The Quest for Noiseless Computers

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Abstract

When The Knoll, the building that houses CCRMA, was completely renovated in 2004, new custom workstations were designed and built with the goal of being both fast machines and completely noiseless to match the architectural and acoustical design of the building.

Keywords

silent computers

1 Introduction

Starting in 2004 The Knoll, the building that houses CCRMA, was completely remodeled. Save for two rooms, the recording studio and its adjoining control room, the rest of the floor plan changed completely and was redesigned to better fill the needs of CCRMA, and to be as acoustically quiet as possible.

Before moving to the newly remodeled building in August 2005, we had almost six generations of Intel/AMD computer systems running Linux and Planet CCRMA, purchased over roughly seven years. Several generations of very reliable but by then old Hewlett Packard workstations, from old PII 450MHz machines to dual processor PIII 660MHz machines, one small batch of dual processor PIII 900MHZ IBM Intellistations and two generations of custom-built computers.

The challenge was to design and build computer systems that would not add noise to the work environment in both open spaces and studios.

2 Approaches

A couple of simple approaches for noise suppression were discarded from the very beginning. The first one was to install the machines in closets or other acoustically isolated spaces so as to separate them from the users. This was done in the Studios (which have Macintoshes in them as well as silent Linux machines) but was impossible due to space constraints in most other rooms and spaces (for example in the main clusters of machines, the Stage and the Listening Room).

A second approach would be to use individual noise isolation boxes so that stock computers could be used. Besides being expensive, that approach does not work very well as the isolation boxes have fans, and even though they are usually low speed they can be heard. A commercial isolation box typically provides only 20 to 30dB of isolation and the end result is not silence (we have one in the Recording Studio Control Room that houses a Macintosh, and it is clearly audible).

The only other option was to build silent computers, which is what we ended up doing.

3 Custom workstations

We had already built custom computers in-house for the previous two generations of workstations.

The first generation of custom-built computers was designed and built in 2002 and was based on Athlon XP and MP processors. They were not too successful in the noise reduction department. The cases we selected were aluminum and looked very nice, but they were not good at containing noise. We incorporated fan speed controllers to be able to throttle down the speed of the cpu and case cooling fans so that there was some noise reduction, but the noise was still there. Furthermore hard disks at the time were not that silent (fluid bearing technology had not arrived yet) and eventually started generating quite a bit of high frequency noise as they got old.

The second generation of custom systems was built in 2003 around the Antec Sonata case, Zalman CPU coolers and Pentium 4 2.8GHz processors. This was more successful as the cases themselves were designed with low noise in mind (with shock absorbers for the hard disk mounts,

120mm low speed case fans, etc). Better cooling components brought the noise down significantly, but as long as there are fans around there is some residual noise left.

When the Knoll was remodelled we wanted computers that could match the acoustic design of the building. That is, completely silent. We explored several alternatives and this report summarizes what happened.

But first a look at what makes a computer noisy...

4 Noise factors

Many components in a computer create noise. There are two main categories. Fans of all types on one hand and hard disks and cd or dvd drives on the other. Let's look first at fans:

4.1 Case fans

Almost all cases (see exceptions below) need one or more fans to maintain adequate internal air flow so that hot air generated by the computer components can be extracted from the case.

4.2 Power Supply fan

Most power supplies need a fan to dissipate heat from its components. The noise generated varies widely, usually you get what you pay for, cheap power supplies that come bundled with cheap cases are generally quite noisy.

4.3 CPU coolers

Although stock fans that come with boxed processors are getting better (and even include heat pipe technology in some cases), they are usually quite noisy when compared to third party coolers. Cpu cooler fans are usually the louder component of a PC so it is usually the first component worth upgrading. Smaller processes in chip manufacturing have meant an actual reduction in power dissipated by the cpu in some cases (reverting the trend for more dissipated power and faster fans), so that the need for noisy cooling equipment has subsided a bit.

4.4 Chipset coolers

Many motherboard manufacturers use an active cooler to keep the motherboard chipset cool. They usually use very small fans that spin quite fast and thus produce annoying high frequency sound.

4.5 Video Card

Most medium and high performance video cards usually dissipate a lot of heat to get the performance they have. As is the case with chipset coolers they normally use small fans that spin very fast and generate quite annoying noise.

4.6 Other fans

Some motherboard manufacturers incorporate other small fans in the motherboard, I would recommend to stay away from those motherboards.

4.7 Storage

Contemporary hard disks are very silent (probably a side effect of the popularity of personal video recorder hardware), they have very little rotational noise and seeks are mostly inaudible in the best of them. You will want to mount them with some sort of shock absorbing mounts so that the platter rotational vibration is not transmitted to the case, otherwise the case will act like a loudspeaker for the low frequency noise coming from the drive.

As for Cd and DVD drives, not much to do here, they are noisy specially when burning or reading disks at high speeds.

5 Solutions

As long as you have moving parts you will have noise. When building custom systems, the first line of defense against noise is to initially select components that need no fans, or for which alternative cooling systems can be provided.

5.1 Case and power supply

If you need to build a computer with fans because of cost or other considerations, start by selecting a case that uses large fans and has been designed for low noise and good internal airflow. A popular choice we have used successfully is the Antec Sonata case. They have one shock mounted 120mm fan that can run at 1/2 speed, includes rubber mounting hardware for the hard disks and has good internal airflow characteristics. Most cases have several 80mm fans which will have to spin faster to provide the same airflow, and will make more noise. In some cases you can add fan speed controllers so slow the fans down as long as you don't have very hot components inside the case.

The materials that make up the case are also important. Best quality cases designed for low noise have damping layers glued to the sides so that the metal panels don't become resonators that amplify the low frequency hard disk drive noises (trying to bring down the resonant frequencies with mass as well). You can also use sound damping blocks installed inside the case

to minimize sound propagation to the walls of the case but you have to pay attention to not block airflow at the same time.

The power supply is usually included with the case. Most power supplies have fans, and cheaper ones are quite noisy. Good quality power supplies have variable speed fans that you can either control manually or that automatically change speed depending on the thermal load. Look for power supplies designed for low noise, and in particular for the ones that have larger 120mm internal fans rather than external facing 80mm fans. This is one area where a bit more money can result in much lower noise.

While they are somewhat hard to find and quite expensive some power supplies do not have fans, examples currently include the Silverstone Nightjar (450W, we have used it successfully) and the 400W FANLESS model from Silentmaxx.

5.2 Cpu

Cpu coolers are probably the highest noise source in custom-built systems. Third party cpu coolers can make a big difference in the total noise generated by the computer. There are several brands of coolers that use low speed or controllable speed fans that are almost noiseless (we have used Zalman coolers successfully).

Some third party coolers are designed for overclocking purposes and will be very noisy, you have to pick the ones designed for low noise.

You might also want to take a look at the CPU itself when selecting components. In some cases a slight decrease in cpu speed or a switch to a different model will mean less heat dissipated and will make the target of low noise easier to achieve. Stock fans that come with boxed processors have gotten better and are not as noisy as they used to be, but third party fans are a good solution to bring noise down.

5.3 Motherboard

Noisy chipset coolers in some motherboards need to be replaced with passive coolers. There are several available. Of course it is better to find a motherboard that uses passive coolers in the first place, but that may not be possible depending on the chipset and other requirements you may have.

Depending on the positioning of the chipset in the motherboard, replacing the chipset fan with a passive cooler can lead to problems when mounting long pci or pci express cards in the expansion slots (the passive coolers are usually much taller than the integrated active fan coolers and could interfere with the card).

Some high performance motherboards have a set of heat sinks that surround the processor socket and cool the main chipset, other important components and the power transistors that supply power to the cpu. And they are designed to rely on air flow provided by the cpu cooler itself. This could become problematic if you use cpu coolers that run at very low speeds or use a cooling solution that has no fans. This will mean those components will probably run hot.

5.4 Video card

High powered video cards can be very noisy. You can opt for less horsepower and if you do so there are several video cards available that have passive cooling. Aftermarket silent coolers are also available for many of them, based on heat pipes coupled with passive radiators or bigger low speed fans, or the video card can be integrated into a water cooled or completely passive system.

6 Extreme solutions

The goal here is to get rid of fans and hopefully other moving parts as well.

6.1 Water cooling

Water cooling is not a magical solution as it unavoidably involves moving parts. But it can bring noise down, specially when dealing with overclocking or the top of the line fastest processors and video cards (which require a LOT of cooling power).

Water cooling solutions involve one or several cooling blocks which attach to the cpu and other components that need cooling. The cooling block or blocks are connected to a closed circuit system that includes a reservoir for the cooling fluid, a pump to keep it moving and some heat exchange hardware to cool the fluid before it is pumped back into the cooling blocks. The net effect is to transfer heat from the affected components to the air surrounding the case.

In terms of noise there are two components that need some care in selection: the water pump and the heat exchange system. Pumps included with kits are usually not very noisy. Usually less than a fan.

The heat exchange or cooling is usually done through a radiator with fans that blow air over it. Even though the fans are usually low speed, they still make noise.

6.2 Fanless water cooling

Some water cooled systems do not use fans. We have successfully used a water cooling system from Zalman (the original Resserator I) that uses a passive cooling tower and does not need fans. The water pump in that system is very quiet and barely audible in a completely quiet studio environment (where we made some measurements presented later). A fanless water cooling system is a very good solution, the only drawback being that the fanless systems have a cooling tower or box that is separate from the computer case and connected to it with flexible hoses. This could be problematic in a not very well controlled environment where someone could move stuff around and accidentally damage the hoses (or cut them with the resulting mess or cooling fluid all over the place).

6.3 Completely passive cooling

The next step up in performance and cost is to use a completely passive system for cooling.

That is the solution we finally adopted when building the new workstations for The Knoll. Zalman offered two cases that were completely passive (TNN300 and TNN500, regretfully no longer being manufactured). Cooling is taken care of by cooling blocks connected to the sides of the case through heat pipes. The heat pipes transfer heat from the cpu, the video card and the chipset to passive radiators, and in such a system the only moving part is the hard disk (heat pipes are filled with a liquid that boils at the temperature of the cooler block, the "steam" travels up to the side of the case, where it condenses into liquid as it cools, and recirculates back to the cooling block).

There are several caveats in building such a system. The first is the selection of the components, including the processor itself. The cases have a maximum thermal load limit that might limit which processors you can use. The smaller case can dissipate up to 70W, the bigger one up to 100W. We have not found that a crippling factor with proper selection of the technology to use. In 2005, when we built the original systems, we used Athlon 64 dual core processors (2.2.GHz core), in 2007 we built additional machines using the smaller case and Intel Core 2 Duo processors running at 3GHZ. Since them we have upgraded all the original systems from the Dual Core Athlons to Quad Core Intel processors running at 2.83GHz.

The selection of the motherboard and video card is also restricted by mechanical constraints in the component placement, so that the heat pipe hardware can be attached properly and routed to the sides of the case (for example, motherboards with the RAM installed to the right side of the processor cannot be used as the RAM gets in the way of the heat pipes). That also applies to the chipset, which might be in a location such that the heat pipe hardware can't reach it. We used passive coolers to get around that problem in our original systems.

There are currently some (very few) alternative options available:

Some system integrators offer fanless designs based on the mCubed HFX Mini Case (see http://www.hfx.at/ for details), which as is the case with Zalman relies on heat pipe technology for a completely fanless design.

You can also find several manufacturers of small industrial fanless computers, but usually they are limited to rather small and low to medium performance processors.

7 Storage

7.1 Hard Disks

So, this is the last stumbling block for a truly noiseless system. We chose to just use standard hard disks when we built our custom systems.

There are some noise optimized models for the PVR (Personal Video Recorder) market but they are usually hard to find and more expensive. So far we have not tested them as the standard OEM drives seem to be good enough for our environment.

There are a couple more solutions for this problem. One is to dispense with the hard disk altogether and boot from the network. This is feasible and we did a few tests (using the hard disk to start the boot process and then turning if off when the machine is up and running), but there were a few problems with no immediately obvious easy solutions so we did not go down that road (this would also require a pretty fast server to provide the remote boot service and storage space).

The other solution which is currently becoming viable is to use a solid state hard disk. They are, for now, small and very expensive (and I have not tested them yet) but they would provide a completely silent solution. No moving parts (save for the CD/DVD player).

As to the selection of which hard drive, the noise characteristics change from generation to generation (and from brand to brand, course).

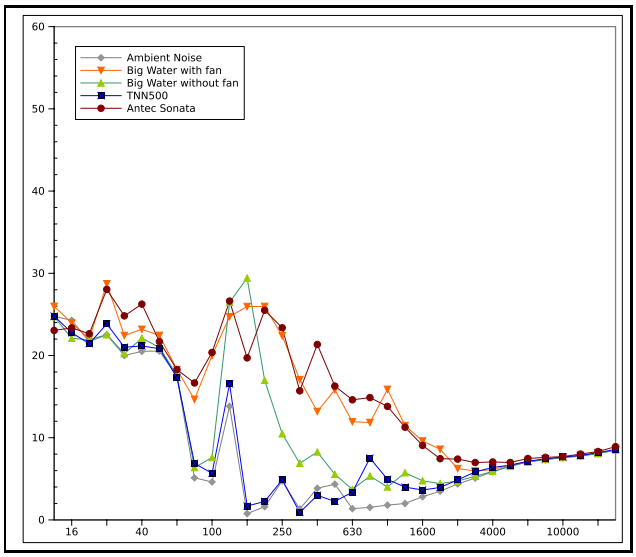

Figure 1: Measurements

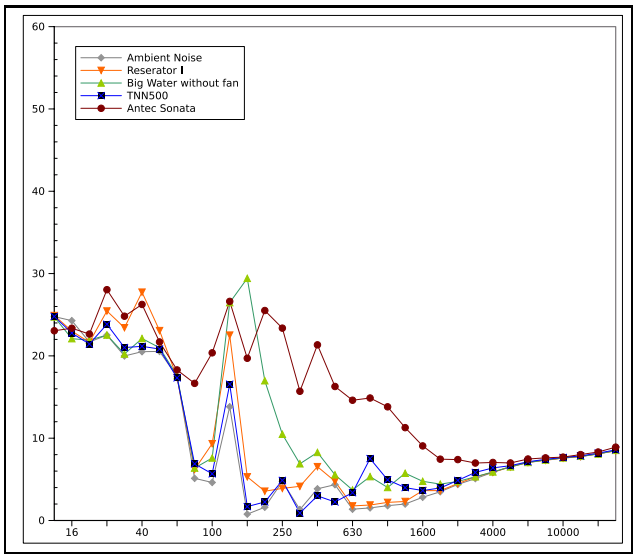

Figure 2: Measurements

Our original drives were Seagate and were very good in terms of rotational noise and seek noise. The latest generation of Seagate drives are not as good, they exhibit a louder rotational noise component - not annoying as it is broad band, but it raises the noise floor nevertheless. Older Western Digital drives are better in that respect. It looks like Samsung drives are the current best choice for low noise. We did not have the resources to do more thorough testing.

7.2 CD/DVD drives

Well, for this I have no solution. The disks have to spin and when they do they are noisy. We'll have to live with the noise for now.

8 Measurements

When we were doing research for this in 2005, Kierkegard and Associates (the acoustic design consultants for the new Knoll) helped us measure several of our existing machines and some of the proposed solutions (we were only interested in relative noise measurements to confirm our subjective impressions, so we did not use the relevant ISO standards [1][2], see [3] for details).

Here are some of them in a couple of graphs (Y axis is dB, X axis is frequency). The first graph (figure 1) includes the ambient noise (the measurements were conducted in CCRMA's Recording Studio which has a very low noise floor), the ThermalTake Big Water system with just the water pump on and with pump and fan on, the Zalman TNN500 passively cooled case and our previous generation Antec Sonata case based system.

You can immediately see how the fan that cools the radiator in the Big Water system brings up the noise to the level of the previous generation Antec case system (with cpu and power supply fans). While the noise is about the same the water cooling system has more cooling capacity, which is not useful for our purposes. The TNN500 is barely above the noise floor as is to be expected (due to the hard disk noise).

In the second graph (figure 2) we look at both water cooling systems (Big Water and Resserator I), the TNN500 system and the reference old Antec case design.

Notice the difference in the pump noise of both water cooling systems. The Big Water pump was clearly audible while you have to be very close to the Resserator I to actually hear it. The winner in overall noise is obviously the TNN500 system.

Designing system tailored to your needs and budget is complicated as there are many options available. An option we have not discussed in detail is to remote the system. Put the computer in another room or a sound isolated closet (but don't forget that a closed closet will need cooling!) and use extensions for the keyboard mouse and display. If that is not possible, budget systems could start with a case designed for low noise coupled with a low noise power supply and third party cpu coolers (and a motherboard and video card that use no fans). From there you have to identify which component is contributing to noise most and get rid of that one. If it is the power supply fan then switch to one without fans. The next step up in price

as well as capabilities is a water cooled system with no fans coupled with a fanless power supply. You have to keep in mind that there is water around and you will need to get distilled water and an algae control chemical so that your computer does not become a biology experiment over time. The ultimate system and the most expensive is one using completely passive cooling (basically a radiator plus heat pipes) - at that point the only components left that generates noise are the hard disk and dvd drives. If the budget allows the hard disk could be replaced with a solid state drive, but so far we have not found that to be necessary.

9 Conclusions

The Knoll is a quiet building, at least while its users are not making odd noises and weird music. In 2005, right after moving in, we designed and built 40 silent workstations to replace almost all the old computers we had around. Almost a year later we finished building 9 more. Just before this submission we upgraded all the original workstations to Quad Core processors. The difference in the quality of the sonic environment is enormous. Our main "cluster" of workstations has 12 fast machines but the room they are in (the old Ballroom, for those who have visited The Knoll) is completely silent. The new Stage (our auditorium) has been host to many concerts, most if not all of them benefiting from a noiseless computer for playback, recording and realtime processing of sound. In all, a very successful project.

10 Acknowledgements

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And thanks to the extended power outage at Stanford sometime in 1998 or 1999 during which I moved around a completely dark, empty and silent building, turning off switches in computers and other equipment, and appreciating the substantially different sonic environment created by the absence of machine noises. And for the opportunity of trying to recreate it, but with the power on.

References

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