Fire Suppression Systems Association

Fire Safety Systems Protecting Data Centers

Fires in data centers occur and can result in loss of information, property, and life. A recent survey of FSSA members who install fire extinguishing systems in data centers indicated that hundreds of fires had been successfully extinguished by gaseous clean agent systems in data centers. In 2018, a fire occurred in a data center at a large university on the East Coast of the United States. The installed clean agent system extinguished the fire quickly and no data loss occurred. The campus fire chief related that the information contained on those servers represented years of research for the University and was in his words “priceless.” Although fires in data centers are not “common,” cases like this where an automatic gaseous agent fire system extinguishes a fire with no loss of data are the rule when clean agent systems are deployed.

Several types of fire safety systems are used in data centers.

Basic Fire Systems

A basic fire safety system is a system which detects fire (smoke, heat, flame, etc.) and produces an alarm so that personnel may take appropriate action. Another very basic system is an automatic fire sprinkler system. These systems typically respond to high temperature and discharge water into the data center while causing the fire alarm to sound. Both of these “basic” fire safety systems have a number of drawbacks.

Systems which only sound an alarm require that trained personnel be present to determine the cause of the alarm and then decide what action should be taken. In some cases, fire department personnel will have to respond to manually fight the fire. There can be substantial delays with resulting data loss and equipment damage while personnel take action.

There are various types of sprinkler systems which can detect fire and spray water onto the fire. There is typically notable delay between the onset of fire in a data center and the operation of an automatic sprinkler system. The delay may be unacceptable in terms of data loss and equipment damage. Many data center operators are concerned about possibility of consequential water damage to equipment. They choose instead to use a clean, dry fire extinguishing agent for their data center – a “clean agent.”

Advanced Fire Safety Systems – Clean Agents

“Clean Agent” fire systems are advanced systems capable of detecting and extinguishing fire very quickly and with no consequential damage (i.e. minimal heat damage, no water damage, minimal clean up, minimal downtime). An automatic clean agent system consists of a fire detection system coupled with an extinguishing system which uses dry gaseous agents to extinguish fire. NFPA Standard 2001 is the Standard on Clean Agent Fire Extinguishing System. To be included in NFPA 2001, an agent must be electrically nonconductive and leave no residue upon evaporation. In addition, clean agents recognized by NFPA 2001 must be evaluated in a manner equivalent to the process used by the U.S. Environmental Protection Agency (EPA) Significant New Alternatives Policy (SNAP) Program for total flooding agents. Clean agents are, in many ways, ideal for fire protection in data centers.

Clean agent gases come in two general varieties: liquefied compressed gas agents and inert gas agents. HFC-227ea, HFC-125 and FK-5-1-12 are examples of liquefied compressed gas agents. Nitrogen, argon, mixtures of nitrogen and argon, and a mixture of nitrogen and argon with a small percentage of carbon dioxide are examples of inert gas agents.

Liquefied compressed agents vaporize quickly upon discharge into a fire zone; inert gases are stored in their gaseous state and are discharged from system nozzles as gases. Since both liquefied and inert agents are dry gases when they enter the fire zone, they leave no residue. After a discharge, no agent cleanup or mop up is required. Gases are capable of penetrating into equipment enclosures, quickly reaching and extinguishing even incipient fires. Because the agents are dry and electrically non-conductive, they do not present an electrical hazard when discharged into energized electrical equipment. These clean agents, properly deployed, do not pose a threat to personnel.

The discharge of a clean agent is typically initiated by smoke detection. Clean agent systems can be capable of sensing and extinguishing fires which are extremely small thus greatly limiting fire damage. There have been cases where a system discharged for "no apparent reason" only to find that the system had reacted to and extinguished a fire in its incipient stage before the fire had any effect on the IT equipment. Indeed, these systems can greatly limit damage, data loss, and system downtime caused by fire.

HDD use in IT applications

We have come to depend on and take for granted the functionality of computers for a multitude of everyday as well as specialized tasks. Words and numbers are routinely stored in "computers" ready to be retrieved on demand. Although there is a growing trend to store data on "solid state" devices, today most computers still depend on the Hard Disk Drive (HDD) to store data. Everything from decades of medical and scientific research to ledgers documenting credit card, bank, and brokerage accounts are stored on HDD.

Although the reliability of HDD is generally excellent, HDD are known to fail for numerous reasons. BackBlaze is a cloud storage company that publishes HDD reliability statistics[1] based on their in-house experience. During 2017, the company had 116,833 drives for which they obtained data. Over 4 drives failed on average each day; a total of 1,508 drives failed during 2017. Although not an enormous number percentage-wise, the value of the data contained on these drives is inestimable. Thus, prudence dictates that data stored on HDD be "backed up" to at least one redundant location, and often to multiple redundant locations. Various schemes have been implemented to provide such backup. We'll not discuss the various schemes used to secure data – the point is HDD are known to fail and it is irresponsible to rely on a single HDD to store valuable information.

Basics of HDD

Typical HDDs consist of round flat metal platters coated with a ferromagnetic film, a motor to spin the platters, read-write heads which are positioned over the platters, mechanical means to move the read-write heads, circuitry to control the positioning of the read-write heads, memory buffers, and various other control circuitry. Data is recorded on the magnetic film on the platters by the write head which changes the magnetization of individual data cells. The cells are organized in tracks that encircle the disk. There are about 10,000 parallel tracks in each millimeter of the platter. The "read" operation is done as the read head passes over the data cells; the magnetization of the data cells induces a current in the read head which is decoded by the HDD circuitry and converted to binary values for interpretation by the operating system and software.

Platters spin at high rate of speed; 5400 revolutions per minute (RPM) or 7200 RPM are typical. The read-write heads float on

[1] See https://www.backblaze.com/blog/hard-drive-stats-for-2017/ for complete 2017 BackBlaze report

an air cushion very close to (less than 10 nm or 3.9370×10^{-7} inches above) the surface of the spinning platters. As the heads read or write data, they must be precisely positioned over the appropriate data cells.

When the HDD is stopped, the read-write head controller "parks" the head on the platter near the center in an area where no data is written. In the photo of the HDD, the head is positioned in the parking zone.

For those interested in more details of HDD design and construction, there are numerous articles available free of charge on the Internet. For purposes of this paper, however, suffice it to understand that for effective writing and reading of data the read-write heads must be precisely positioned over extremely tiny data cells and contact between the spinning platters and the read-write heads can do irreparable damage.

HDD Failures

"Failures" of HDDs can range from momentary failure to write (or read) data to complete failure of the drive's capability to retrieve data previously written to the drive.

As with all mechanical devices, failure can be the result of age related wear on moving parts. Such failure can result in permanent loss of data stored on the HDD. Electronic circuits within the drive can also fail; failures of electronic circuits are extremely rare, most often occurring early in the life of a HDD. Manufacturing defects are another cause of failures; failure due to manufacturing defects commonly occur relatively early in the life of a HDD. "Head crashes" occur when the read/write head contacts the surface of the platter. A head crash can scratch the magnetic coating on the platter resulting in permanent and typically irreparable damage to the HDD. Head crashes can be caused by vibrating the HDD while the platters are spinning. The vibration could be caused by moving, striking, or dropping the HDD. The impingement of acoustic waves on the HDD likewise could cause components of the HDD to vibrate resulting in a head crash.

"Failures" Due to Vibration

In recent times, temporary difficulties in reading/writing data and even permanent HDD damage have been observed because of the impact of sound waves ("noise") on HDDs. In 2008, Brendan Gregg demonstrated the effect of "sound waves" on HDD in a well-known (among computer geeks) YouTube video "Shouting in the Datacenter."[2] By simply "shouting" at an array of HDD, he was able to cause increases in the time it took to read-write data from the drives. The observed delays occurred when the impact of the sound waves disturbed the precise positioning of the read-write heads over the proper data tracks on the HDD platters.

In line with the findings in the Gregg's report, interruption of data processing and even permanent damage to HDDs due to loud sounds in data centers have been reported. The discharge of gaseous fire extinguishing agents[3] have been reported to have caused problems with HDD including loss of data and, in a few cases, permanent damage to HDDs. These events prompted further investigation into the phenomenon of acoustic interference with HDD operations.

Multiple studies have demonstrated that failures of HDDs due to sound waves are most often linked to vibration of the mechanical components within the HDD. For example, vibration induced by the impingement of sound waves on the read-write heads can cause the head assemblies to vibrate and get out of alignment with the data track being read or written – hence a delay in the read-write operation (as noted by Gregg in his "shouting" experiment). Vibration of the platter may also be induced and result in a head crash causing permanent and, in some instances, irreparable damage to the HDD.

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[2] Shouting in the Data Center https://www.youtube.com/watch?v=tDacjrSCeq4

[3] Gaseous fire extinguishing agent systems come in two general categories: liquefied agent systems and inert gas systems. Both types of systems generate noise; further there are audible fire alarms associated with all fire extinguishing systems. Thus far all the reported incidents of interruption of HDD operation have been during discharge of inert gas systems.

Tendency for noise induced vibration of HDD components to affect data throughput or cause damage depends on the physical structure of the HDD drives exposed to sound waves. The tendency of HDD components to vibrate when exposed to sound waves depends on both the amplitude (sound pressure level SPL) and the frequency of the sound waves, not on sound pressure (decibels) alone. Objects all have "resonant" frequencies at which they vibrate freely and most vigorously. If the sound waves to which a HDD is exposed contain the resonant frequency of HDD components, the sound waves may cause those HDD components to resonate, i.e., vibrate at their resonant frequency.

For example, if a sound wave containing the resonant frequency of the read-write head assembly impinges on the HDD, the read-write head assembly may begin vibrating vigorously; vibrations may be large enough to displace the read-write head from the required position over the proper data track; hence data throughput will be reduced. Vibration of the platters during a read-write operation can have a similar effect. If the vibrations of the heads or the platters is severe enough, the heads may contact the spinning platter causing permanent loss of data and irreparable damage to the HDD. Sound waves containing the resonant frequencies of the HDD components can induce vibrations at much lower sound pressure levels than waves which do not include the HDD component's resonant frequencies.

While much of the focus regarding acoustic interference with HDD performance has been on sound waves in the audible range, a study by Bolton[i] et al reported loss of data due to acoustic waves in the ultrasonic range, another potential cause of HDD failure. Acoustic waves in the ultrasonic range can falsely trigger the shock sensors incorporated in some HDD causing the read-write heads to park, thus stopping data throughput.

Some Studies

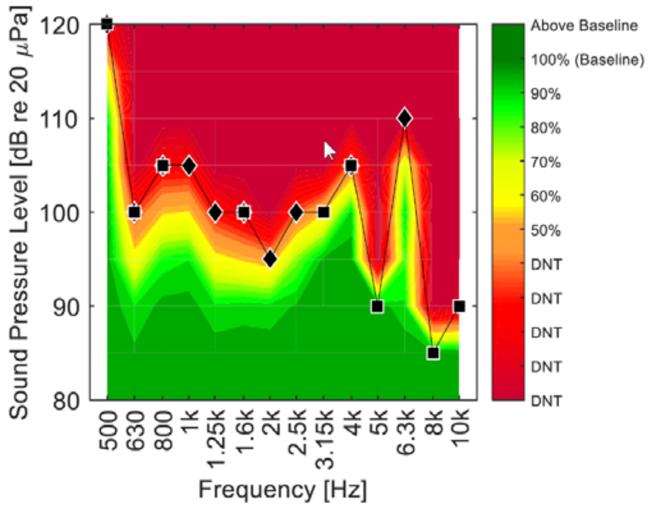
Tyco Fire Protection Products (now Johnson Controls), Siemens, and IBM are among those who investigated the effects of sound waves on HDD. Studies have also been performed at various colleges and universities including Michigan University, Zhejiang University, Purdue University, Princeton University, and Michigan Technological University.

In these studies, multiple makes and models of HDD were exposed to sound waves, the frequency and amplitude of which were controlled. The results conclude that the likelihood that sound waves will induce failures or damage to HDD depends on three factors:

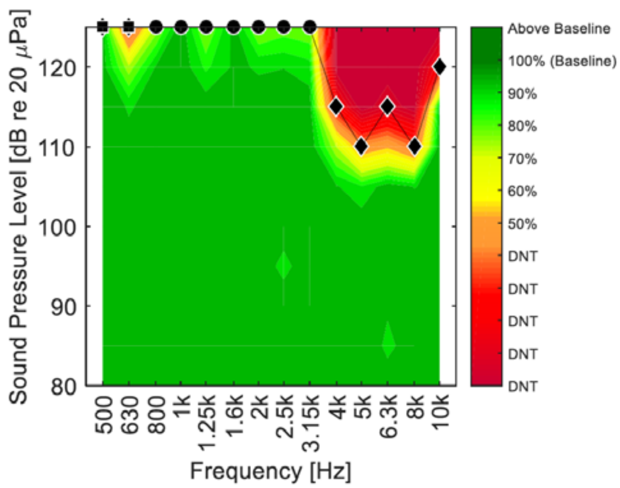
1. Frequencies contained in the sound waves impinging on the HDD
2. Amplitude of the sound waves which reach the HDD
3. The HDD itself.

The 2017 report "Performance of Hard Disk Drives in High Noise Environments"[4] submitted by T. Dutta as part of the requirements for a Master of Science degree at Michigan Technological University presented data showing the relationship between Sound Pressure Level and frequency required to cause a 50% reduction in data throughput for 14 different HDD makes and models. A few representative graphs are shown below. The black diamonds and squares on each graph indicate the point at which a 50% reduction in throughput was measured. Note that the amplitude of the sound wave needed to be increased by a relatively small amount from the 50% reduction point to cause complete loss of throughput.

[4] https://digitalcommons.mtu.edu/cgi/viewcontent.cgi?article=1491&context=etdr

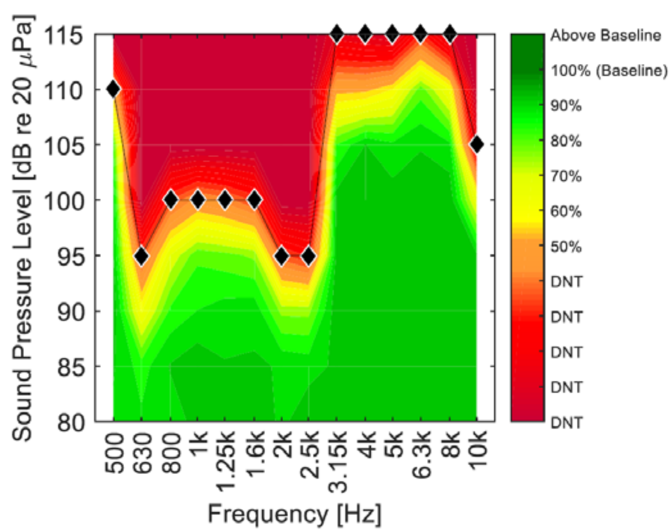


HDD A Graph SPL as low as 85 dB for a frequency of 8 kHz caused a 50% reduction. At a frequency of 6.3 kHz SPL had to be increased to 110 dB in order to cause a 50% reduction in data throughput.



HDD Graph B indicates that for frequencies between 500 and 630 Hz a SPL of 125 dB was required to cause a 50% loss of data throughput. For frequencies between 1 kHz and 3.15 kHz (black circles) no degradation of throughput was observed with SPL as high as 125 dB. At frequencies of 5 and 8 kHz SPL of 110 dB caused 50% reduction in throughput.

From the above graphs one might conclude that HDD are most sensitive to higher frequency sounds. One more graph for another of the 14 HDD models tested will dispel that conclusion:



HDD Graph C illustrate a HDD which is more sensitive to lower frequency sounds than to high frequency sound. 50% degradation of data throughput was measured at SPL of 95 dB at a frequency of 630 Hz. At high frequencies in the range of 3.15 kHz to 8 kHz the SPL had to be increased to 115 dB to produce a 50% reduction in data throughput.

From these graphs and the eleven additional graphs presented in Dutta's report, it is obvious that the sound pressure level required to cause serious loss of data throughput depends on the frequency of the sound wave and the design and construction of the HDD. The response of HDD to sound varies greatly from HDD model to HDD model.

What we know . . .

There are various reasons a HDD can fail resulting in temporary degradation of data throughput or permanent loss of data or permanent damage to the HDD. Anything that induces vibration in the HDD can cause such failures. In addition to physically shaking the HDD or causing the supporting structure (floor) on which the HDD is located to vibrate, the impingement of sound waves on the HDD can induce vibration.

The characteristics of sound waves which will cause notable reduction in data throughput vary from one HDD make and model to another. For a given HDD, the sound pressure level (SPL) required to substantially reduce throughput also depends on the frequency of the sound wave.

Tests have shown that sound pressure levels as low as 85 dB in the frequency range of 8 to 10 kHz can result in complete loss of throughput for at least one make/model of HDD. For another make/model of HDD, tests indicated that throughput continued at over 90% of "normal" when sound waves of 125 dB impinged on the HDD if the frequency of the sound wave was in the 800Hz to 2.5 kHz range.

When vibration of the HDD platters or read-write heads causes physical contact between the heads and the spinning platters ("head crash") permanent data loss and irreparable damage to the HDD is likely. Such vibration can be induced by anything that "shakes" the HDD including impingement of sound waves on the HDD. Such serious damage is generally linked to vibrations at resonant frequency of the HDD components.

Of course, age related mechanical failure of the HDD can also cause loss of data.

Fire Alarms

All of the fire safety systems discussed at the beginning of this document generate sound waves when they are activated. Smoke detection systems activate fire alarms. Water sprinklers activate fire alarms and water flow alarms. Gaseous agent systems activate fire alarms and produce sound waves as the fire extinguishing gas discharges into the protected data center.

NFPA Standard 72, the Fire Alarm and Signaling Code, requires the sound pressure level of audible fire alarm devices to be 15 dB above the average ambient sound pressure level[5] in the data center. The maximum sound pressure level generated by alarms and background noise may not exceed 110 dBA.

The average sound pressure levels in an operating data center are on the order of 70 to 85 dBA[ii]. Thus, the *minimum* SPL in the data center due to the fire alarms is required to be at least 85 dBA. If the average sound pressure level in the data center is closer to the upper end of the average reported SPL, the fire alarm must produce an SPL of nearly 100 dBA.

Of course, the SPL which will adversely affect HDD performance is linked to the combination of SPL and frequency – and required combination of SPL and frequency is known to vary between make/model of HDD. Most standard fire alarm horns produce a frequency in the range of 2 kHz to 4 kHz. Theoretically, based on the testing of various HDD for noise sensitivity and the know characteristics of fire alarms, failure of HDD due to sound waves generated by fire alarms appears to be possible. To date there have been no reported incidents of HDD failure (notable reduction of data throughput or damage to the drive) due to fire alarms activated by smoke detection systems or water sprinkler systems.

[5] For "public mode" NFPA Standard 72 Edition 2016, Chapter 18, requires the SPL from the alarm to be at least 15 dB above the average ambient sound pressure level or at least 5 dB above the maximum sound level that lasts at least 60 seconds, whichever is greater.

Gaseous Fire Extinguishing Systems

Gaseous clean agent fire extinguishing systems discharge fire extinguishing agent from one or more nozzles located within the protected room. As noted above, these systems extinguish fires using clean, dry agents are capable of greatly limiting fire damage and business interruption. The discharge of a gaseous agent from a nozzle produces sound waves. The amplitude of the sound waves and the frequency spectrum of the sound waves depends on the agent (liquid or gas), the physical design of the discharge nozzle, and the flow rate of agent from the nozzle. Sound pressure levels at the nozzles in excess of 130 dB have been measured at a variety of frequencies.

Theoretically the discharge of any gaseous agent could produce sound waves of sufficient amplitude and in the required frequency range to cause reduction in data throughput in a HDD, depending on the characteristics of the HDD. To date, reports of interruption of data throughput due to discharge of a fire extinguishing agent have centered around inert gas agent systems with no reported incidents linked to discharge of liquefied compressed gaseous agents. In 2012, Rawson and Green[iii] published an excellent article describing the phenomenon and recommending means to avoid loss of data and possible damage to HDD during a system discharge. The means recommended by Rawson and Green and some additional means are:

1. IMPROVED DESIGN OF HDD Realizing that sound waves have an impact on the performance of HDD, manufacturers of HDD could improve designs to reduce the possibility of adverse performance due to sound waves. Manufacturing equipment having sensitivity over a narrower range of frequency and at higher sound pressure level would reduce the chance of interruption of operation.
2. SHUTDOWN THE HDD All gaseous agent fire extinguishing agent systems sound an alarm prior to discharge of the agent. The alarm permits personnel to exit the data center. If HDD are shut down coincident with the sounding of the alarm the alarm, data loss and HDD damage will be avoided. While an obvious way to avoid data loss due to sound waves produced by fire safety systems, many modern data centers desire to not shut down HDDs to minimize customer interruption.
3. REDUCE THE SOUND AT SOURCE Lessening the flow rate from a given nozzle will reduce the amplitude of the sound waves. Thus, the use of multiple nozzles versus a single nozzle to discharge a given quantity of agent will lessen the amplitude of the sound waves generated by each nozzle. Some inert gas system manufacturers have developed “silent” nozzles which, although they are not totally “silent,” do produce sound waves of considerably less amplitude than “standard” nozzles. Using such nozzles reduces the likelihood of shutting down data throughput and causing permanent damage to the HDD. Because of range of frequencies and related amplitudes of the sound to which various HDD are sensitive, use of these “silent” nozzles cannot guarantee that data loss or damage will not occur to all the current and future HDD which might be found in a given data center.
4. PLACEMENT OF NOZZLES WITH RESPECT TO HDDS Avoid placing HDDs close to nozzles. Increasing distance helps reduce of the sound pressure level at the drives.
5. USE OF MODELING TOOLS TO FIND WAYS TO REDUCE NOISE REACHING HDD One manufacturer has developed a tool that can be used to calculate the sound pressure level reaching the HDD. The tool relies on a number of inputs, such as the type of sound absorbing material used in the construction of the data center (different materials of construction reflect or absorb sound differently), the number of racks present (as each object in the space will absorb sound), the agent flow rate (as this directly affects the sound generated), and the number and location of nozzles used in the system). More information on this technology may be found in a white paper[iv] by Sandahl, Elder, and Barnard. Use of such modeling tools can help in determining steps to alleviate the impact of noise on HDDs.
6. REDUCE THE SOUND REACHING THE HDD Many IT equipment manufacturers can provide acoustic sound insulating covers and doors for IT equipment racks. The use of such acoustic barriers on HDD racks can prevent potentially harmful sound waves from all external sources from reaching the HDD. Only acoustic barriers approved by the IT equipment manufacturer should be installed. The installation of “home-made” barriers has potential to block airflow and cause overheating of equipment. In addition to or in lieu of shielding individual equipment racks from external sound waves, the amount of acoustic energy reaching HDD can be decreased

by increasing general room acoustic absorption across the critical frequencies of 500 to 10k Hz. This can be done with special wall and ceiling treatments such as those used in recording studios. The location of nozzles at the greatest possible distance away from HDD arrays will also reduce the acoustic energy which reaches a HDD.

7. USE OF ROBUST HDDs Since there is a notable difference between the noise sensitivity of the various makes and models of HDD, the use of HDDs requiring the greatest sound pressure level and the narrowest frequency band before loss of data throughput will reduce the likelihood of data loss and HDD damage.
8. USE OF SOLID-STATE DATA (SSD) STORAGE DEVICES, having no moving parts, would eliminate sensitivity to sound waves and all other causes of vibration. Advanced SSD devices are currently available and offer a number of advantages over traditional HDD including elimination of sensitivity to vibrations. The article "What the Future Holds for Data Storage"[v] provides an update on the technologies currently available for ultra-high speed and capacity data storage.

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[i] "Blue Note: How Intentional Acoustic Interference Damages Availability and Integrity in Hard Disk Drives and Operating Systems" Connor Bolton, Sara Rampazzi, Chaohao Li, Andrew Kwong, Wenyuan Xu and Kevin Fu, University of Michigan, Zhejiang University, Reported at the IEEE Symposium on Security and Privacy 2018

[ii] "Noise within a Data Center" Dubravko Miljković, Hrvatska elektroprivreda, Zagreb, Croatia; dubravko.miljkovic@hep.hr

[iii] "Inert Gas Data Center Fire Protection and Hard Disk Drive Damage" Rawson, B. P., & Green, K. C. (2012). Data Center Journal, http://www.datacenterjournal.com/inert-gas-data-center-fire-protection-and-hard-disk-drive-damage/ .

[iv] "The impact of sound on computer hard disk drives and risk mitigation measures" Sandal, Elder, & Barnard. https://www.sensecosystems.com/wp-content/uploads/2017/12/White-Paper-on-Data-Center-Acoustic-Research-1.pdf

[v] "What the Future Holds for Data Storage" http://www.itpro.co.uk/solid-state-storage-ssd/31387/what-the-future-holds-for-data-storage