SOUND ISOLATION DESIGN FOR A MAGNETIC RESONANCE IMAGING SYSTEM (MRI)

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Abstract

Background: This Noise control case study is about problems, constraints and design solutions for a proposed magnetic resonance imaging system (MRI) installation in an existing medical research facility. This is a companion paper to a structural vibration control case study on the same installation presented by this author at ICSV10 in 2003. Objective: Manufacturer’s data indicated that airborne sound level emissions over a broad frequency span could exceed permissible noise criteria for nearby occupied rooms. Previous experience with MRI’s indicated possibility of structure borne vibration induced by airborne sound that could result in radiated noise in other spaces. Containment design was required for anticipated loud and annoying noises in the magnet room, to prevent excessive or annoying and distracting noise to MRI control room or other adjacent (but unrelated) office spaces. In addition, the structure borne vibration paths needed attenuation or isolation. Methods: Proposed architectural designs would utilize steel stud framing with gypsum wallboard, and would incorporate continuous sheet copper EMI shielding. The building structure was reinforced concrete. Wall, partition, window, door, air conditioning ducts and other penetration designs were developed to accommodate the required shielding and proposed construction methods. Material selections and decoupled assembly configurations were based on anticipated source sound levels and receiver room permissible noise criteria. Results: Post-construction airborne sound transmission loss measurements are compared with noise criteria to show quantitative result of the design. Photos of the MRI suite are shown. The final result satisfies acoustical criteria and occupants' subjective evaluations. Conclusion: This case study demonstrates the advantage of decoupling structure borne vibration paths and matching airborne transmission loss barrier performance to sound source spectra to achieve noise criteria.
INTRODUCTION

Baylor College of Medicine, Human Neuroimaging Laboratory proposed a magnetic resonance imaging (MRI) suite that would incorporate two MRI’s in individual rooms which would be separated by their respective control rooms. The large magnet assemblies generate moderately loud noise during startup and scan sequences. The noise can be transmitted to adjacent spaces by airborne and structure borne paths, resulting in annoying and distracting intrusions. The proposed suite location would have unrelated office spaces to either side, research laboratories above and a transgenic research mouse vivarium below. Noise containment was an important parameter for the MRI suite’s architectural and building system designs. Floor vibration control in the structural design, to prevent or minimize distortion of the scan images, was discussed in a companion paper presented at ICSV10 in Stockholm. MRI equipment modification to reduce source noise and vibration generation was not included in the scope of work. Based on our own previous experiences and that of colleagues, structure borne vibration paths can result in radiated noise levels in nearby rooms, which exceed the sound level due to airborne noise transmission paths through walls, floors and ceilings. Therefore, sound and vibration transmission loss designs were needed to minimize noise disturbances to other nearby spaces.

![Fig. 1. Plan View of Proposed MRI Suite Showing Post-Occupancy Measurement Locations](image)

Decoupled mass design concepts were employed for partition, floor and ceiling assemblies, because both airborne and structure borne noise paths were anticipated. Double leaf (mass-air-mass) assemblies have been shown to have greater transmission losses than those predicted for monolithic panels by Mass Law, and decoupled assemblies have greater transmission losses than either monolithic panels or double leaf assemblies. Other design considerations included various means of preventing flanking noise transmission paths via doors, air conditioning ducts and other penetrations for pipes and conduits. The noise control designs and results of post-occupancy sound transmission loss measurements are discussed below.
EXISTING CONDITIONS AND SOURCE NOISE

Airborne noise measurements were conducted before and during the design process within the existing vivarium and laboratory spaces to determine minimum, “normal” and transient maximum levels (also see structural vibration measurements, discussed in the companion paper, re: ISCV10). Equivalent level (Leq) was used to represent “normal” or average condition. The adjacent office and conference spaces were to be modified during the construction process, so pre-design measurements of existing conditions were less relevant there. ASHRAE allowable continuous background design guidelines were to be used for proposed office and conference spaces.

Study of the measurement results revealed the following:

♦ The logarithmic average of ambient sound levels in vivarium animal holding and procedure rooms (below MRI) was 45 dBA, and crossing the RC 45 line, near rodent peak hearing sensitivity, 2K–4K Hz (Fig. 2).

♦ The logarithmic average of ambient sound levels in research laboratories (above MRI) was about 55 dBA, and near RC 50 over the human speech/peak hearing sensitivity, 250–2000 Hz (Fig. 2).

♦ Logarithmic average of 1/3 octave band sound pressure level data for three Siemens MRI models (actual spectra are proprietary and cannot be shown here) was approximately 105 dBA at the source (Fig. 3). Note: distance factored on chart above for semi-reverberant room, based on manufacturer level at patient location or bore).

ALLOWABLE NOISE CRITERIA

Noise criteria in adjacent spaces varied by the functional requirements of the different occupancies. Wall, floor and ceiling required transmission loss noise reductions would be equivalent to the differences between the source noise level and the receiver
room ambient levels, plus a small allowable “audibility” or exceedence over ambient. Although speech interference or articulation index analyses were possible, for this project it made sense to base noise containment decisions on avoidance of distraction and annoyance. Therefore, we decided to design for magnet-scan noise transmission to adjacent spaces no louder than ambient sound level or just above ambient levels in the receiver rooms. Measurements of continuous ambient noise levels were used to establish permissible intrusive noise criteria for existing vivarium and laboratory spaces. ASHRAE continuous noise criteria for office and conference spaces were used.

\[
\text{TL}_{\text{NR}} = L_{\text{source}} - L_{\text{receiver}} - C_{\text{allowable}}
\]

Where:
- \( \text{TL}_{\text{NR}} \) = Transmission Loss through wall, floor or ceiling
- \( L_{\text{source}} \) = Siemens MRI noise emission (distance adjusted)
- \( L_{\text{receiver}} \) = Receiver room ambient sound level
- \( C_{\text{allowable}} \) = audible exceedence above receiver room ambient

Fig. 4. Differences Between MRI Source Noise and Existing Ambients or Criteria (re: Figs 2 & 3, above) Indicating Full Octave (1/1) Transmission Loss Requirements (before adding exceedence tolerances to office and lab space criteria)

The research mice in the vivarium below the MRI are expensive. The institution conserves research funds by reproducing the mice. Noise and vibration can stress mice, decreasing feeding and reproduction rates. Intrusive noise should neither be louder nor more tonal than the background noise in the vivarium, especially at frequencies near 4K Hz, rodents’ peak hearing range. Therefore, the design goal is to prevent audible MRI noise intrusion. (\( \text{TL}_{\text{NR}} \sim 100-45-0=55 \text{ dBA} \))

For adjacent office and conference spaces, intrusive noise criteria were established to prevent speech interference, distraction and annoyance. MRI noise audibility would be permitted, but not more than 3 dB above the anticipated receiving room ambient sound level (re: ASHRAE). (\( \text{TL}_{\text{NR}} \sim 90-42-3=45 \text{ dBA} \))

The wet and dry laboratories above the MRI suite are less susceptible to interruption of speech communication or distraction, and can permit short duration transient intrusive noise. MRI noise intrusion up to 4-6 dB above the ambient sound level can be tolerated. (\( \text{TL}_{\text{NR}} \sim 95-56-4=35 \text{ dBA} \))
OBJECTIVES AND STRATEGY

The primary acoustical design objective was to develop noise control methods to be integrated into the architectural and building system designs. The concentrated structural loads of the magnet assemblies required floor reinforcement, but due to concerns for vivarium contamination and research mice distress, a platform structure above the floor was proposed in lieu of installing reinforcing within the vivarium ceiling plenum. The platform deck and structural floor slab below would act as a decoupled mass noise barrier, although some structure borne flanking would be possible via the structural connections at building columns. The platform would also accommodate decoupled partition assemblies. Resilient suspension of the MRI room ceiling would supplement the structural floor sound and vibration isolation to the spaces above. By utilizing decoupled mass barrier concepts to acoustically isolate the MRI magnet rooms from adjacent spaces, a “room-within-a-room” concept, structure borne and airborne noise transmission paths can be attenuated.

As a first selection process, sound transmission class (STC) test results were reviewed for the floor–ceiling assemblies above and below the MRI rooms, and for the drywall or gypsum board partitions enclosing the suite. The mass of the copper sheeting was considered as equivalent to an additional thin layer of gypsum board.

By comparing the STC’s with recommended noise reductions, the remaining additional sound transmission loss requirements were determined.6

- Laboratories (above): The floor-ceiling assembly above the MRI room was adequate to achieve the approximately 35 dBA of noise reduction required. Independent support of the ceiling and shielding assured isolation of the structure borne path
- Offices (horizontally adjacent): A double stud drywall assembly with at least three layers of gypsum board was adequate to achieve the approximately 45 dBA of noise reduction required. Placing the inner stud wall on the platform structure completely decoupled inner and outer partition elements and isolated structure borne path.
♦ Vivarium (below): The structural floor and ceiling assembly below the MRI was inadequate to achieve the required 55 dBA of noise reduction. The addition of the platform floor above the structural floor provided substantial additional decoupled mass with a large air space, and was expected to result in much greater noise reduction than the design goal.

Design integrity required identification of potential flanking paths, such as duct, pipe and conduit penetrations. Flexible couplings were recommended between decoupled elements of assemblies. Duct attenuation and lagging (enclosure of ducts) were recommended near wall and structure penetrations. A duct located within the room was recommended to be relocated outside the room for noise control.

Fig. 7. Mechanical Plan: Ducts Modified to Achieve Noise Containment, Including Relocation of Penetrating Duct Out of MRI Room and Duct Lagging Near Penetrations

DESIGN IMPLEMENTATION

The architectural and engineering designers adopted major architectural and structural noise and vibration control recommendations. Building systems (mechanical, electrical and plumbing) noise containment and control recommendations were adopted, except where existing physical conflicts prevented implementation. Decoupled double stud wall inner and outer parts were erected separately on the platform and structural floors, respectively. Door and window elements between MRI and Control Rooms were specified to achieve necessary sound isolation and electromagnetic shielding. Wall penetrations and interfaces with structure were sealed airtight. Air conditioning supply and return duct penetrations were permitted only for diffusers and registers. All other ducts were relocated outside the MRI magnet rooms. High mass barrier jackets (lagging) were wrapped around ducts near demising partition penetrations to prevent noise breakout via ducts.

POST-CONSTRUCTION PERFORMANCE VALIDATION

Ambient noise and sound transmission performance validation measurements were conducted after the facility was occupied. Measurement locations included an MRI Room, a Control Room and the adjacent “Hyperscan” office (see Fig. 1. MRI Suite Plan). The spaces were in “normal use.” We were not able to enter the Vivarium below the MRI or laboratories above for post-occupancy testing. According to
conversations with the MRI Operator and a Facility Manager, no noise intrusion complaints have been received from Vivarium or Lab occupants.

Ambient (MRI not operating) equivalent sound levels (Leq) are compared to room criteria (RC). Desktop computers operating in the rooms influenced higher frequency noise exceeding criteria. MRI scan sequence noise emission Leq’s are shown in 1/3 octave spectra to show levels and tonality.

![Fig. 8. MRI Suite Ambient Noise Levels](image8.png)  ![Fig. 9. MRI Scan Sequence Noise Spectra](image9.png)

Sound transmission measurements were made in general accordance with ASTM E 336, Measurement of Airborne Sound Insulation in Buildings, except that source room measurements were made less than 1 m (3’) from walls. Metallic items are not permitted near the MRI magnet due to the magnetic fields. Receiver measurements were 1 m (3’) from partition.

![Fig. 10. Control Room Noise Reduction](image10.png)  ![Fig. 11. HyperScan Office Noise Reduction](image11.png)
SUMMARY

On-site observations and measurement results (above) showed the following:

♦ The MRI to Control Room sound containment was limited by the window and door, but achieved NIC 34.
♦ The MRI to “Hyperscan” Office decoupled double stud partition, has a single above-ceiling penetration for (lagged) supply air duct to the MRI room, but achieved NIC > 45.
♦ Transmitted test sound levels in the Hyperscan receiver room were very similar to the ambient, indicating at or below ambient results.

Decoupling of walls, floors and ceilings created rooms within rooms, resulting in good sound isolation from vertically and horizontally adjacent spaces. Both airborne and structure borne transmission paths were effectively attenuated. Noise intrusion to occupied office, laboratory and the research animal vivarium met design intent and noise reduction criteria.

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REFERENCES

3 “MRI Suite Floor Vibration and Ambient Noise Measurement Analysis for Baylor College of Medicine, Human Neuroimaging Laboratory,” JEAcoustics Rpt No. 2203-01 (2/2002)