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Holographic Visualization of Sound Radiation from Computer Hard Drives

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HOLOGRAPHIC VISUALIZATION OF SOUND RADIATION FROM COMPUTER HARD DRIVES

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INTRODUCTION

- Sound radiation from computer hard drives
  - Computer hard drives are relatively compact in size.
  - Source of hard drives are closely spaced.
    e.g., disc, disc bearing, head mechanism, surface vibration
  - Span wide frequency range
    e.g., 120 Hz ~ 10 kHz.
  - Coherent or incoherent
  - Limited position for reference measurement
- Statistically Optimized Nearfield Acoustical Hologrpahy
  - High resolution
  - Multi-reference acoustical holographic procedure

Sound Radiation from Hard Drives

- SONAH formulation (1)

- The sound pressure, $p(\mathbf{r})$, can be expressed as linear combination of the measured sound pressure $p(\mathbf{r}_n)$,

$$p(\mathrm{r}) \approx \sum_{n=1}^{N} c_n(\mathrm{r}) p(\mathrm{r_n})$$

- If a good representation of the sound field can be obtained by using a finite subset of wave functions, the coefficients c_n can be determined.

$$\Phi_{\mathrm{Km}}(\mathrm{r}) \approx \sum_{n=1}^{N} c_n(\mathrm{r}) \Phi_{\mathrm{Km}}(\mathrm{r_n}), \qquad m = 1 \quad \ldots \quad M$$

Sound Radiation from Hard Drives

- SONAH formulation (2)

$$p(x,y,z)=\frac{1}{(2\pi)^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}P(\mathbf{K})\Phi_{\mathrm{K}}(x,y,z)\,d\,\mathbf{K}$$

- Defining wave function,

$$\Phi_{\mathrm{K}}(x,y,z)\equiv e^{i\left(k_x x+k_y y+k_z(z+d)\right)},\qquad z\geq z_s=-d$$

where,

$$k_z=\begin{cases}\sqrt{k^2-|\mathbf{K}|^2} & \text{for}\quad k\geq|\mathbf{K}|\\ -i\sqrt{|\mathbf{K}|^2-k^2} & \text{for}\quad k<|\mathbf{K}|\end{cases}$$

Sound Radiation from Hard Drives

- SONAH formulation (3)

$$\mathbf{A} \equiv \left[\Phi_{\mathrm{K}q,m}(\mathbf{r}_{h,j}) \right] \quad , \quad \boldsymbol{\alpha}(\mathbf{r}) \equiv \left[\Phi_{\mathrm{K}q,m}(\mathbf{r}) \right] \quad , \quad \mathbf{c}(\mathbf{r}) \equiv \left[c_j(\mathbf{r}) \right].$$

- Estimated pressure $p(\mathbf{r})$ is,

$$p(\mathbf{r}) \approx \sum_{n=1}^{N} c_n(\mathbf{r}) p(\mathbf{r}_n) = \mathrm{p}^{\mathrm{T}} \mathrm{c}(\mathbf{r}) = \mathrm{p}^{\mathrm{T}} \left(\mathrm{A}^{+}\mathrm{A} + \theta^2 \mathrm{I} \right)^{-1} \mathrm{A}^{+} \alpha(\mathbf{r})$$

where, $\mathbf{p}^{\mathrm{T}}$ is measured pressure vector at $\mathbf{r}_{\mathrm{n}}$

- Estimated normal particle velocity $u_z(\mathbf{r})$ is,

$$u_z(\mathbf{r}) \approx \mathrm{p}^{\mathrm{T}} \left(\mathrm{A}^{+}\mathrm{A} + \theta^2 \mathrm{I} \right)^{-1} \mathrm{A}^{+} \beta(\mathbf{r})$$

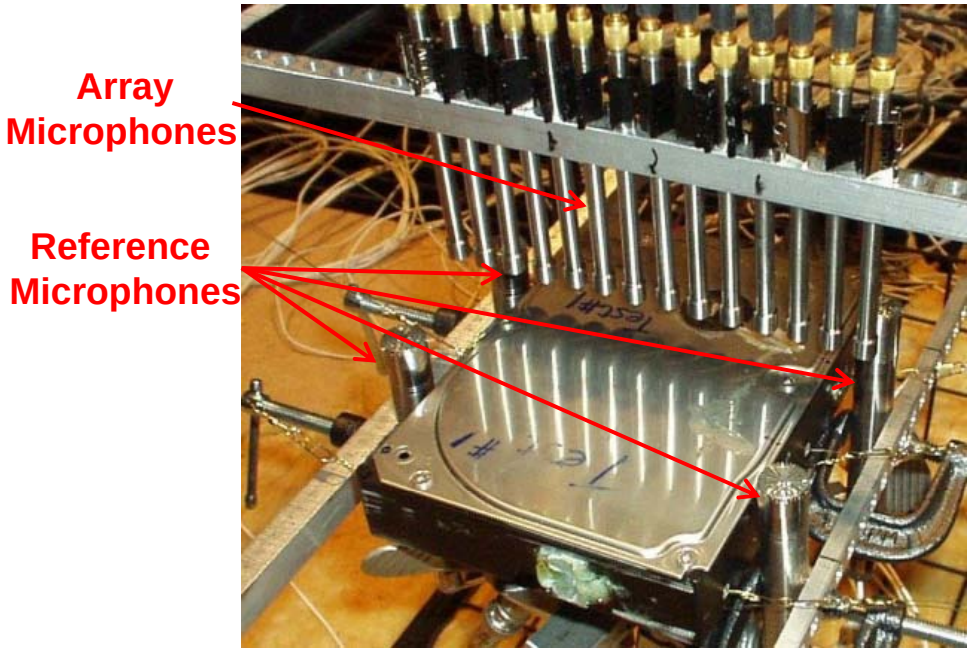
where, $\mathbf{A}^{+}\boldsymbol{\beta}(\mathbf{r})$ is a correlation vector that relates measured pressure and particle velocity.

Sound Radiation from Hard Drives

- Hard drive measurement

Top surface

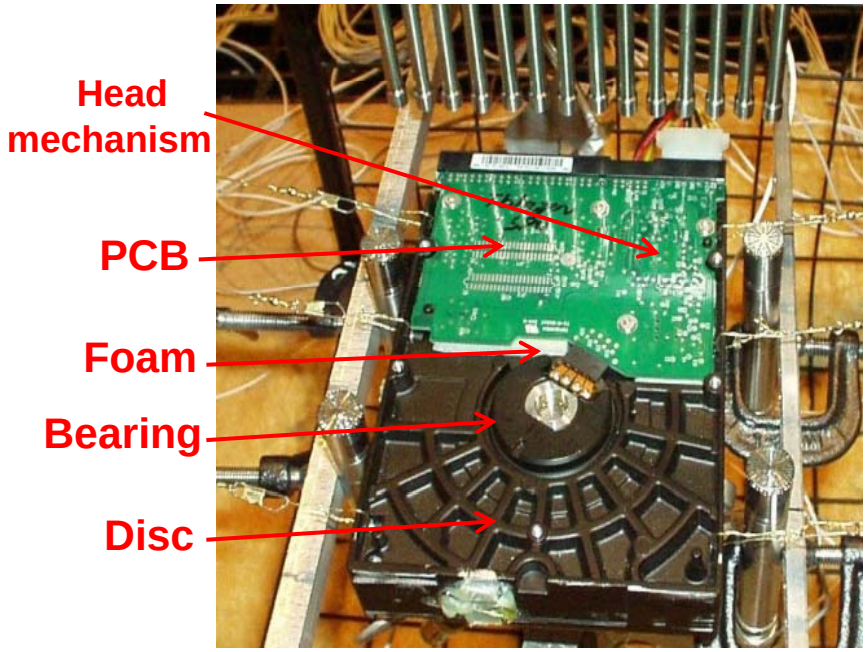
(z_o=1 cm, N_x=14, N_y=17)



x_{inc} = 1 cm, y_{inc} = 1 cm

Bottom surface

(z_o=1 cm, N_x=14, N_y=17)



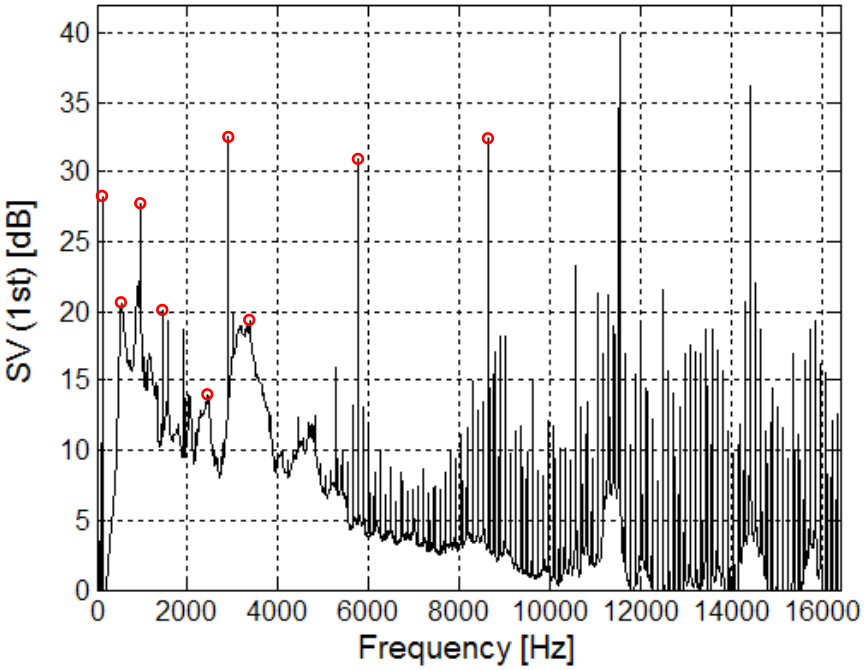
x_{inc} = 1 cm, y_{inc} = 1 cm

Sound Radiation from Hard Drives

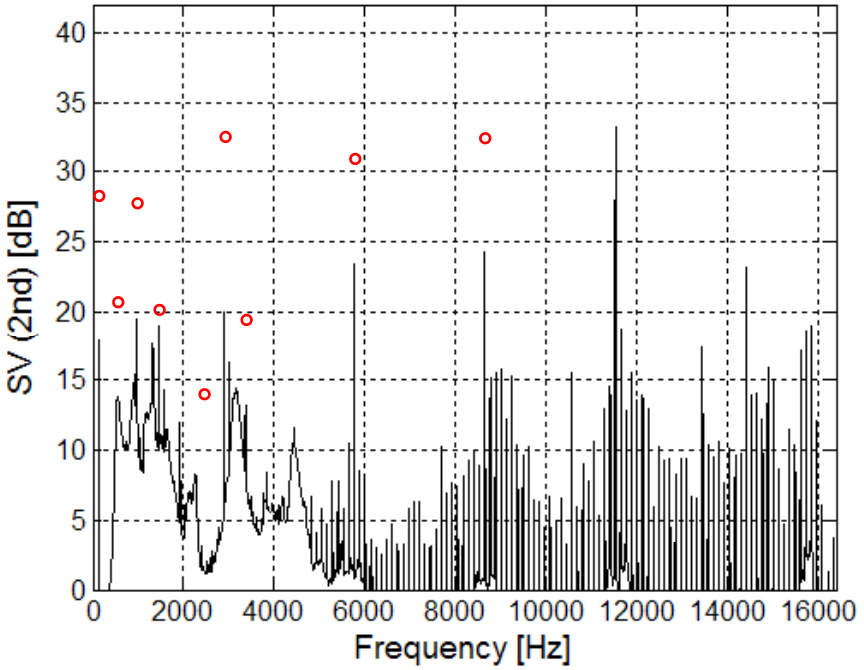
- Hard drive measurement result

Singular values of reference measurement

First Singular Values



Second Singular Values



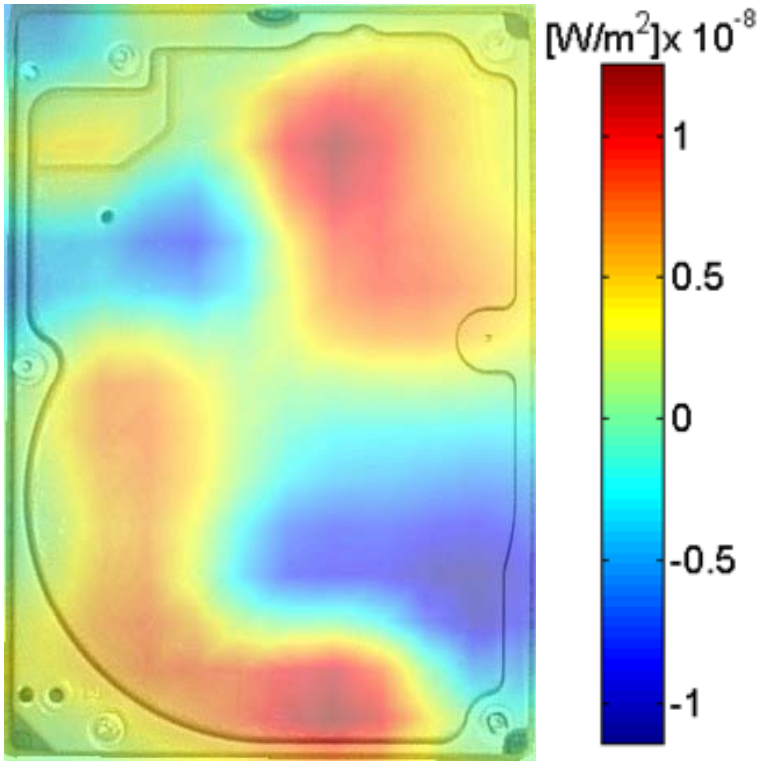
Difference between first and second singular values > 7 dB

However, six singular values with regularization are used for reconstruction

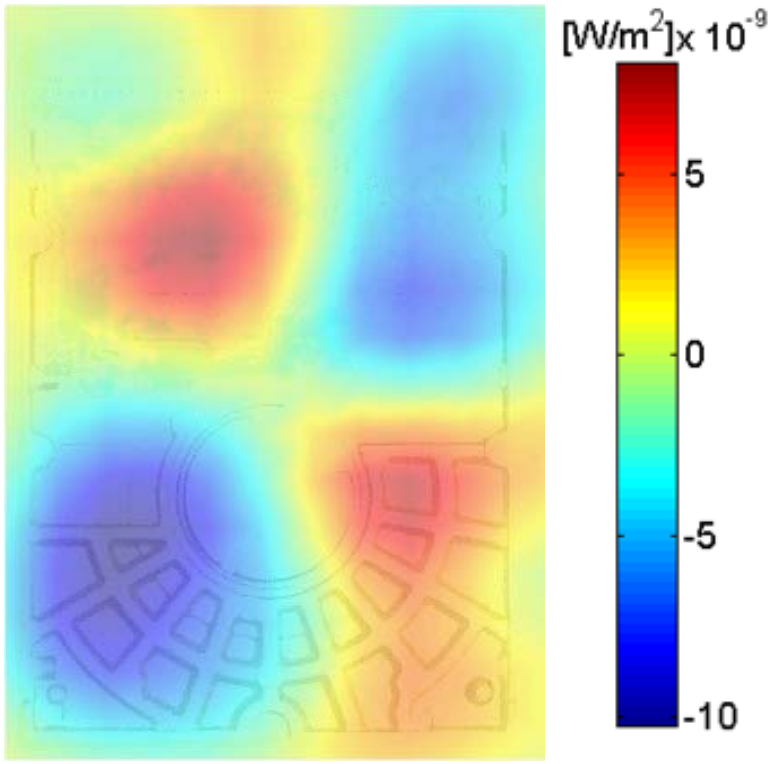
Sound Radiation from Hard Drives

- Sound intensity estimate, 120 Hz

Top surface*



Bottom surface

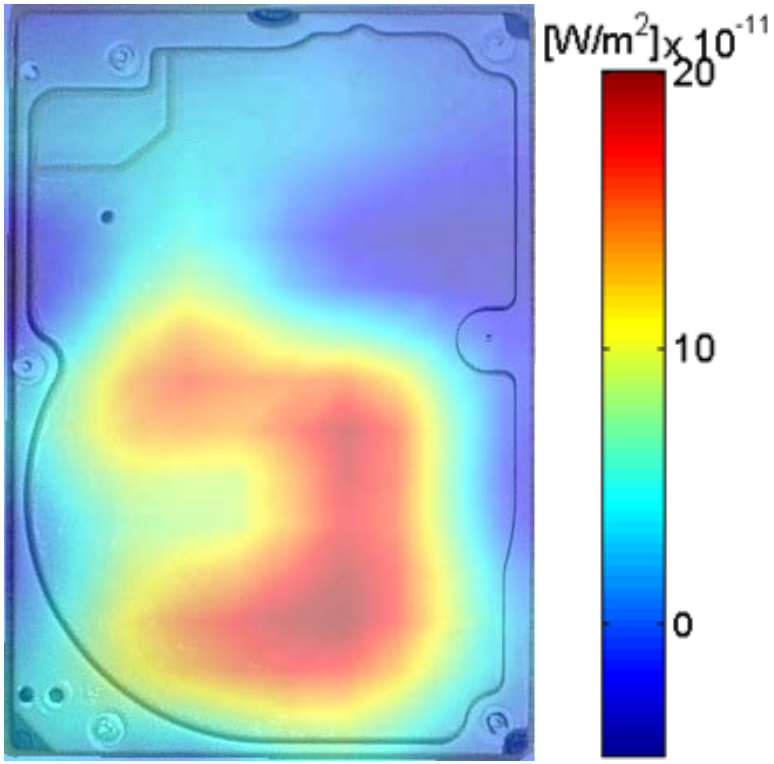


Rocking motion of hard drive

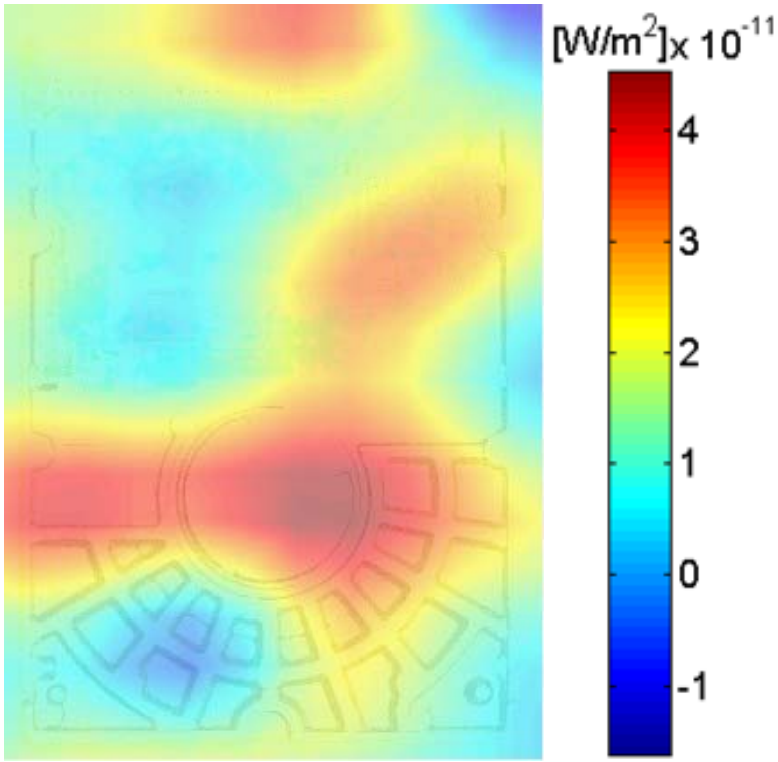
Sound Radiation from Hard Drives

- Sound intensity estimate, 600 Hz

Top surface*



Bottom surface

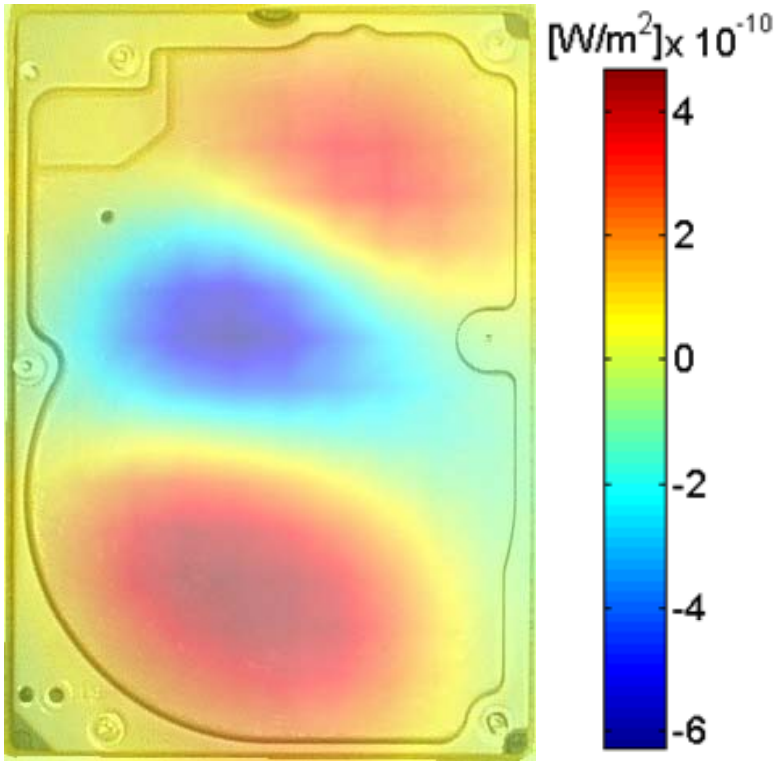


Radiation due to vibration of hard drive

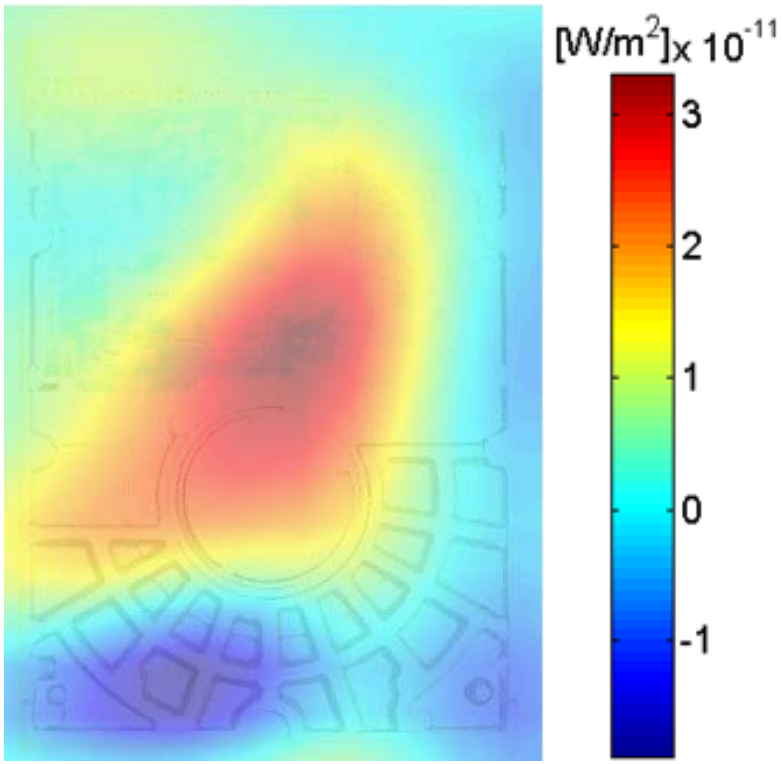
Sound Radiation from Hard Drives

- Sound intensity estimate, 1172 Hz

Top surface*



Bottom surface

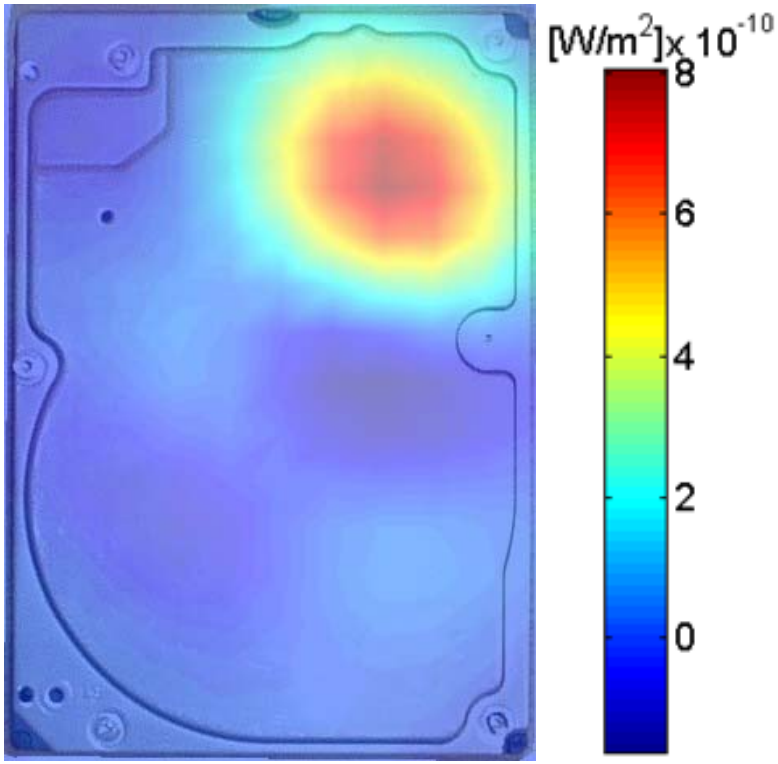


Radiation due to vibration of hard drive

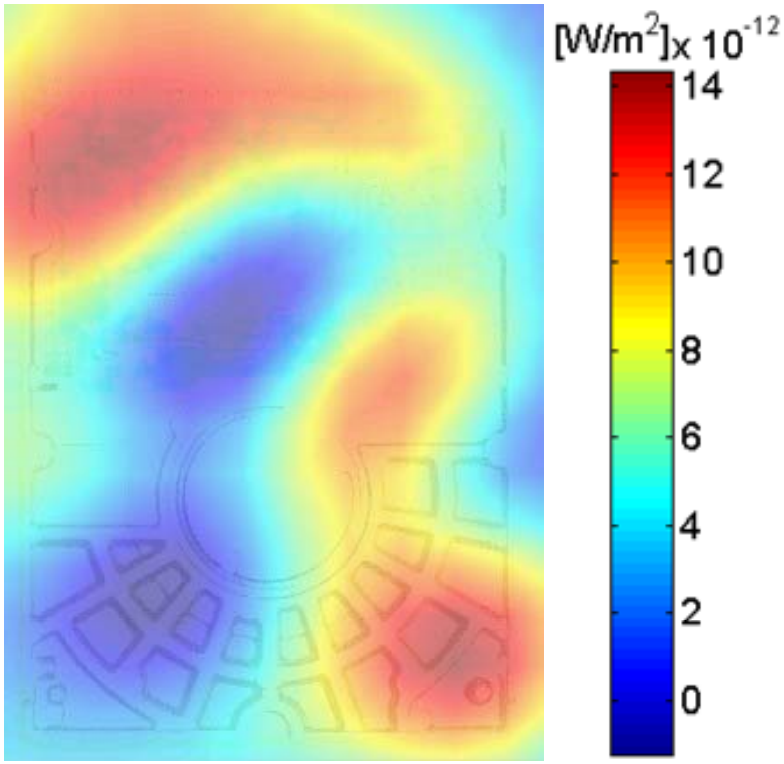
Sound Radiation from Hard Drives

- Sound intensity estimate, 1672 Hz

Top surface*



Bottom surface

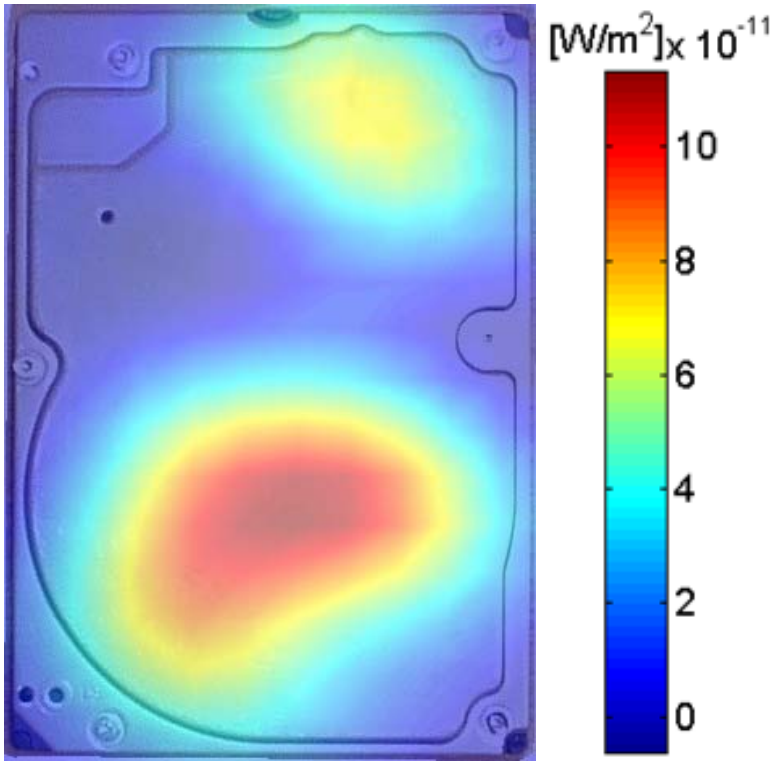


Radiation due to vibration of hard drive

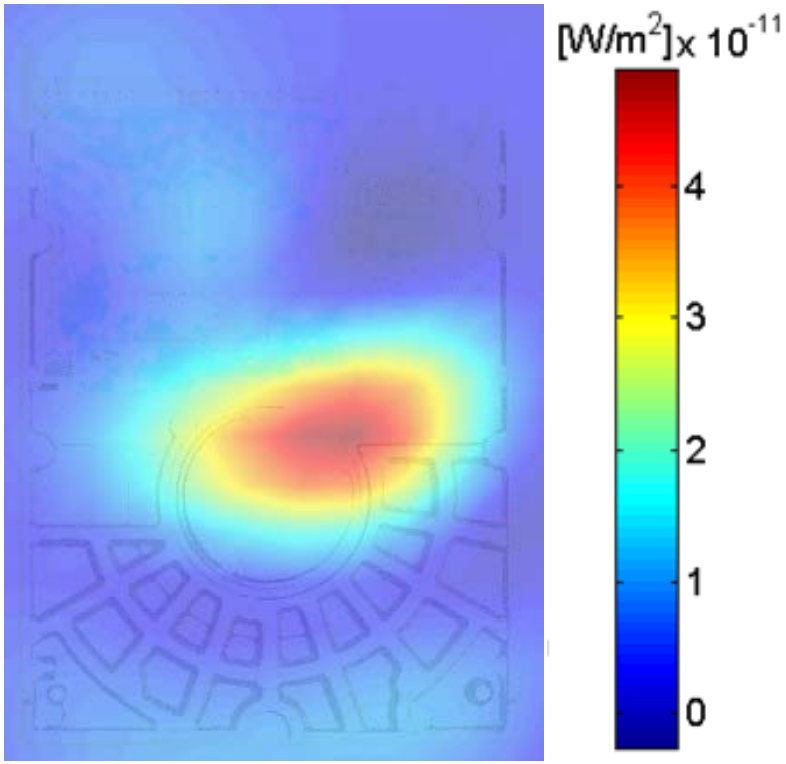
Sound Radiation from Hard Drives

- Sound intensity estimate, 2332 Hz

Top surface*



Bottom surface

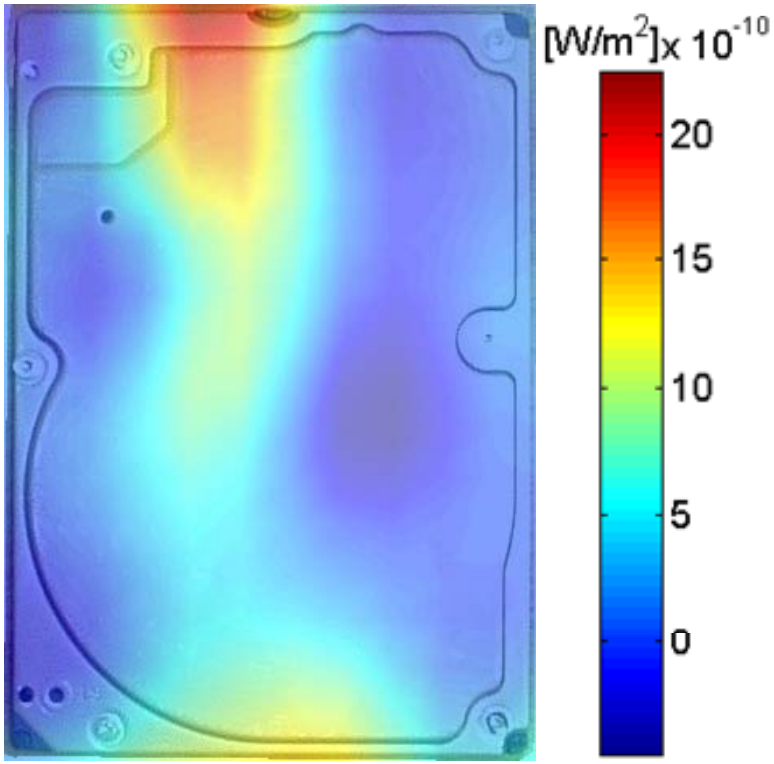


Radiation by disc from the top surface

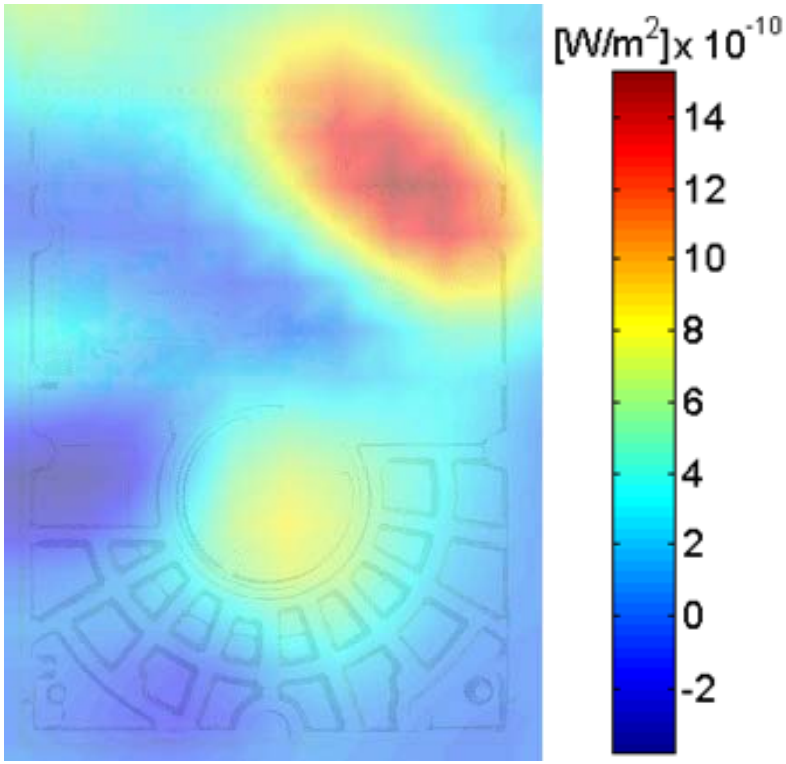
Sound Radiation from Hard Drives

- Sound intensity estimate, 2884 Hz

Top surface



Bottom surface*

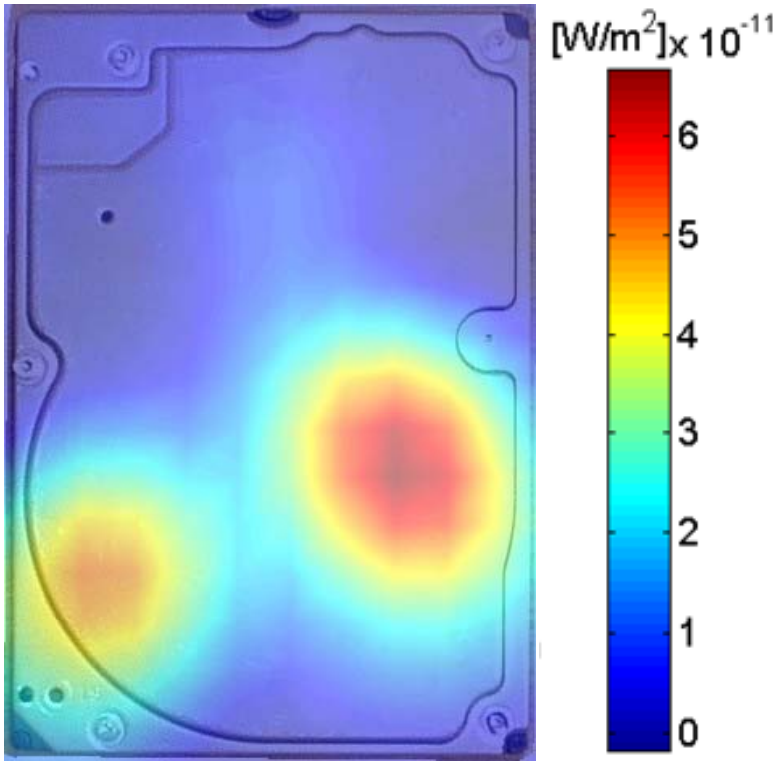


Power connector and head mechanism

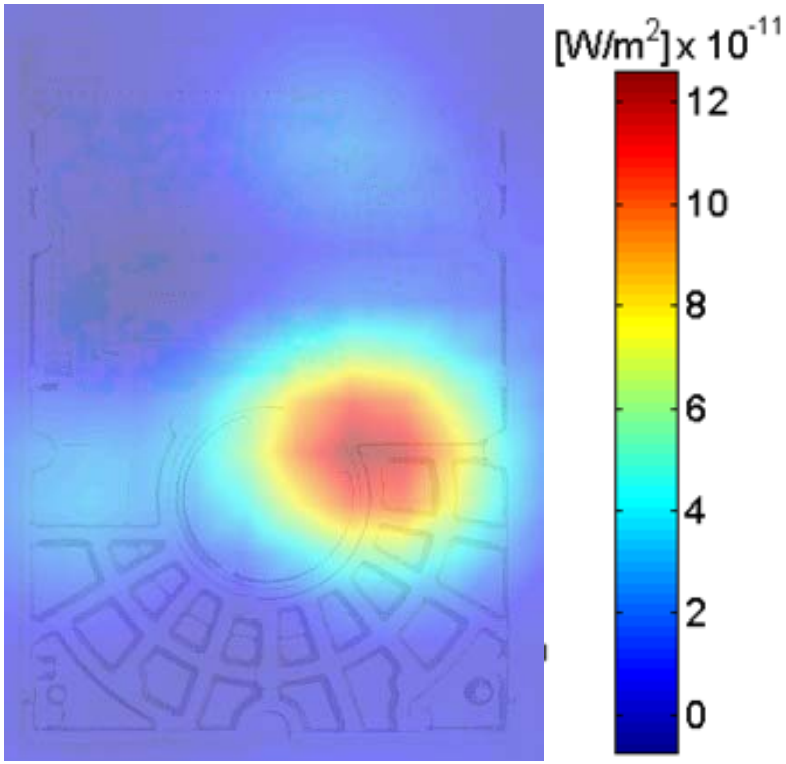
Sound Radiation from Hard Drives

- Sound intensity estimate, 3068 Hz

Top surface



Bottom surface*

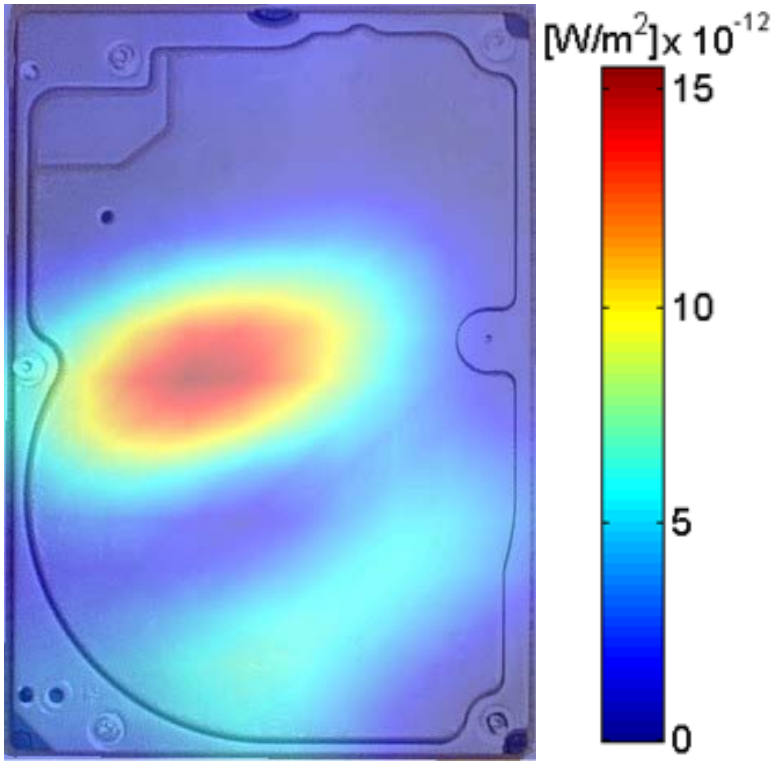


Disc bearing

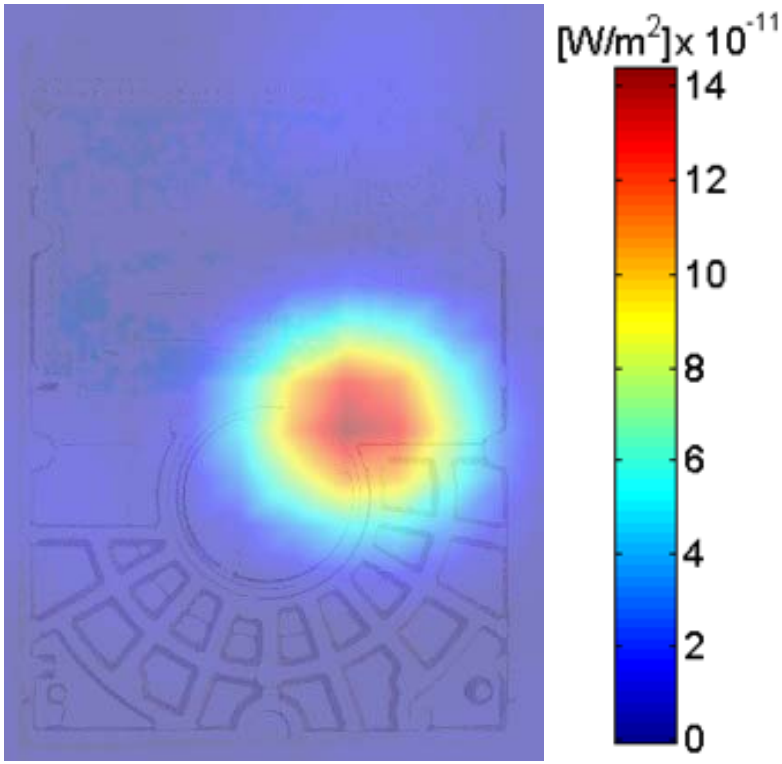
Sound Radiation from Hard Drives

- Sound intensity estimate, 3592 Hz

Top surface



Bottom surface*

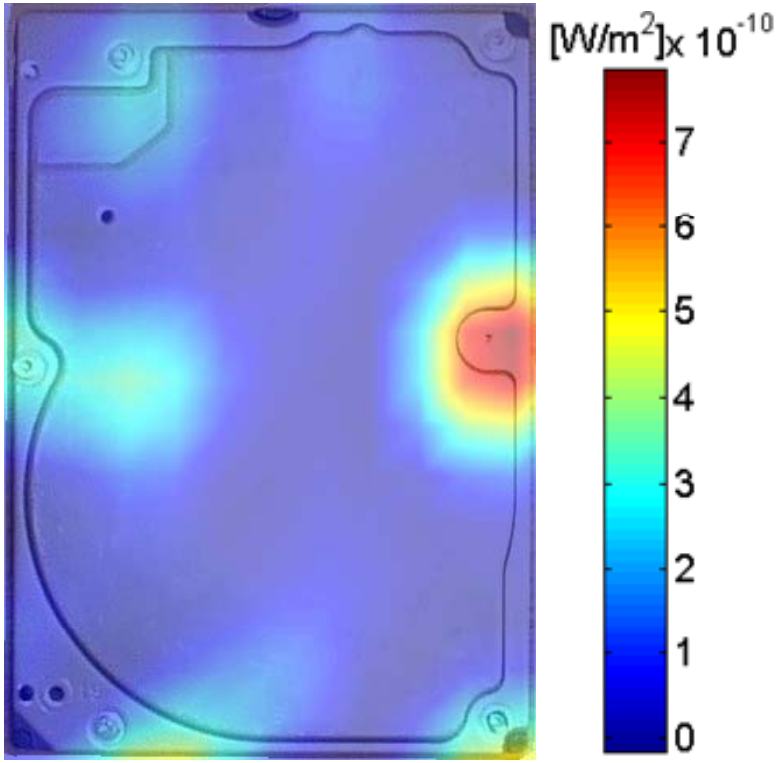


Disc bearing

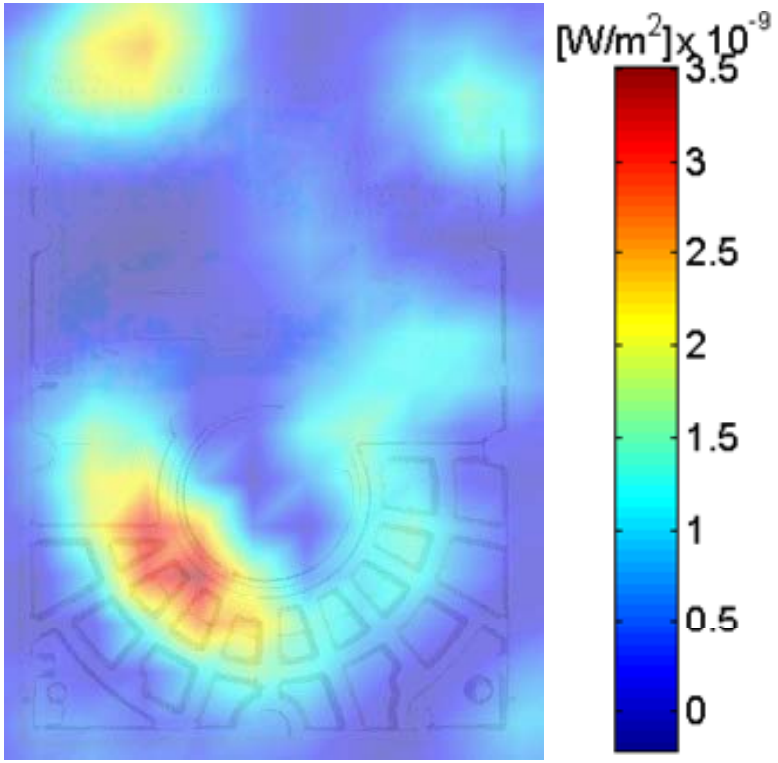
Sound Radiation from Hard Drives

- Sound intensity estimate, 5764 Hz

Top surface



Bottom surface*

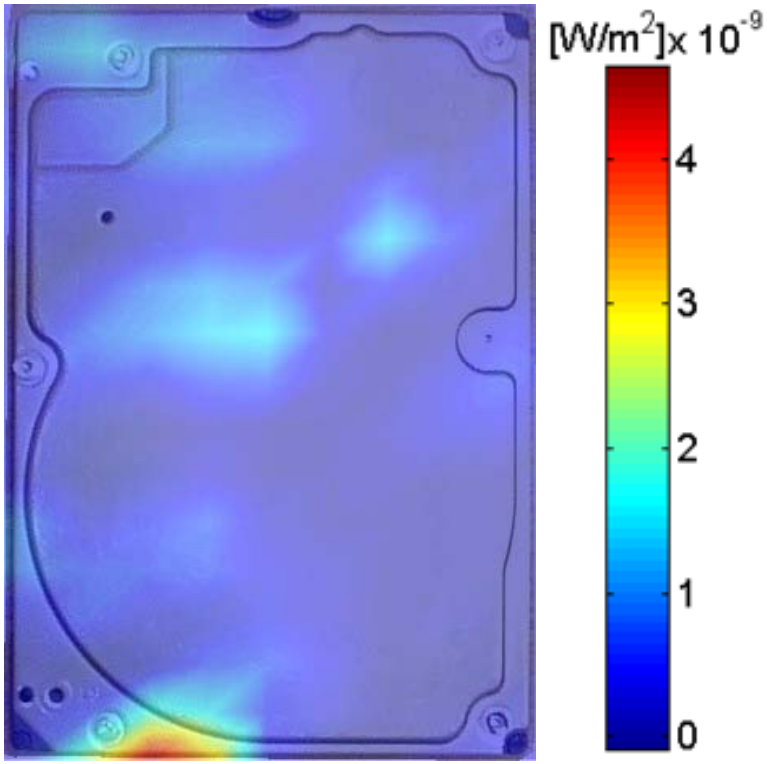


Disc bearing

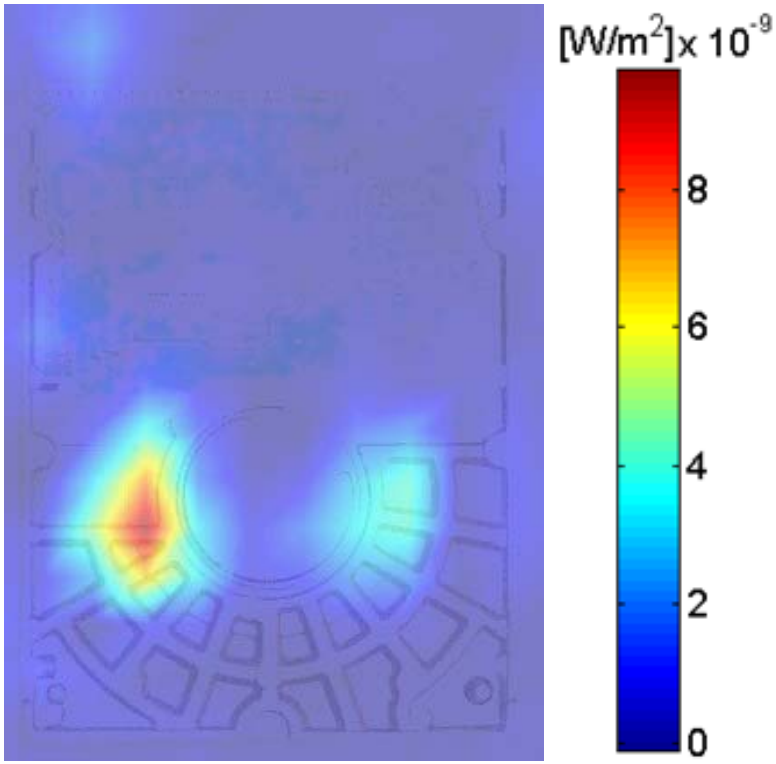
Sound Radiation from Hard Drives

- Sound intensity estimate, 8648 Hz

Top surface



Bottom surface*

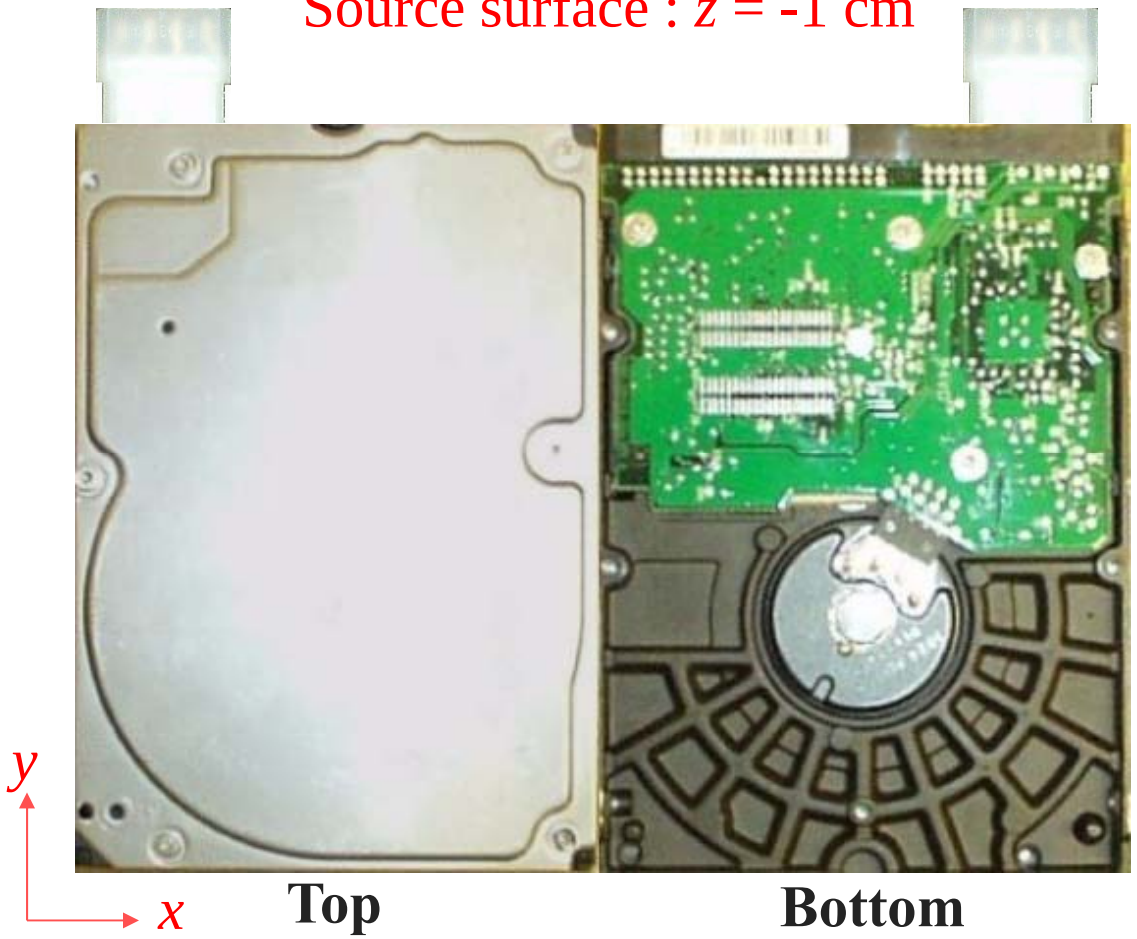


Disc bearing

Sound Radiation from Hard Drives

Animation coordinate

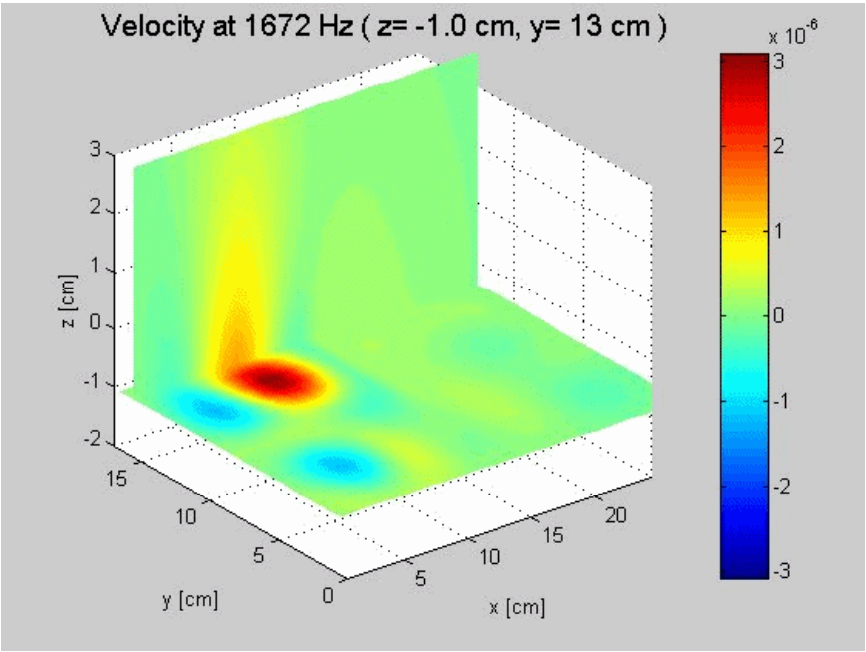
Source surface : z = -1 cm



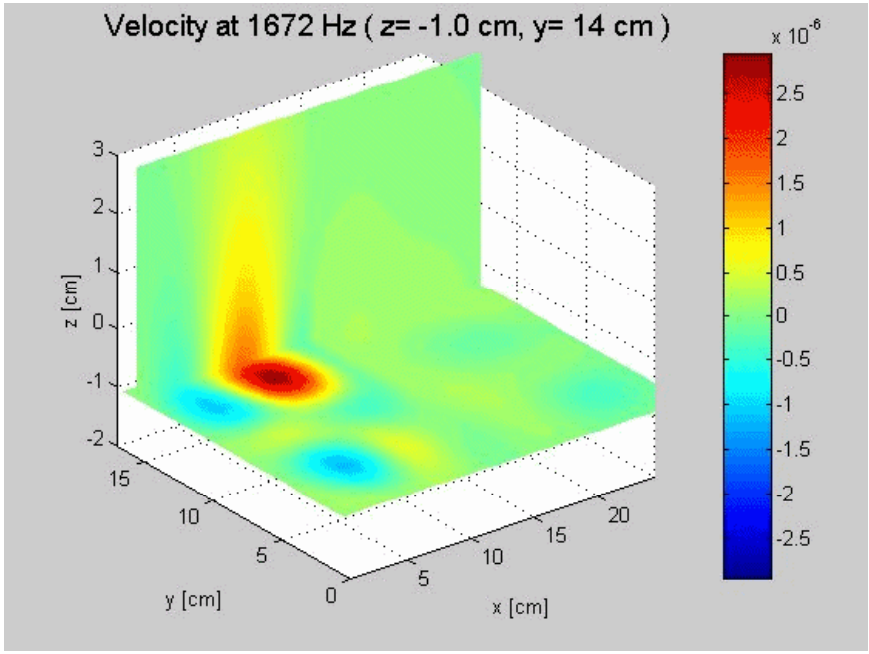
Sound Radiation from Hard Drives

Velocity, 1672 Hz

Base model: Top and Bottom



W/o Foam: Top and Bottom

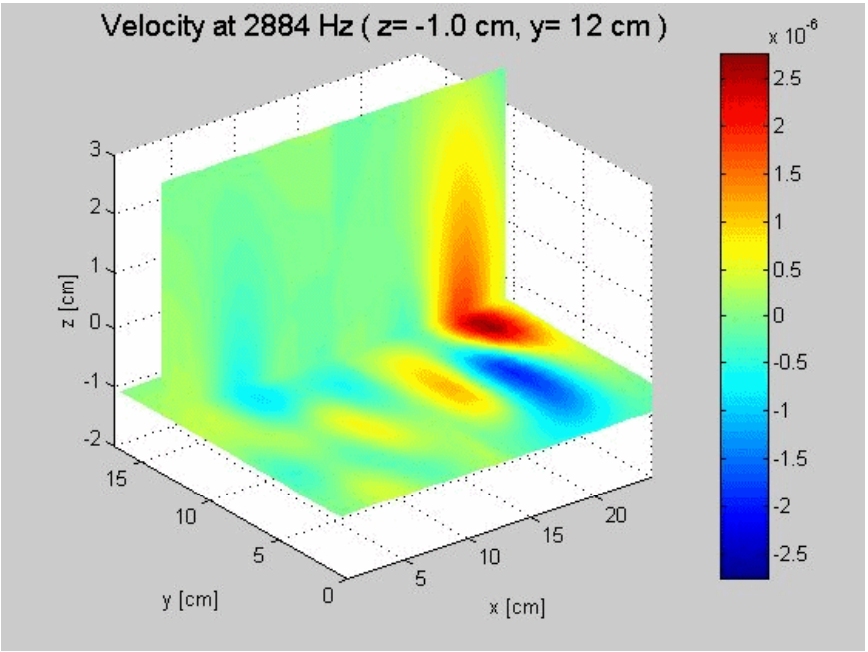


Radiation due to vibration of hard drive

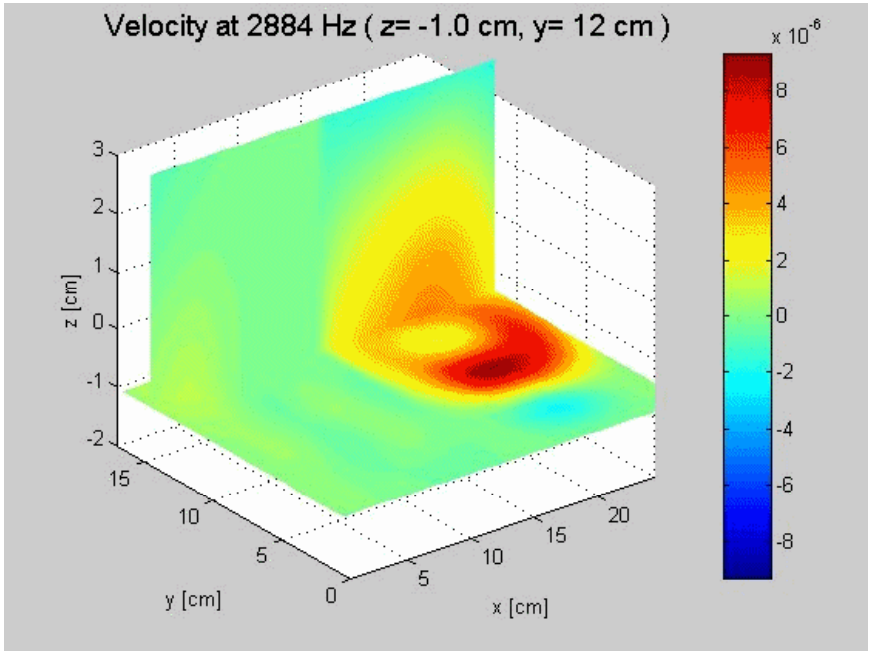
Sound Radiation from Hard Drives

Velocity, 2884 Hz

Base model: Top and Bottom



W/o Foam: Top and Bottom

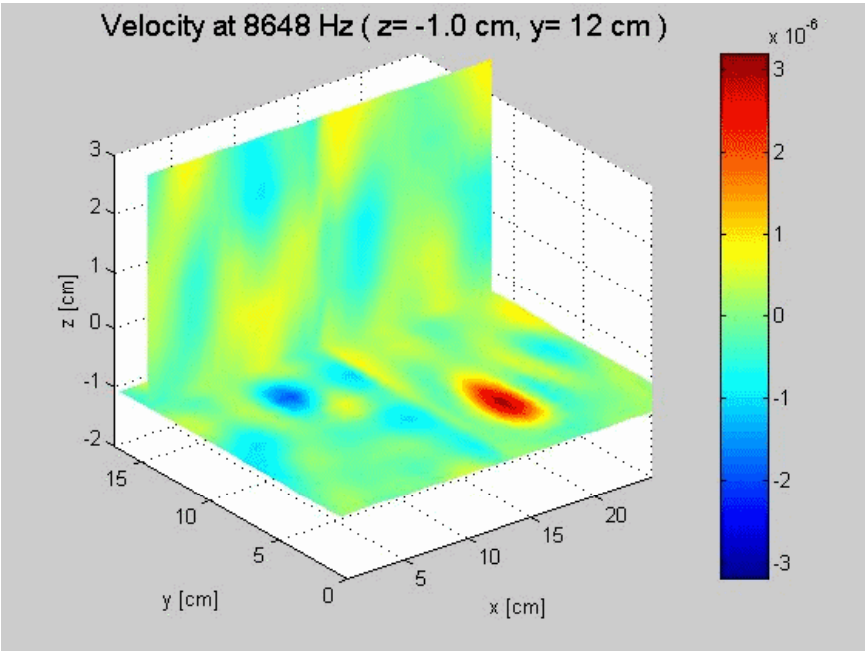


Power connector and head mechanism

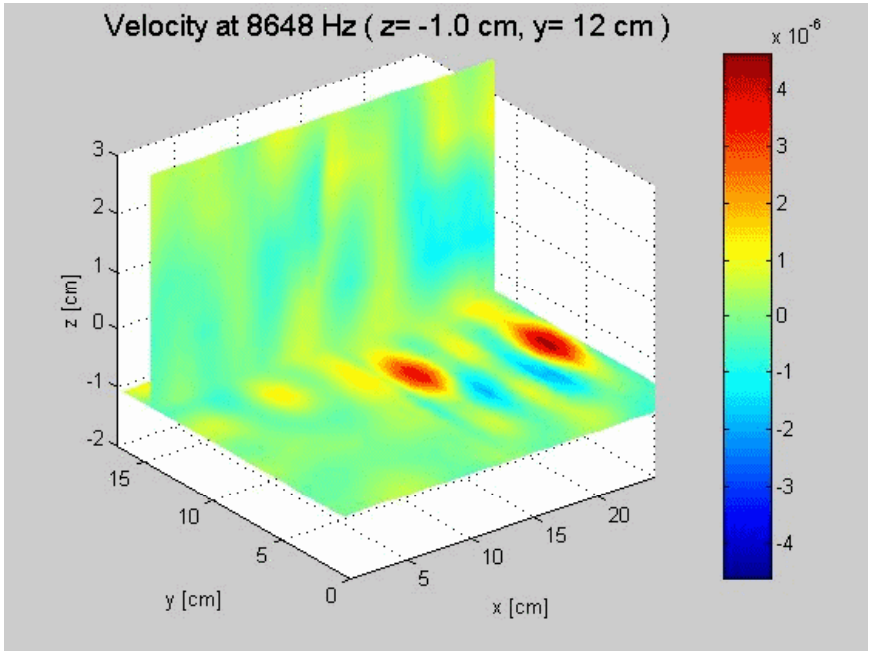
Sound Radiation from Hard Drives

Velocity, 8648 Hz

Base model: Top and Bottom



W/o Foam: Top and Bottom



Disc bearing

Sound Radiation from Hard Drives

- Conclusions

- **Possible to visualize closely located sources on compact machine accurately by using high resolution, multi-reference acoustical holographic procedure over a wide range of frequencies**
- **Sound radiation from disc bearing, disc, head mechanism, and hard drive shell were clearly visualized over wide range of frequencies**
- **Clearly shown that sound radiation above 3 kHz is primarily from disc bearing**
- **Sound absorption by using relatively thin sound absorption material placed beneath the PCB was clearly visualized**