This poster was presented at the 8th Biennial Workshop on Single Molecule Biophysics (SMB) in Aspen, Colorado, January 5-9, 2015

TMC VIBRATION CONTROL
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Vibration Isolation Strategies for Biophysics

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Solutions and Approaches to Enhance Resolution

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ABSTRACT

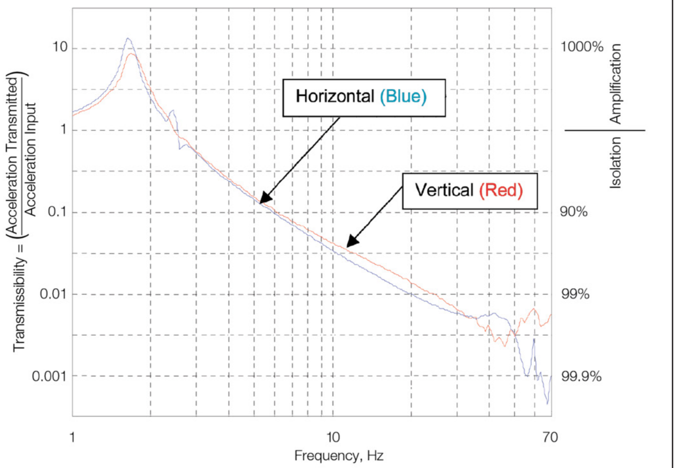
Ambient vibration presents a resolution limit for microscopies of all types. It diminishes the localizability of features in obvious ways — an escalating issue for the long acquisition times and diminishing scale of today's imaging applications.

What may not be obvious is the interplay of mechanical, seismic, cable-borne and acoustic stimuli. Bolting equipment to a generic air-table is insufficient to achieve today's required nanoscale stabilities.

Here we provide a concise review of isolation approaches ranging from the classical to the latest. We also spotlight under appreciated contributors to system instabilities and suggest productive strategies for mitigation.

CONVENTIONAL AIR ISOLATORS

The air table has been a common tool for improving stability since the 1970s. A pressurized diaphragm supports the table-top while providing a low-friction, weak-spring support that attenuates high-frequency vibration from the floor. The resulting spring-mass system presents a transmissibility curve with a typical resonant frequency (F_{res}) of 1-3Hz, amplifying spectral components near these frequencies. See Figure 1.



Measured performance of TMC 14 Series Micro-g® System 1 Gimbal Piston™ Isolators

FIGURE 1. Conventional air isolator transmissibility curve

PIEZO TECHNOLOGY ADDRESSES LOW-FREQUENCY TRANSMISSIBILITY AND AMPLIFICATION

FIGURE 2.
High-force piezo stacks

Air isolators provide good attenuation of high-frequency components of floor vibration, but their transmission of low frequencies and amplification at F_{res} in the 1-3Hz range is problematic for advanced imaging techniques.

Fortunately, the piezoelectric technology that provides responsive nano-actuation and long-term positional stability of sample positioners, objectives and scanning probes [1] has been leveraged in novel isolators that actively nullify low-frequency transmitted floor excitation. In these truly active vibration cancellation systems, sensors continuously monitor and measure floor vibration, and the piezoelectric devices expand and contract to deliver canceling forces in real time under digital control [2].

In a unique hybrid approach of specific interest for advanced microscopies, high-reliability piezoelectric active nullification technology is combined with pneumatic isolation elements to provide exceptional combined isolation.

In this approach, the strengths of each technology is leveraged: the piezoelectric active isolation addresses the transmissibility and amplification of the pneumatic element at low frequencies, while the pneumatic element addresses the inevitably finite bandwidth of the active isolation technology. See Figure 3.

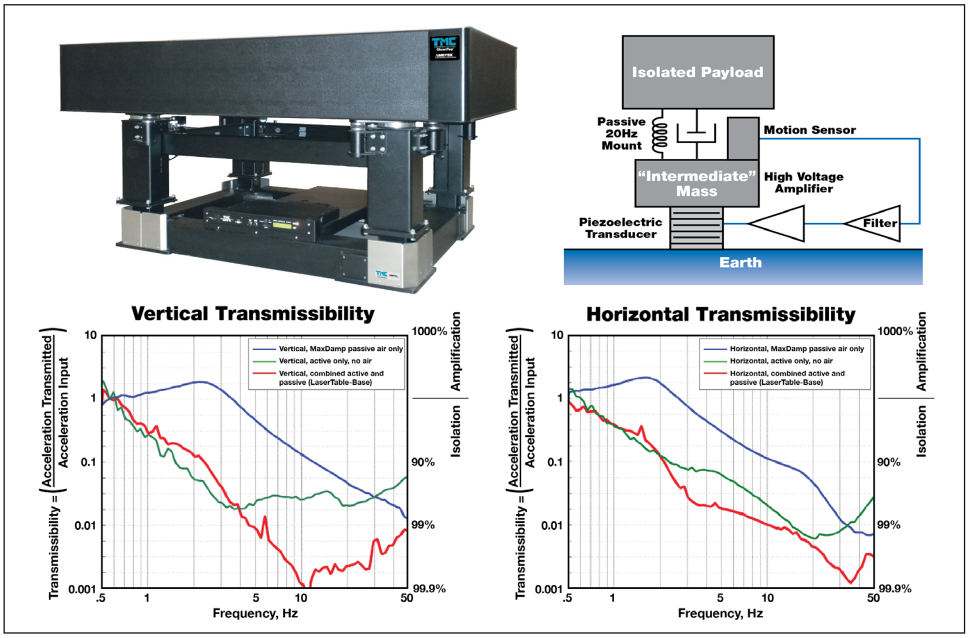


FIGURE 3.
Comparative transmissibilities for passive vs. hybrid isolation.

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THE FLOOR IS ONLY ONE SOURCE

Tables are resonant structures. Damping elements integrated into better models reduce their response to stimulus, whether a residuum of floor vibration through the isolators, or from acoustic, cable-borne or onboard sources such as fans and transformers. Mitigation strategies include:

- ***Leverage structural nodes***
  Mounting isolators on the node-lines of the lowest-order resonant mode reduces excitation. (As familiar from Chladni analysis, these node-lines reside approximately 20% of a rectangular leaf's length from the short sides of the leaf.) This is also the place to drape cables which can convey vibration.

- ***Reduce coupling of acoustic room-modes***
  A box on the table can isolate optics from obvious air currents, but acoustic disturbances are another matter. While a helium-filled enclosure has been shown to reduce the noise spectral density due to reduced path fluctuations [3], airborne disturbances are coupled directly to the isolated platform.
  For a typical laboratory of 10 meter length, the lowest longitudinal room mode frequency is $f = c / 2L$; the speed of sound c ~ 340 m/sec, so f ~ 17Hz. This is subaudible but definitely problematic for sensitive equipment. Mitigation includes using separate frames for shielding boxes and reducing their surface area (Figure 4). "Bass traps" from recording-studio engineering can also help.

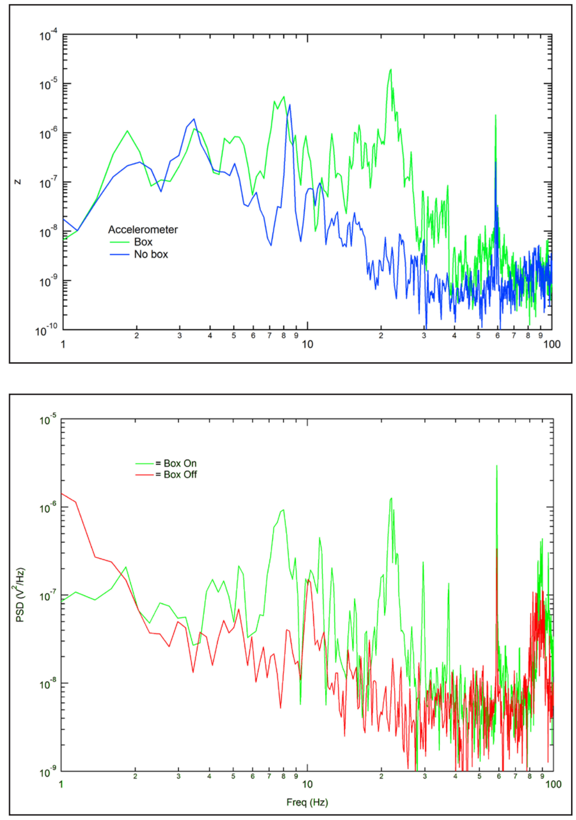

FIGURE 4.
Before/after quiescent spectra of an advanced microscopy apparatus with "isolation box" attached or removed from the table-top [4]. Top: accelerometer data. Bottom: Data observed at AFM tip. [Courtesy Thomas Perkins, JILA, National Institute of Standards and Technology and University of Colorado, Boulder].

Additional Application Photos of LaserTable-Base™

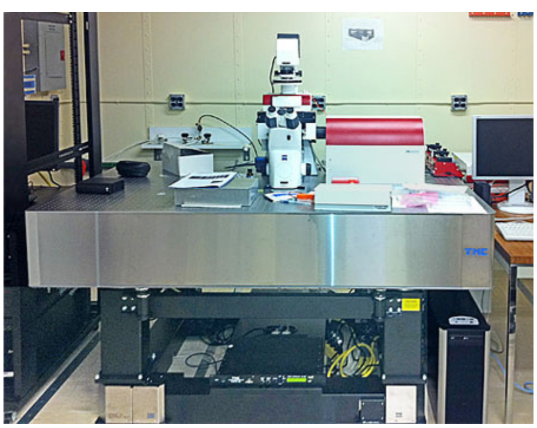

Photo courtesy of IBM Corporation

Photo courtesy of Uppsala University

REFERENCES

[1] Jordan, S. and Anthony, P., Curr. Pharm. Biotechnology, 2009, 10, 515-521

[2] Yuan Shen et al., 2013, Advanced Materials Research, 706-708, 1423

[3] Abbondazieri *et al*, Nature, Nov. 24, 2005, 438(7067): 460–465.

[4] The authors thank Thomas Perkins for contributing this vivid before/after data.