New Research on Low-Frequency Absorption Using Membranes

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Summary: This paper briefly describes the problem of destructive room modes (also referred to as eigentones, resonances, or standing waves) in critical-listening and sound recording environments; the difficulties associated with testing low-frequency (LF) absorbers which are most often used to mitigate room modes; recent research into the effectiveness of membrane-based low-frequency absorbers; and the partially-unexpected results of the lab tests of a new LF absorber design, with corresponding applications toward mitigating room modes.

Contents:

The Room Problem:

Room modes consist of nodes (sound energy cancellations) and anti-nodes (sound energy additions) which result from sound excitation in a room by frequencies at wavelengths that match one or more of the room's primary (axial) dimensions (length, width, height). Modes result in resonances at quarter-wavelengths and nulls at half-wavelengths along each room axis throughout the room, as well as at multiples of the fundamental mode frequencies. Though room modes exist throughout the room at all audible frequencies (and all modes are found in all trihedral corners), they are strongest in the 20Hz to 200Hz range in small rooms, usually defined as under 5,000 cubic feet in volume. The destructive extent of modes is also dependent on listener/microphone and sound-source positions in the room.

Modes are one of the greatest concerns when considering accurate sound recording and reproduction. As a distortion of the original sound, modes change the perceived tonal characteristics of the sound (such as much more apparent bass or much less apparent bass, depending on position), and cause longer reverberation times at resonant frequencies, which is perceived as a "smearing" of the sound. This results in a loss of sonic detail and impairs the perception of sound-source localization ("imaging").

All room anti-node (energy-addition) pressure is at maximum at hard-wall and corner surfaces, which can be exploited with proper placement of bass absorbers. No acoustic absorber can lessen a node (energy cancellation) directly, because energy cannot be subtracted from zero energy. However, when an anti-node (addition of energy) is diminished, its frequency-corresponding node (cancellation of energy) is equally diminished, i.e. as you decrease the strength of an addition, the strength of the cancellation equally decreases. We need only address the anti-node, or resonance areas, to diminish the destructiveness of both.

Low-frequency (LF) absorbers, often called “bass traps” or “bass absorbers”, are used to mitigate modes in professional and consumer audio rooms, and are also used for industrial and commercial workplace low-frequency noise reduction. LF absorbers are typically rated in effectiveness for frequencies under 200Hz, which is the approximate frequency below which most small rooms become pressure-responsive (the “room crossover”), rather than velocity-responsive, because one or more of the dimensions of the room are shorter than the longest wavelengths to be propagated in the room.

The Product-Testing Problem:

Sound absorbers are used to reduce sound energy (echo and reverberation) in rooms. To ensure the effectiveness of absorber products, they are tested in laboratories using reverberant (diffuse) chambers per ASTM standard C423-09a (excerpt from Section 1.1: “This test method covers the measurement of sound absorption in a reverberation room by measuring decay rate.”). This standard requires reporting on the absorption amount, in sabins* and Absorption Coefficient (a derivative of sabins and absorber surface area), from 125Hz to 4KHz, and stipulates that test results below and above those frequency requirements may also be reported when measured per C423-09a.

Nearly all independent testing laboratories have reverberant chambers of under 300 cubic meters in volume, which is large enough to measure accurate results above 160Hz but not below. This is not a problem when measuring the effectiveness of absorbers meant to work above 160Hz. However, it is a very important issue when products designed to absorb below 160Hz are to be accurately tested for effectiveness. While test methodologies exist for in-situ testing (measuring in non-calibrated non-test-lab room situations), they are not repeatable elsewhere, and are therefore not useful for accurate effectiveness comparison purposes.

Fortunately, for product designers – and consumers - there is one test lab which is large enough, at 738 cubic meters, to be accurate for measuring absorption down to 40Hz: NWAA Labs, in Elma, WA. This facility, containing the two largest independent reverberant test chambers in the world (situated in a never-online former nuclear power plant), is run by former NASA scientist Ron Sauro, who has authored many professional studies and papers on acoustical testing and research. (Full disclosure: he agreed to check this paper for accuracy.)

Sound-absorber products fall into four broad categories: the most common is frictional absorbers, which are primarily fiber- or foam-based (including glass, cotton, mineral, etc.), diaphragmatic absorbers, which are primarily membrane-based (including mass-loaded vinyl and other thin, flexible materials), resonator absorbers (such as Helmholtz chambers), and a newly-discovered category, diffractive absorbers. All four absorber categories reduce reflected sound energy by turning a portion of it into heat energy.

Frictional absorbers (fiber and foam) act on sound *velocity* in air, which is approximately 1130 feet-per-second (fps), using the friction caused by the large available surface area ratios (relative to product working surface area, up to approx. 50-to-1). Diaphragmatic (membrane) absorbers act on sound *pressure*, which is maximum at wall, ceiling, and floor surfaces, especially in corners. Sound has a velocity at hard reflective surfaces of zero feet-per-second, and this is the primary reason fiber- and foam-based absorbers work less effectively than properly-designed membrane absorbers to reduce low-frequency energy under 200Hz.

Therefore, a very large amount of fiber or foam – both in volume and depth – is needed to absorb low frequency energy, on the order of many cubic meters. However, for membrane absorbers, the differing impedances on either side of an enclosed membrane (free air vs. enclosed-volume air) allow it to react in response to LF energy by displacing; this displacement reduces some of the sound energy at lower frequencies and results in more efficient energy absorption - by frequency and volume of materials used (and room space taken up) - than is possible with fiber- or foam-based absorbers.

In addition to the size of the test lab and the category of absorber, another consideration in laboratory testing of low-frequency absorbers is their intended-use mounting or deployment configuration. While many absorber products can be tested per ASTM E-795 standard mounting practices (e.g. “A-Mount”: products mounted flat on a wall or floor surface), products with less-frequently utilized test mounts are also included in the E-795 standard (e.g. “J-Mount”). This allows absorbers – especially low-frequency units, for which test results are more susceptible to room placement variations - to be tested where they are designed to be used in real room situations while still inside the calibrated test laboratory. This is a more accurate measurement method, leading to more relevant conclusions from the test results, especially for end-users.

***Sabin**: The “sabin” is defined as a unit of sound absorption. Sabins could be calculated with either imperial or metric units. In theory, one square foot of open window is one imperial sabin; one square meter of open window is one metric sabin. The unit is named in honor of Wallace Clement Sabine.

Test Method & Results:

Based on the results of earlier testing done on the MLV (mass-loaded vinyl) membrane absorbers built into the back of each Curve Diffusor™ (see photos and charts below), the CornerSorber™ was designed as a dedicated LF absorber for different frequency bands to compliment the Curve Diffusor’s LF absorption capabilities. The design goal was to use different membrane densities to offer different effective frequency ranges for the same LF absorber enclosure, making them easily changeable in manufacturing to target desired room mode ranges. The design assumption was that, based on a theory of membrane density-dependent resonances, the various membrane/enclosure combinations would yield different center frequencies and ranges of frequencies absorbed.

To test the effects of different densities of membranes, 18 beveled enclosures (see photos below) were built with slide-in membrane-frame retainers, which accepted MLV carrier frames holding different sets of densities, with 18 frames per density. The three densities tested were one pound per-square-foot (1# PSF), one-half pound (½# PSF), and one-quarter pound (¼# PSF), contained in frames which were simply "swapped-out" prior to each test run.

The number of test enclosures (18) was dictated by the minimum surface area (120 square feet or more) needed to obtain accurate results in NWAA's large main chamber. The design goal of the three-bevel-sided enclosures was to place a pair of membranes at a 90-degree angle as closely as possible to - and in parallel with - the corner surfaces, either vertically or horizontally. The volume of each enclosure and its internal damping (cotton-fiber absorbent material) did not change, and therefore changing the membrane density – again, based on resonance theory assumptions – should have yielded different results for each of the tests we ran. It did not.

Another assumption – also based on actual data from the Curve Diffusor tests - was that the most effective distance from the corner wall surfaces for the new product's membranes would be the same as for the Curves: one inch from the wall surface, parallel to the wall. And again, this assumption was not correct for this design.

When the test results were examined and compared (a total of ten full tests were run), many of the outcomes were different from predicted results, which were based on our understanding of various resonance theories and subsequent logical assumptions, in these areas:

- The absorption ranges and center frequencies, as well as the effectiveness ("Q") of the low-frequency absorbers, did not change significantly with changes in membrane densities (excepting the 1# density membranes, which showed less efficiency at the center frequency);
- The most effective distance from the wall for the membranes of the new design (CornerSorbers set three inches from the wall surfaces in parallel) was not the same as for the earlier-tested design (Curve Diffusors mounted one inch from the wall surface in parallel);
- The absorption profiles of the new designs in "semi-free space" (more than one meter from any wall) was approximately an octave higher in range and center frequency than when in the "pressure zone" or close-coupled in parallel with the wall surface;
- When the enclosures were reversed in membrane orientation – with their backs against the wall surfaces in the corners and the membranes facing into the chamber – the results were also higher in range and center frequency than expected.

Additionally, we were testing our design assumption that the most effective and efficient location for the membrane absorbers would be closely-coupled to and in parallel with wall surfaces in room corners, placed on the floor. This design assumption proved to be accurate.

To summarize our test results: Some of the design assumptions we made, based on our understanding of how low-frequency diaphragm absorbers work in rooms, were incorrect, and caused us to re-think how we designed and specified the final product. The type of absorber, and its location and orientation in a room, are all highly critical to LF absorber effectiveness.

This set of tests proves the value of actual laboratory testing: if we had released these LF absorber products to the public without accurate testing - guided only by intuition, experience, broad theory-based assumptions, impedance-tube testing, interpolation, or other *approximations* of product effectiveness in real-world, in-use configurations - our claims of product absorption ranges and efficiencies would have been wrong. This cannot be overstated: *without standardized laboratory absorption testing in a lab capable of accurately testing absorption down to 40Hz, we would not be able to state conclusively that our low-frequency absorber products perform as we claim*. We believe this holds true across product categories.

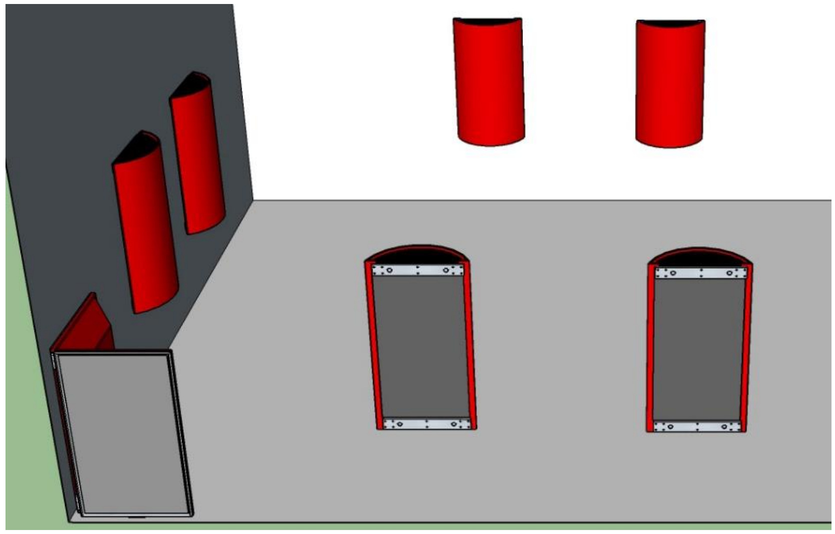
Applications:

The Acoustic Bass Management™ (ABM) System consists of the newly-released CornerSorber™, a unique close-corner-located MLV membrane bass absorber, and the Curve Diffusor™, containing a built-in MLV membrane bass absorber. The two products, used in combination, have been shown in separate tests at NWAA Labs – under real-use mounting conditions - to effectively absorb low frequencies from 45Hz to over 200Hz. Sound is only pressure at boundaries, not velocity; ABM System absorbers are pressure-based, and are the most efficient and effective way to mitigate boundary-created room modes.

The dimensional equivalents for room-mode frequency (wavelength) absorption ranges for each product are (approx.): 5.5 to 14 feet (200-80Hz) for CornerSorbers, and 14-25 feet (80-45Hz) for Curve Diffusors.

Photo: Membrane views of the Curve Diffusor (top) and two CornerSorbers (corner configuration, bottom)

CornerSorbers have an approximately 3-to-1 efficiency ratio to Curve Diffusors - they are dedicated LF absorbers, whereas Curves are also highly-effective phase-coherent cylindrical (constant-radius) diffusors. We recommend a minimum of six Curves and two CornerSorbers per room, depending on room size and geometry, and room diffusion requirements. Visit our website (www.AcousticGeometry.com) for the Curve Diffusor and CornerSorber low-frequency absorption Test Reports (per ASTM C423-09a). Our YouTube Channel is also a resource for acoustical information: www.YouTube.com/AcousticGeometry.

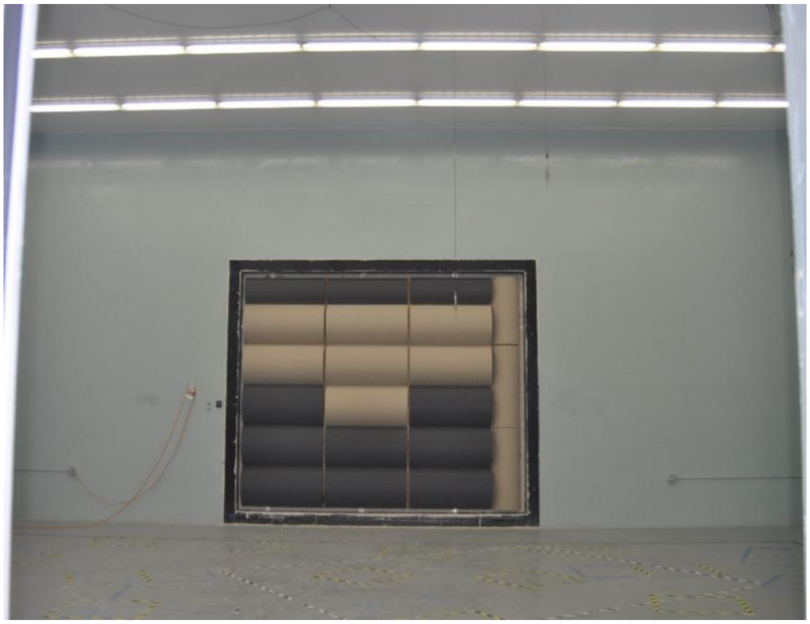


Test Reports:

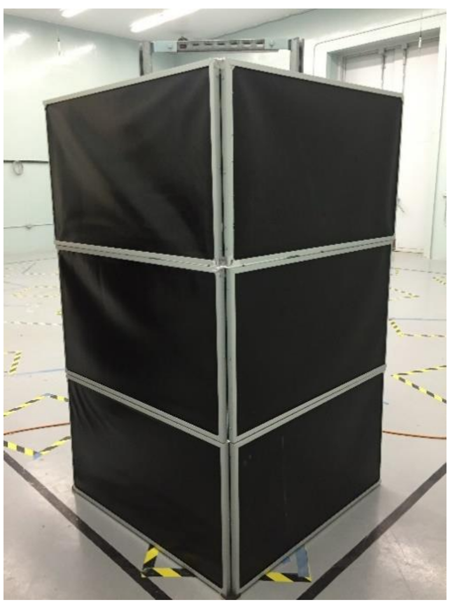
Acoustic Geometry tested both the Curve Diffusor and the CornerSorber for low-frequency absorption per ASTM C423-09a protocol at NWAA Labs in Elma, WA. Curve Diffusors were tested on 18 August, 2015; CornerSorbers tested on 8 September, 2016. NWAA Labs has the world's largest absorption test chamber (approx. 42' x 35' x 17', 26,000 cubic feet or 738 cubic meter volume), which can accurately test with better than 95% precision and bias (variation) down to 40Hz. The tests were conducted with the test units mounted as they would be in real-use configurations. Curves were mounted on the test wall (A-Mount) with standard Z-Clips, with 21 units covering 120 square feet, the NWAA Labs standard minimum test-sample area (both Medium and Small Curves with an equivalent membrane area of 19 Medium Curves). CornerSorbers were set on the floor (J-Mount), oriented horizontally in close-corner configuration, with 18 units covering 126 square feet (overage accounted for in calculations), grouped six units per corner, in three of the test chamber's corners.

The following photos show the low-frequency absorption test mountings and arrays for the Curve Diffusors and the CornerSorbers.

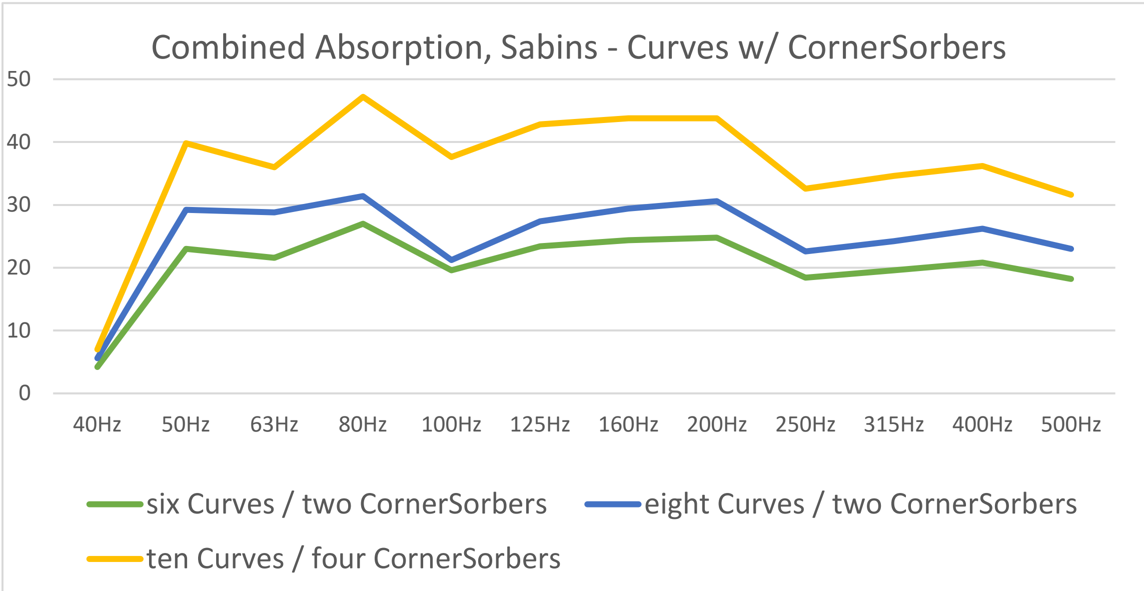
Photos: Curve Diffusor Low-Frequency Absorption test, NWAA Labs, 18 August 2015

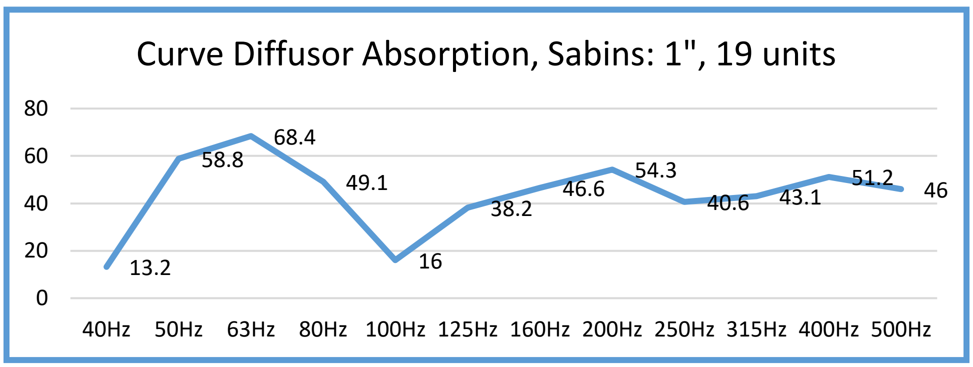


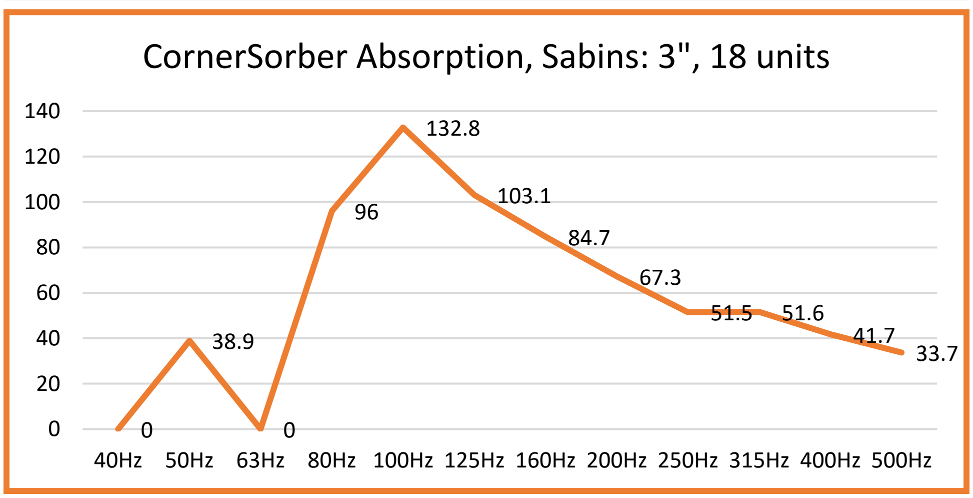
Photos: CornerSorber Low-Frequency Absorption test, NWAA Labs, 8 September 2016



The following absorption charts are in sabins, which are the actual measured units of sound absorption (as opposed to less-reliable Absorption Coefficients) with suggested combinations of Curves and CornerSorbers, and separate Curve and CornerSorber test results for the units shown in the combination chart. The Combination chart utilizes single-unit sabin amounts multiplied by number of units in each suggested example. The CornerSorber and Curve charts show absorption in sabins for the units as tested.







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