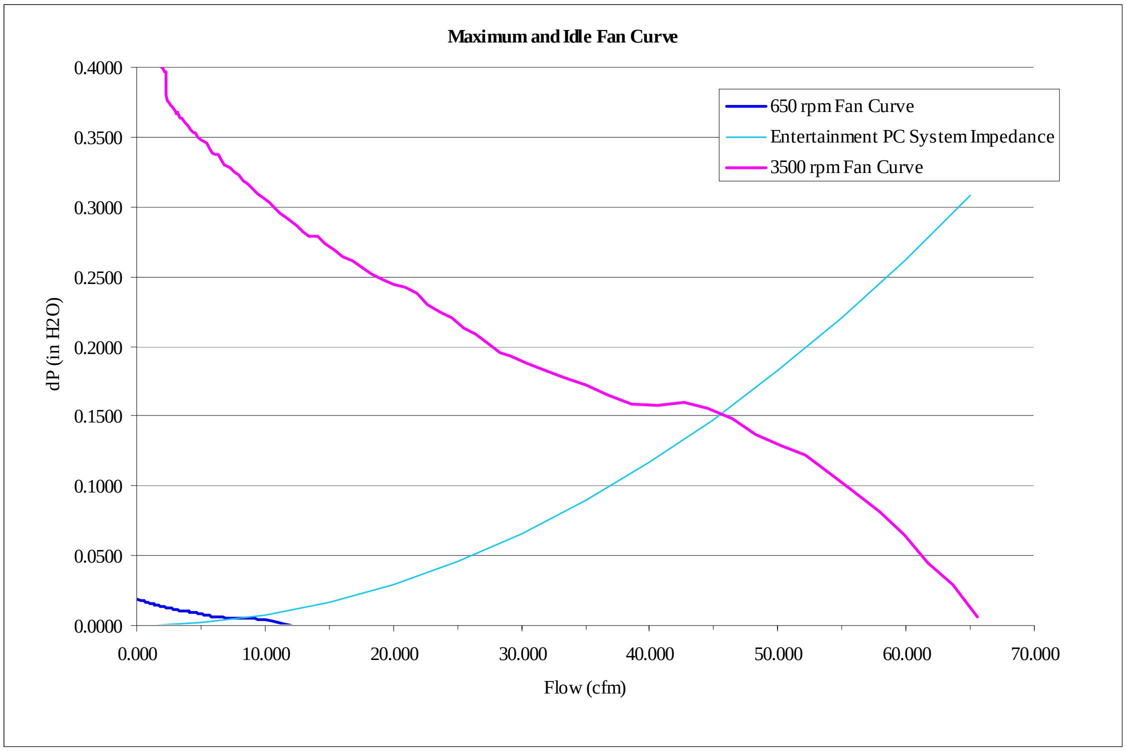
The HDD was independently tested in an acoustic chamber and values of 2.6 BA in Idle mode and 2.8 BA in Active mode were recorded.

4.6 Numerical Model Construction and Design Optimization

A Computational Fluid Dynamic (CFD) numerical model was constructed based on the design illustrated in Figure 9 and run for each use condition to predict the airflow and temperature behavior.

TMA and PSU fan curves were generated by testing the TMA and PSU assemblies at incremental fan speeds on a wind tunnel. These fan curves were used in the numerical model. For each placement and ventilation option evaluated, fan curves were scaled until the CFD model indicated that subsystem temperatures were compliant with their requirements. From these scaled fan curves, fan speeds can be determined. The PSU fan speed can be determined by comparing the required PSU airflow to the tested PSU fan curves. The TMA fan speed can be determined by comparing intersection of the TMA fan curve with the CFD model predicted system impedance (Figure 13).

Figure 13: Maximum and Idle Fan Curve and System Impedance



Component placement and ventilation position options were evaluated in the numerical model to ensure that the design was optimized prior to the construction and testing of a prototype. Inlet ventilation for the Thermal Module Interface (TMI) is illustrated in Figure 14 and Figure 15. This generous inlet ventilation allows sufficient airflow and low airflow impedance, and allows the continuous front bezel illustrated in Section 2.5.1.

Figure 14: Ventilation: TMI Inlet and Memory Exhaust

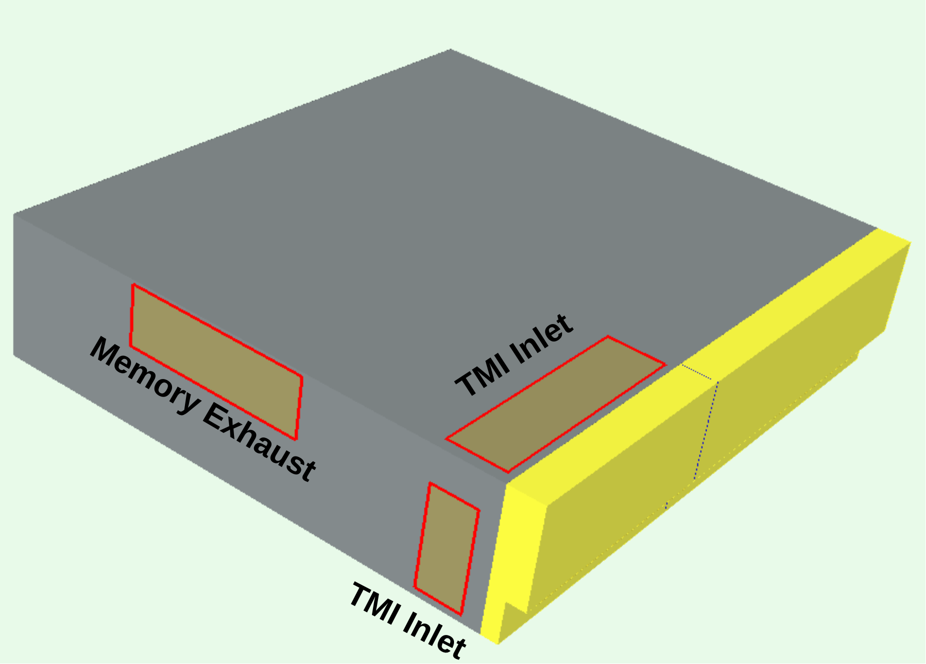
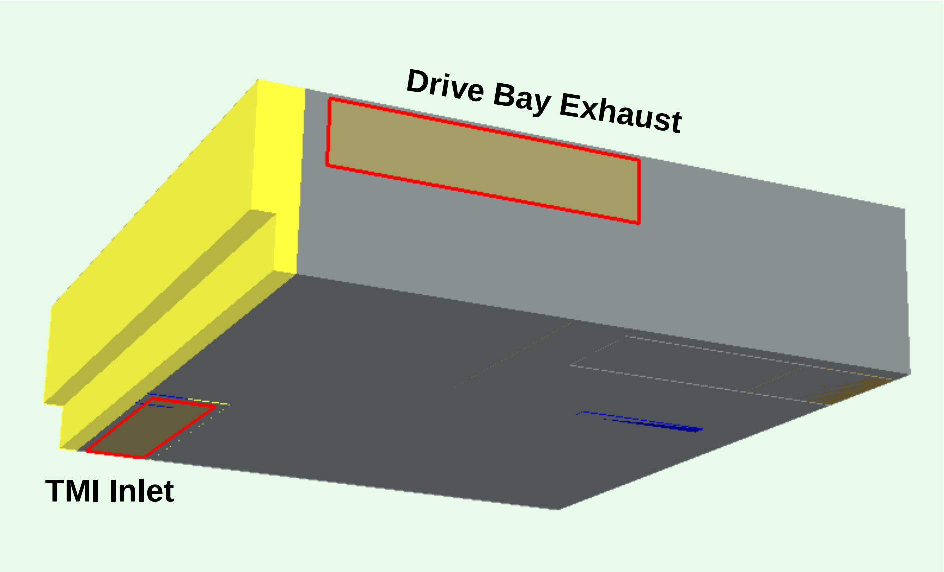


Figure 15: Ventilation: TMI Inlet and Drive Bay Exhaust

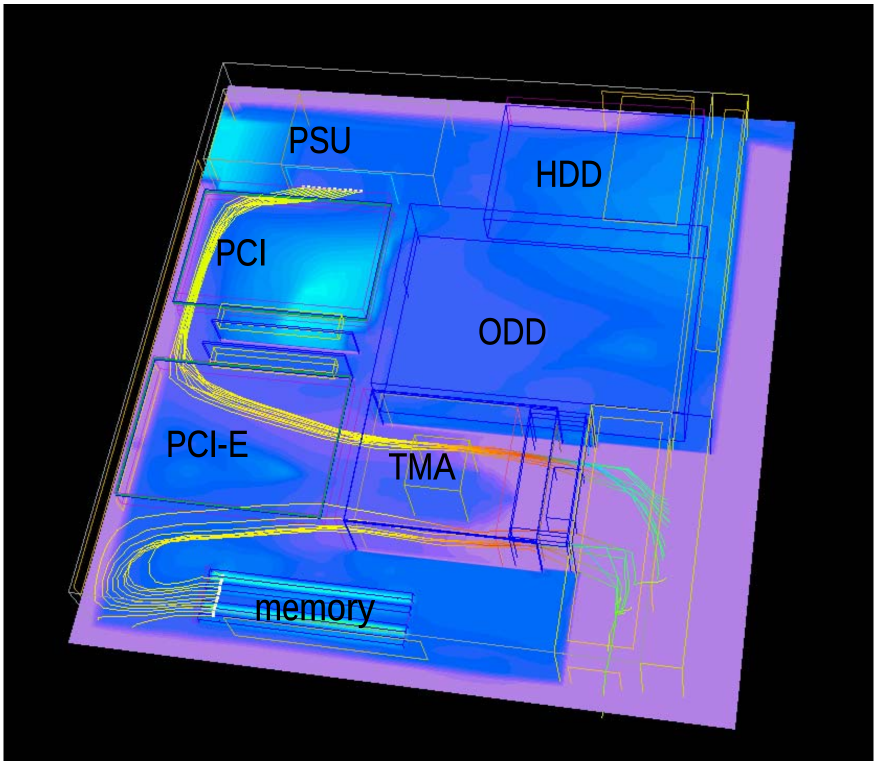


The location of exhaust vents is also critical to performance. The drive bay exhaust illustrated in Figure 15 ensures that there is minimal stagnation and temperature rise in not only the drive bay area, but also in the low power PCI card area. The memory exhaust vent illustrated in Figure 14 is critical for memory temperature, but its important to note that its position can have a significant influence on the entire system. If the memory exhaust vent is located too close to the TMI side inlet vent, the heated air will simply reenter the system, increasing the inlet temperature and affecting he temperature of every component in the system.

4.6.1 Airflow Pattern

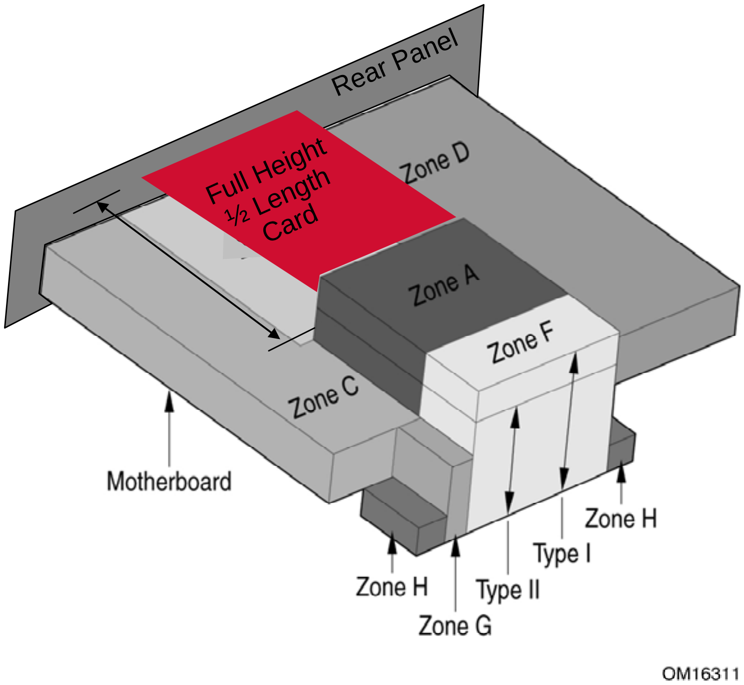
The predicted airflow pattern in this system profile is illustrated in Figure 16. Air is drawn into the system by the TMA through side, top, and bottom sheet metal vents (illustrated in Figure 14 and Figure 15). The inlet duct minimizes recirculation of internal heated air back into the TMI inlet. As noted in Section 2.5.1, the inlet duct and top, side, and bottom ventilation scheme allow airflow to be drawn into the system without pulling air through the bezel.

Figure 16: CFD Airflow Pattern Prediction



The airflow that enters the TMA will exhaust past the PCI Express x16 DVI card on a riser. This position allows the use of a quiet and cost effective passive heatsink for a high performance card. The *BTX Interface Specification* essentially limits full height cards in this position to ½ length (Figure 17). With appropriate rear panel ventilation, the majority of this airflow will split into two distinct return airflow paths. Since each return path will have lower velocity after turning, high power cards should be placed on the first riser and lower power cards on the second.

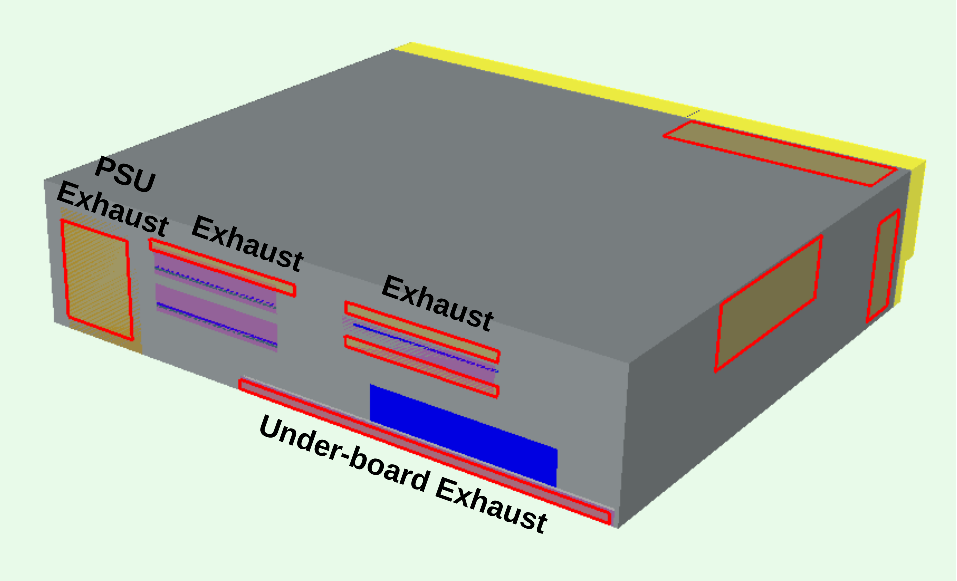
Figure 17: Full Height Half Length Add-in Card on a Riser



Returning to Figure 16, one return path travels from the rear panel into the memory area before exhausting from a well-placed side panel vent. Remember that placing the memory exhaust vent too close to the side panel TMI inlet vent will cause heated air to enter the TMA, which will increase temperatures inside the system.

The other return path travels from the rear panel into the PCI card and drive bay area before exhausting from a side panel vent. The power supply fan also pulls some of this return air through the card area. The PSU exhausts heated air through a rear panel vent. Finally, as is recommended in all BTX system designs, a rear panel exhaust vent is placed under the I/O connector aperture to ensure that the benefits of under-board airflow are available. Rear panel ventilation is illustrated in Figure 18.

Figure 18: Rear Panel Ventilation



4.6.2 Predicted Thermal Performance

Table 4 shows the predicted component temperature from the CFD model.

Table 4: Predicted Component Temperatures

Component	Temperature Requirement (°C)	Idle Prediction (°C)	Typical Prediction (°C)	Maximum Prediction (°C)
Processor Case	67.7	48	47	67.7
MCH Ambient	47	34	41	39
ICH Ambient	50	40	54	40
PSU Inlet Ambient	50	43	47	42
Memory Ambient	50	39	47	43
PCIe† x16 Ambient	55	51	43	45
PCI Ambient	55	48	54	46
HDD Ambient	55	48	48	47
ODD Ambient	50	39	47	43

Table 5 shows the predicted operating point and flow balance in each use condition, along with the fan speeds required. In the Maximum Use Condition the Fan Speed Control circuit will demand that the TMA and PSU fan operate at the maximum operating speed. Minimum operating speeds will be dictated in the Idle Use Condition. The Typical Use Condition would require that TMA fan operate above its minimum speed, but the PSU fan can remain at its minimum.

Table 5: Predicted Fan Speed and Operating Point

Use Condition	TMA Fan Speed (rpm)	PSU Fan Speed (rpm)	Pressure Drop (inches H_2O)	Flow Rate (cfm)
Idle	650	1000	0.005	7.2
Typical	1200	1000	0.018	15.1
Maximum	3500	4000	0.109	44.7

4.6.3 Predicted Acoustic Performance

All the elements of the acoustic prediction have been described in previous sections. First, Equation 2 describes how the constituent noise sources can be used to predict the system noise. Second, Equation 4 in Section 4.3 can be used to determine the TMA noise at the TMA fan speed required for each use condition. Finally, the PSU and HDD contributions were provided in Sections 4.4 and 4.5, respectively.

Table 6 shows component sound power information and the output of Equation 2 to predict the Idle and Typical system acoustic performance.

Table 6: Predicted System Sound Power (BA)

Use Condition	TMA Sound Power	PSU Sound Power	HDD Sound Power	System Sound Power
Idle	2.7	3.1	2.6 / 2.6	3.4
Typical	3.7	3.1	2.6 / 2.8	3.8

4.7 Actual Performance

Figure 19 is a picture of the prototype that was fabricated to correlate the numerical thermal and acoustic model predictions. A BTX Thermal Test Board (TTB) was installed in the prototype chassis. Memory and add-in card thermal loads were replicated using thermal load cards. Thermal Test Vehicles were used to replicate CPU, MCH, and ICH thermal loads. Board and voltage regulation thermal loads were replicated with component resisters designed into and placed on the TTB. Drive bay loads were replicated with film heaters attached to HDD and ODD surfaces. The prototype was instrumented with thermocouples, which were placed at the same locations as the monitor points selected in the CFD model. Measured temperatures were within a few ^{o}C of the predicted temperature (Table 4).

Figure 19: Prototype

Acoustic performance was measured by building a fully functional prototype with functional components and a functional Fan Speed Control circuit. The system was then tested using the Idle and Typical applications defined in Table 1.

Unfortunately, acoustic chambers monitor but do not regulate the chamber temperature so it was not possible to measure the Typical acoustic performance directly. Instead, the functional prototype was inserted into a 28 °C thermal chamber where the TMA and PSU fan speeds were measured while the Typical use condition applications were running. Then the prototype was placed in the acoustic chamber for testing. The fans were independently set to operate at the same speeds as those measured in the thermal chamber while the Typical use condition applications were running. Table 7 shows that the measured acoustic performance matches well with the predictions (Table 6) in the Idle and Typical use conditions. The results also align well with the suggested Entertainment PC acoustic performance criteria (Table 1).

Table 7: Measured Acoustic Performance

Use Condition	Measured Sound Power (BA)
Idle	3.37
Typical	3.81

A second set of tests was conducted to determine the potential improvement if a second HDD was not included in the system design. To simulate this condition, the second HDD in the prototype system was turned off, and the tests described above were repeated. The results are described in Table 8.

Table 8: Measured Acoustic Performance with One HDD

Use Condition	Measured Sound Power (BA)
Idle	3.21
Typical	3.79

4.8 Additional Optimization Opportunities

As with the evaluation of any new system profile that includes prototype testing, there were additional optimizations identified that would likely improve system performance.

As noted in Sections 2.5 and 4.3, a lower torque motor and lower fan speeds are available with an improvement in the convection performance of the heatsink. The *BTX System Design Guide* includes Type I and Type II Thermal Module case studies that point to additional heatsink performance improvements that may allow even lower TMA fan speed. For instance, the inclusion of a Flow Partition Device to divert airflow from the voltage regulation to the heatsink could be explored. A trade between the heatsink length and fan /stator depth could also lead to improvements. Preliminary testing on the Intel reference design fan has shown that the fan curve can be sustained even with a reduction in blade count and blade depth. Since the TMA fan is the primary airflow source for all system components, it is important to numerically and empirically verify all system component temperatures with any changes in TMA fan speed or fan curve.

The fan motor used in the acoustically optimized TMA prototype had an unfortunate design flaw. The control circuit limited the minimum speed to 900 rpm, even though the magnet and windings were designed to allow 650 rpm minimum. The 650 rpm fan speed required for the testing was achieved by reducing the fan's supply voltage from 12V to 9.4V, which would likely increase the cogging current. As explained in Section 2.5, the increase in cogging current may limit the noise reduction at low fan speeds.

Finally, a reminder that Section 2.5.3 identified an opportunity for reduction in PSU fan speed. Orienting the PSU so that it pulls in external air instead of using heated air inside the system may allow lower fan speeds. An evaluation of system component temperatures is required to ensure that the airflow pattern without the PSU affect would be sufficient.

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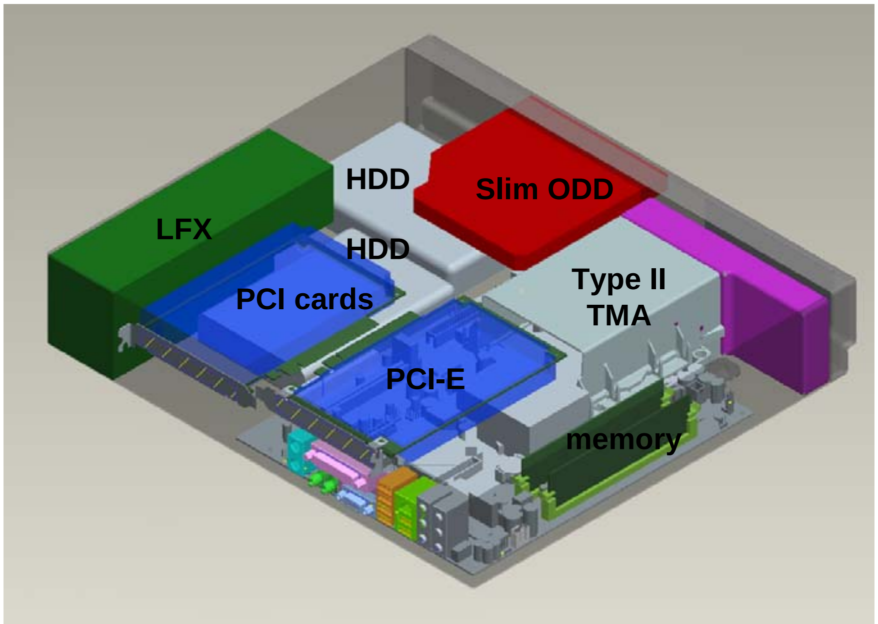
5. Case Study 2: 3" System Thickness

The profile illustrated in Figure 20 is one that demonstrates the minimum Entertainment PC system thickness. It employs a Slim /Mobile ODD and the smallest standard thermal module and power supply components, Type II and LFX12V respectively.

Figure 20: Entertainment PC – 3" System Thickness



As noted in Section 2.1, this thickness is limited by the LFX12V power supply. LFX12V power supplies will have a lower total power than other larger PSU form factors. It will be important to compare the total system load to the LFX12V capability.

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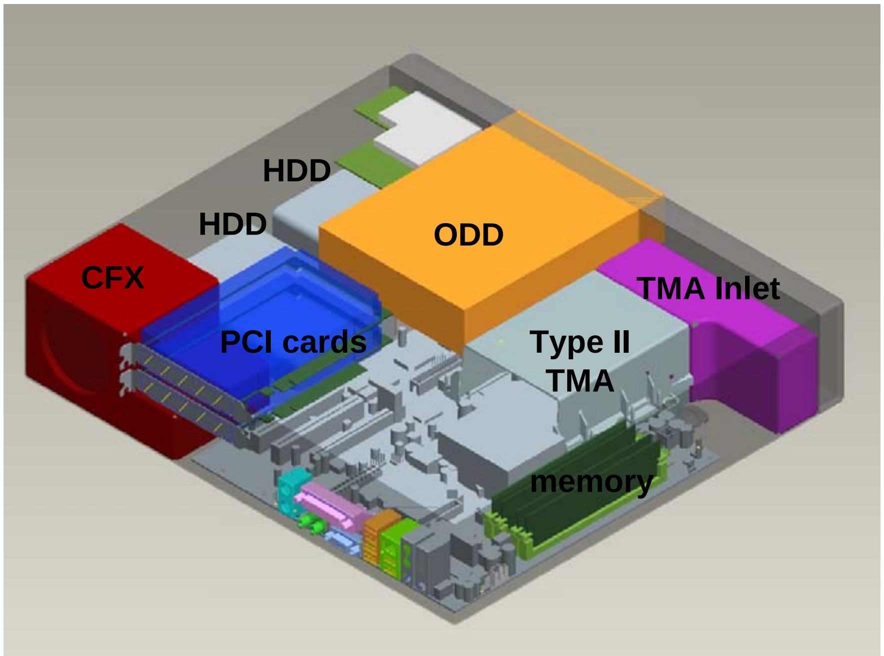
6. Case Study 3: 3.6” System Thickness

The profile illustrated in Figure 20 is one that demonstrates the narrow Entertainment PC system thickness but has greater total power capability than the system profile illustrated in Section 5. The increase in PSU form factor thickness with the migration from a LFX12V to CFX12V allows a Standard ODD but requires the smaller Type II TMA. As noted in Section 2.3, a smaller TMA has a smaller fan that will likely be required to spin faster. This acoustic performance of this system profile and the one illustrated in Section 5 will not be as favorable as the system illustrated in Section 4. Concerns about acoustic performance for system profiles that use smaller PSU form factors and the Type II TMA may require careful inspection of feature loading and component power levels, since the required fan speeds will vary with component power levels.

Figure 21: Entertainment PC - 3.6" System Thickness



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