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Acoustic Emission for active pest detection. Enhancement and integration into IPM strategy

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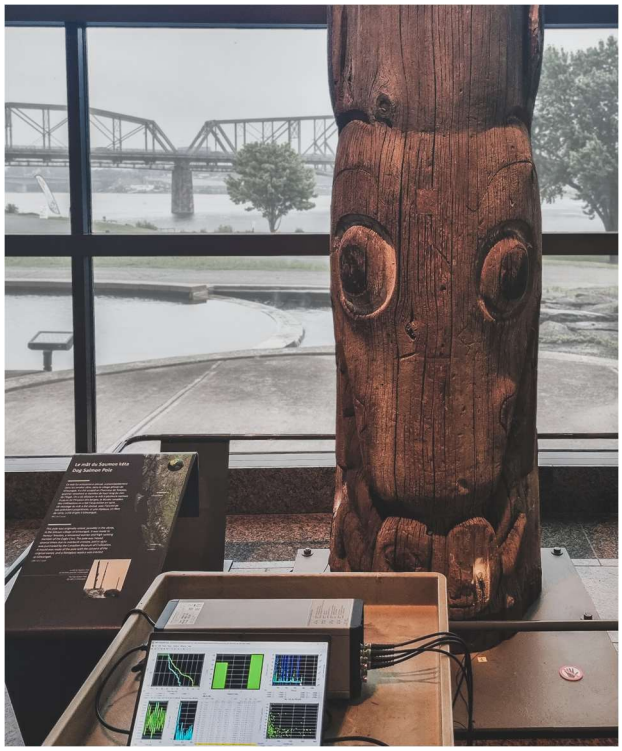

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MUSÉE CANADIEN DE L'HISTOIRE

Hes·so

"*Bugs thrive on carnage, Tiger. They consume, infest, destroy, …*"

- MIB, Agent K

Commitment

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Corrigendum

30.09.2025

The following corrigendum lists all minor corrections made to the thesis according to the feedback received after the defense. Syntactic improvements as well as corrected typographical and grammatical errors are not listed.

P.4-7 The word « material » was replaced with « object » in the phrase "Exploring the feasibility of extending AE to other organic objects such as books and textiles" in each summary.

P.8 The structure of the report was added to the general introduction.

P.9-10 More detailed information was added to the description of the AE technology and its uses.

P.12 Precisions were added about the CO_2 anoxia treatment legislation.

P.25 Precisions were added about the type of moisture meter used.

P.18-28 More pictures of the methodology and tests setup were added

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Abstract

Pest infestation represents a significant threat to heritage collections, with woodboring and keratinophagous insect being particularly destructive. Conventional detection methods such as quarantine or sticky traps are time-consuming, provide limited information and can lead to unnecessary preventive treatment, generating important costs. This research investigates the use of Acoustic Emission (AE) as a non-invasive technique to detect active infestation in heritage collections, while enhancing the Integrated Pest Management (IPM) strategy of the Canadian Museum of History (CMH), following the recent ban of CO2 treatment that was previously used.

This study includes three major components:

- Collecting a dataset of AE signals from both infested and non-infested wooden samples to support artificial intelligence (AI)-based classification (parallel Bachelor thesis conducted by Tom Marti, engineering student at Haute Ecole Arc, Switzerland)
- Exploring the feasibility of extending AE to other organic objects such as books and textiles.
- Develops practical tools for IPM, including automated heatmap for pest tracking and AE testing protocol

Laboratory and in-situ experiments were conducted using Vallen® AE equipment. *Coupling material* used are renaissance wax, solvent-free spray cyclododecane (CDD) and non-chemical method such as clamps or ribbons.

Results confirmed the great efficiency of AE for detecting woodboring activity, due, among other factors, to the low attenuation in wooden artefacts. Conversely, attenuation in textiles and paper was found to be too high for reliable monitoring, with the current setups tested.
Additional findings highlight the impact of surface shape, grain orientation, coupling methods and wood moisture content on AE signals transmission.

While AE shows strong results on wooden artefacts and is already used in some institutions, the current state of the research does not provide sufficient conclusive data for recommending the extension of the technology to softer and more porous material. Nevertheless, this study introduces news elements and perspectives that could serves as foundation for future research.

Résumé

Les infestations d'insectes, en particulier les xylophages et kératinophages, représentent une importante menace pour les collections patrimoniales. Les méthodes de détection conventionnelles telles que la mise en quarantaine ou les pièges collants sont souvent chronophages et fournissent des informations limitées. Cela peut conduire à entreprendre des traitements préventifs sur des objets pour lesquels cela n'aurait pas été nécessaire, entrainant des coûts importants. Ce travail se penche sur l'utilisation de l'émission acoustique (EA) comme technique non-invasive pour la détection des infestations actives dans les collections patrimoniales, tout en renforçant la stratégie de gestion intégrée des ravageurs (IPM) du Musée Canadien de l'Histoire, à la suite de l'interdiction récente de l'utilisation des traitements au CO2, précédemment utilisé, sur le territoire.

Cette étude comprend trois axes principaux :

- Constituer une base de données d'émissions acoustiques sur des échantillons de bois infestés et sain, dans le but de permettre une classification des signaux par intelligence artificielle (travail de Bachelor parallèle réalisé par Tom Marti, étudiant en ingénierie à la Haute Ecole Arc, Suisse).
- Explorer la faisabilité de l'utilisation de l'émission acoustique à d'autres objets organiques tels que les livres et les textiles.
- Développer des outils pratiques pour améliorer la stratégie IPM du musée, comme une carte thermique automatisée permettant le suivi des nuisibles trouvés dans les pièges ainsi que des protocoles détaillés pour utiliser l'EA au sein du musée.

Les expériences ont été réalisées avec l'équipement d'émission acoustique de l'entreprise Vallen®. Les matériaux couplants utilisés sont la cire Renaissance®, le cyclododécane (CDD) sans solvant en spray ainsi que des méthodes n'incluant pas l'ajout de produits, comme des serre-joints ou des rubans.

Les résultats confirment l'efficacité pour la détection des infestations dans les objets en bois, due notamment à la faible atténuation dans les artefacts. A l'inverse, l'atténuation dans les textiles et le papier s'est révélée trop élevée pour permettre un monitoring fiable, malgré les différentes configurations testées.
D'autres résultats mettent en évidence l'influence de la forme de l'objet, de l'orientation des fibres, des méthodes de couplage ou encore le taux d'humidité du bois sur la transmission des signaux d'EA.

Bien que l'émission acoustique donne des résultats probants sur les artefacts en bois et peut être recommandée au musée dans le cadre de sa stratégie IPM, l'état actuel de la recherche ne permet pas de faire la même recommandation concernant les matériaux organiques plus mous et poreux. Néanmoins, cette étude introduit de nouveaux éléments et perspectives, qui pourraient constituer un point de départ pour de futures recherches

Zusammenfassung

Schädlingsbefall stellt eine erhebliche Bedrohung für Kulturgutsammlungen dar, wobei holzbohrende und keratinophile Insekten besonders zerstörerisch sind. Herkömmliche Nachweismethoden wie Quarantäne oder Klebefallen sind zeitaufwändig, liefern nur begrenzte Informationen und können zu unnötigen vorbeugenden Behandlungen führen, die erhebliche Kosten verursachen. Diese Forschungsarbeit untersucht den Einsatz von Akustikemissionen (AE) als nicht-invasive Technik zur Erkennung von aktivem Befall in Kulturgütern und verbessert gleichzeitig die integrierte Schädlingsbekämpfungsstrategie (IPM) des Canadian Museum of History (CMH) nach dem neuen Verbot der zuvor verwendeten CO2-Behandlung.

Diese Studie umfasst drei Haupkomponenten:

- Erfassung eines Datensatzes von AE-Signalen aus befallenen und nicht befallenen Holzproben zur Unterstützung der Klassifizierung auf Basis künstlicher Intelligenz (KI) (parallele Bachelorarbeit von Tom Marti, Ingenieurstudent an der Haute Ecole Arc, Schweiz).
- Untersuchung der Machbarkeit einer Ausweitung von AE auf andere organische Objekt wie Bücher und Textilien.
- Entwicklung praktischer Tools für IPM, einschließlich einer automatisierten Heatmap zur Schädlingsverfolgung und eines AE-Testprotokolls

Labor- und In-situ-Experimente wurden mit Vallen® AE-Geräten durchgeführt. Als Kopplungsmaterial wurden Renaissance®-Wachs, lösungsmittelfreies Sprühzyklododecan und nicht-chemische Methoden wie Klammern oder Bänder verwendet.

Die Ergebnisse bestätigten die hohe Effizienz von AE bei der Erkennung von Holzbohraktivitäten, unter anderem aufgrund der geringen Dämpfung in Holzartefakten. Umgekehrt wurde festgestellt, dass die Dämpfung in Textilien und Papier für eine zuverlässige Überwachung mit den derzeit getesteten Aufbauten zu hoch ist.
Weitere Ergebnisse unterstreichen den Einfluss der Oberflächenform, der Maserungsausrichtung, der Kopplungsmethoden und des Holzfeuchtegehalts auf die Übertragung von AE-Signalen.

Während AE bei Holzartefakten gute Ergebnisse liefert und bereits in einigen Einrichtungen eingesetzt wird, liefert der aktuelle Stand der Forschung keine ausreichenden schlüssigen Daten, um eine Ausweitung der Technologie auf weichere und porösere Materialien zu empfehlen. Dennoch liefert diese Studie neue Elemente und Perspektiven, die als Grundlage für zukünftige Forschungen dienen könnten.

Riassunto

L'infestazione da parassiti rappresenta una minaccia significativa per le collezioni del patrimonio culturale, con insetti xyilofagi e cheratinofagi particolarmente distruttivi. I metodi di rilevamento convenzionali, come la quarantena o le trappole adesive, richiedono molto tempo, forniscono informazioni limitate e possono portare a trattamenti preventivi non necessari, generando costi importanti. Questa ricerca studia l'uso dell'emissione acustica (EA) come tecnica non invasiva per rilevare infestazioni attive nelle collezioni del patrimonio culturale, migliorando al contempo la strategia di gestione intergrata dei parassiti (IPM) del Canadian Museum of History (CMH), a seguito del recente divieto di utilizzo delle trattamento con CO2, precendentemente utilizzate.

Questo studio comprende tre componenti principali :

- Raccolta di un set di dati di segnali acustici EA da campioni di legno infestati e non infestati a supporto della classificazione basata sull'intelligenza artificiale (IA) (tesi di laurea parallela condotta da Tom marti, studente di ingegneria presso la Haute Ecole Arc, Svizzera)
- Esplorazione della fattibilità di estendere l'EA ad altri oggetti organici come libri e tessuti.
- Sviluppo di strumenti pratici per l'IPM del museo, tra cui una mappa termica automatizzata per il monitoraggio dei parassiti ritrovati nelle trappole e un protocolllo di test AE.

Gli esperimenti di laboratorio e in situ sono stati condotti utilizzando apparecchiature EA Vallen®. I materiali di accoppiamento utilizzati sono cera Renaissance®, ciclododecano spray senza solventi (CDD) e metodi non chimici come morsetti o nastri.

I risultati hanno confermato la grande efficienza dell'EA nel rilevare l'attività dei tarli, grazie, tra l'altro, alla bassa attenuazione nei manufatti in legno. Al contrario, l'attenuazione nei tessuti e nella carta è risultata troppo elevata per un monitoraggio affidabile, con le attuali configurazioni testate.
Ulteriori risultati evidenziano l'impatto della forma della superficie, dell'orientamento delle fibre, dei metodi di accoppiamento e del contenuto di umidità del legno sulla trasmissione dei segnali EA.

Sebbene l'EA mostri risultati positivi sui manufatti in legno e sia già utilizzato in alcune istituzioni, lo stato attuale della ricerca non fornisce dati conclusivi sufficienti per raccomandare l'estensione della tecnologia a materiali più morbidi e porosi. Tuttavia, questo studio introduce nuovi elementi e prospettive che potrebbero servire come base per ricerche future.

General introduction

Infestations have long represented a persistent scourge, causing significant damage to heritage collections over the centuries. In recent decades however, climate change has accelerated the development of pest populations, particularly in northern countries. Furthermore, intense intercontinental traffic contributes to the proliferation of species previously absent from Western ecosystems. More than ever, having efficient strategies to detect and treat these insects is essential for museum institutions.

For several years, acoustic emission (AE) has been applied in the heritage field to detect active infestations in wood. This promising method can be further refined to open up new avenues for the detection and monitoring of infestation.

The present work contributes to the ongoing update and improvement of the Integrated Pest Management (IPM) strategy at the Canadian Museum of History. This research aims to provide the Museum with detailed insights into the potential applications and limitations of this technology within their collections.

This thesis is structured as follows: The acoustic emission technique is introduced along with the IPM strategy at the Canadian Museum of History, followed by the problem statement and a review of existing literature. The objectives are defined, leading to the description of the methodology applied for data collection and feasibility testing. The results are presented and discussed before concluding on the potential and limitations of AE for heritage applications. Finally, the appendix provides complementary illustrations and detailed protocols designed for CMH conservators to implement AE testing and data analysis in their regular preventive workflows.

1 Context

1.1 Acoustic emission

Acoustic emission refers both to a physical phenomenon and a non-invasive testing technology.
The phenomenon is characterized by transient elastic waves caused by energy being promptly released within a solid material. This can typically occur during destructive events, friction or plastic Deformation (Laghari, 2023, p.6).
As a technology, acoustic emission relies on piezoelectric sensors to detect these stress-induced waves. Piezoelectric materials possess the ability to produce an electrical charge when subjected to mechanical stress. The mechanical vibrations are converted into electrical signals, which can then be analyzed to gather useful information about the structural condition of the tested object (Tressler, 1998, p.257; American Piezo, 2024).

This technology has been used in several fields such as civil engineering to monitor infrastructures like bridges, tunnels or buildings by detecting and localizing new cracks and monitoring the propagation of already existing cracks (FHWA, 2025).
In industrial field, it is used to monitor the wear of mechanical components or tools (Angelopoulos, 2024, p.1).
AE can also monitor corrosion and be a tool to study internal mechanisms inside materials such as plastic deformation, friction, coating detachment and fractures (Zaki, 2015, p.1).
In cultural heritage, it has been used for the monitoring and conservation of industrial heritage but also in ethnographic collection to detect and localize cracks inside of objects (Zhou, 2023, p.1). Its application for the detection of active infestation by detecting the feeding activity of insects will be discussed through this research.

Acoustic emission sensors are constituted of the following parts (figure 1):

- Wear plate: commonly made of ceramic, it protects the piezoelectric element while transmitting mechanical waves. This component is in direct contact with the tested object.
- Piezoelectric element: the core of the sensor, responsible for converting vibrations into electric signals. It is most often composed of piezoelectric ceramics such as lead zirconate titanate (PZT) or, less commonly, by quartz or gallium phosphate.
- Electrically conducting bond: ensures stable electrical and mechanical contact between the piezoelectric element and the wear plate.
- Molding: fills the empty space inside the sensor, protecting the components and reducing parasitic vibrations.
- Case: a metal shell that protects all internal parts and offers shielding from external perturbations.
- Connector: allows the electrical connection between the piezoelectric element and the acquisition system.

(Vallen, 2015; ES France, 2025; Kistler, 2025)

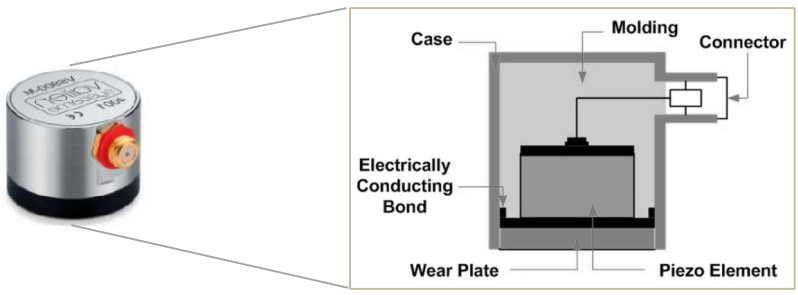


Figure 1, AE sensor composition

The exact composition and materials of the sensor depend on its intended application and the environmental constraints such as exposure to very high or low temperature.

The other components of AE equipment are the pre-amplifier (figure 2), necessary to amplify the low amplitude signal to a usable level, without degrading the signal-to-noise ratio (Ortec, 2025).
The data acquisition unit, composed of a metal chassis and the AE signal processor, which converts the electrical signals from the piezoelectric element into digital data and displays them on the computer.
Dedicated software may be needed to consult, visualize and analyze the data more efficiently (Vallen, 2025)

Figure 2, Vallen pre-amplificator

The standard AE setup will present as follows:

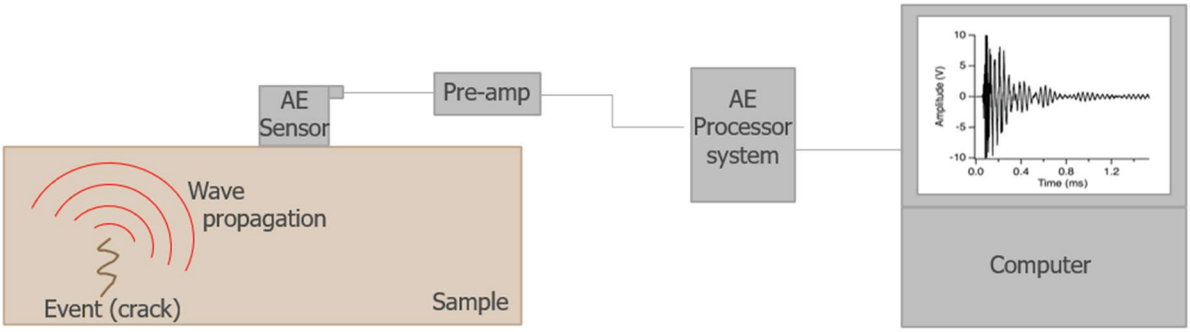


Figure 3 Standard AE setup

A coupling material such as gel or wax can be used between the AE sensor and the sample to improve the contact between the sensor and the surface by removing the air in between the two interfaces.

Although acoustic emissions cover a broad frequency spectrum, the stress waves associated with destructive events or deformation are most commonly found in the ultrasonic range, between 100kHz and 1MHz. (Laghari, 2023, p.6).

1.2 Canadian Museum of History

1.2.1 General information

The Canadian Museum of History (CMH), formerly known as "Canadian Museum of Civilizations" until 2013, is a Crown Corporation founded in 1856 in Montreal and later relocated in Ottawa, now displaying collections in 4 permanents galleries and the Children's Museum[1]. The famous building designed by architect Douglas Cardinal (Canadian Museum of History - Architecture and grounds, 2024) was inaugurated in 1989 and now houses more than four million artefacts and archival documents (Canadian Museum of History – Our history, 2024).

The museum's mandate involves not only the transmission of history and cultures that have shaped Canada but also a strong commitment to work in collaboration with Indigenous communities (Canadian Museum of History – Our purpose, 2024).. This includes appropriate conservation practice, honouring

[1] "*Having a Children's Museum is a massive pest vector*" (Jessica Lafrance Hwang, 14.07.25)

community wishes with regards to collection care, working with shared custody agreements and the repatriation of cultural objects (Canadian Museum of History, 2020)
In 2024, the museum made 434 new acquisitions and had 56 loan groups entering or leaving the museum. These collection movements underline the importance of ensuring pest-free status of involved objects[2].

1.2.2 Current IPM strategy

All the information below uses the unpublished document of the museum "Guideline: integrated pest management (IPM), by R.Latourel & S.Warren, 2020 as a source, along oral communications on common practices with conservation staff members.

Rooms maintenance

In conservation laboratories (1st floor), each staff member is responsible for keeping their space clean.

In collections storage rooms (1st to 6th floor), collections coordinators are responsible for the cleanliness of the spaces. The primary task supporting this is of dry sweeping the floor regularly.

In exhibitions, regular dusting and cleaning behind artifact barriers is done by a conservation technician[3]. Props are regularly dusted and cleaned by the exhibit preparators. The rest of the museum is under the care of cleanings staff who do regular floor sweeping and take care of garbage bins. The Museum closes once a year for a week for deeper maintenance.

Pest detection

In conservation laboratories, people are asked to stay vigilant and notify the Preventive Conservation Specialist of anything suspect.

In collections storage rooms, sticky traps are installed at each door, which represent 3 to 6 traps per room on average. Additional traps may be temporarily installed if increased monitoring is deemed necessary. All the traps are checked monthly, and findings are, if possible, immediately identified. If needed, photographs of the insects found are submitted to bugguide.net for external help with identification. Once identified, specimens are recorded on physical data sheets in a dedicated binder. A digital quarterly report is then produced based on these records. It indicates the type and number of insects found, their locations and additional comments when relevant.

In public spaces and non-collection storage spaces, an external contractor is responsible for placing traps, checking them once a month and reporting findings to the conservation team within three working days.

New acquisition

Upon arrival, all external packaging materials of new acquisitions are systematically discarded. The objects are then placed in quarantine within a dedicated room. A sticky mat barrier is used to define the quarantine zone inside which the items are isolated. The quarantine time may vary from one week to several months, depending on the volume of the shipment as well as the operator's workload.

[2] Jessica Lafrance Hwang, personal communication, 18th June 2025

[3] Appendix 6, document 1, p.59

Treatment
In the case of suspicious objects, they are treated using freezing cycles, unless contraindicated by the object's material or condition. The standard treatment is to place the item in the freezer at -12°C to -17°C for one week, removing it for 24 hours and returning it to the freezer for a second week. If they are too big to fit in the freezer, an external contractor will be contacted to rent the equipment to the museum, or to treat them by fumigation or freezing treatment, depending on the nature of the material. In the event of a large-scale infestation, a professional pest control will be contacted to carry out a complete disinfection of the affected area.

Staff education
All employees are provided with a copy of the museum's IPM guidelines and are required to read them. Each year, a summary document outlining current IPM procedures and updates is sent to every staff member.

1.3 Other partner institutions

To gather sufficient data in various environmental conditions, several collaborations were established with institutions across the National Capital Region (NCR) and Eastern Ontario.

1.3.1 Ingenium

Ingenium is a Crown Corporation founded in 1990 composed of three different national museums: the Canada Agriculture and Food Museum, the Canada Aviation and Space Museum and the Canada Science and Technology Museum (Ingenium, 2025).
During this project, we were welcomed in the Canada Aviation and Space Museum to conduct testing on wood pieces from crates and pellets that had been stored outside.

1.3.2 National Gallery of Canada

The National Gallery of Canada was founded in 1880 and houses both historical and contemporary art collections (National Gallery of Canada, 2025).
We were granted access to one of their several off site warehouses to test wooden artwork suspected of active infestation.

2 Problem statement

The Canadian Museum of History previously used a CO_2 bubble to treat infested objects. This method was systematically applied to all incoming objects as a preventive measure to reduce the risk of infestation. However, Canadian legislation, enforced by the Pest Management Regulatory Agency of Canada PMRA) has now heavily restricted the use of CO_2 treatment in a museum or gallery setting[4]. As the museum relied heavily on this method, the consequence of this new regulation had resulted in the discontinuation of CO_2 anoxia treatment and a significantly less stringent preventive detection approach. For that reason, the Museum is seeking to adapt its IPM strategy to ensure rapid and reliable detection, so that only objects showing clear signs of infestation can be treated, typically through freezing.

[4] Appendix 6, document 3, p.60-61

Beyond monitoring current collections in storage and on display, the effectiveness of the chosen detection method is critical for newly acquired objects. These must be thoroughly checked before being moved into storage or exhibition areas to prevent widespread infestation.
Conventional detection methods, such as quarantine, require considerable time and space. The use of traps can reveal the presence of insects within a room but does not allow staff to easily identify the specific object that is infested.

For these reasons, acoustic emission is the technique currently under consideration by the Museum to optimize its IPM strategy and fill the gap left by the prohibition of CO2 treatment.

While the integration of acoustic emissions for wooden objects is not expected to present any major obstacles as it has already been applied in similar contexts, its use on other organic materials such as textiles, leather or book has not yet been validated.

3 State of the art

Application
AE has been used to detect a wide range of woodboring insects, including bigger species such as *Hylotrupes bajulus* (old house borer) (Plinke & al. 2022; Krajewski & al., 2024; Limmer & al., 2024), *Xestobium rufovillosum* (deathwatch beetle) (Creemers, 2015) and smaller ones such as *Lytus brunneus (Creemers, 2015)* and *Anobium punctatum* (furniture beetle) (Le Conte & al., 2014; Creemers, 2015) The primary signals detected are related to larval feeding activity on wood substract. Their movements inside their gallery and mandibles friction produce weaker signals as well. (Nasswettrová & al., 2016, p.756; Bilski & al., 2017, p.62; Sutin et al., 2019, p.1328; Jakiela & al., 2007, p.2).

Laboratory experiments have demonstrated the feasibility of early-stage detection of larvae such as *H. bajulus*, even though the success of the detection depends on favorable conditions such as high larval density and optimal temperature and humidity (Krajewski & al., 2024, p.2094; Creemers, 2015, p.4-6; Plinke & al., 2022, p.8). Insect activity generally decreases sharply under 10°C and increases greatly above 20°C. This indication can help to choose the right period for AE monitoring campaigns (Limmer & al., 2024, p.4; Creemers, 2015, p.4-7)

AE has also shown great results for verifying the effectiveness of thermal or anoxia treatment by comparing activity before, during after intervention (Le Conte & al., 2014, p.342; Nasswettrová & al., 2016, p.760-764). During heat treatment, it has been notified that AE signals show higher pulse rate and amplitude (Plinke & al., 2022, p.9).

Type of sensors
The sensors are typically designed for frequencies between 100kHz and 1MHz and sometimes extending up to 2MHz (Le Conte & al., 2014, p.340). However, several studies have successfully used lower-frequency sensors, such as 20-450 kHz (Plinke & al., 2022, p.3) or 1-60 kHz for detecting feeding sounds of old house borer (Krajewski & al., 2024, p.2095-2096).
Therefore, sensors should be chosen according to the species we try to detect. If no specific species is targeted, a broadband sensor would offer wider detection possibilities.
The appendix 3, table 1, p.16 presents an overview of the sensitivity of sensors that have been successfully employed for various species.

Coupling methods

The efficiency of AE signal transmission depends greatly on the quality of coupling between the sensor and the tested object's surface. Several studies experimented with different coupling methods and products that could be applied to conservation field. Their results are gathered in table 1 below.

Coupling method	Remarks	Suitability for heritage	References
Wax	Commonly used	High	Le Conte & al., 2015 Costa, 2024
Cyclododecane	Negligible signal loss compared to wax	Very high	Le Conte & al., 2015 Costa, 2024
Silicone	High efficiency	Low	Limmer & al., 2024
Sticky dots	Fast set up, adhesive residue risk	Low	Limmer & al., 2024
Nano tape	Residue risk	Low	Limmer & al., 2024
Clamp / Magnet	No added material, apply force	High, when feasible	Limmer & al., 2024 Creemers, 2015
Rubber band	No added material, apply force	High	Jakiela & al., 2007

Table 1, Suitability of coupling methods for heritage application

Coupling efficiency also depends on the force applied. Horst Trattnig, managing director at Vallen® advised[5] to apply 1N force to optimize transmission. A force between 20-50 N is recommended to compress viscous coupling material and avoid excess thickness. The same research advises to keep the thickness under 15 µm to obtain the best result, as thicker coupling material will cause transmission loss for higher frequencies (Ono, 2017, p.2,10-11).

Detection parameters

The quality and interpretation of AE signals depend not only on the sensor characteristics and coupling materials, but also on the physical properties of the material tested and the environment. In wood, signal attenuation varies with density, moisture content and grain orientation (Łukomski & al., 2020, p.9-20; Bilski & al., 2017, p.62; Nasswettrová & al., 2016, p.756).

With regards to sensor spacing, Jos Creemers, Project Manager at SHR, explained in a mail exchange (08.07.25) that "[…] at the highest sensitivity level using a pencil lead breaks up to 5 m […] they [the sensors] still picked up the vibration. […] I registered the gnawing of a larva 2m away in a pine beam. […] I always say that I register about 0.5m on both sides of the sensor lengthwise. […] beams may be very thick and if the larva is exactly on the other side the vibrations will be attenuated more crosswise." Targeting suspected infestation zone is therefore important to give ample consideration to the sensor placements.

Test duration also affects success. While short recordings (5-30minutes) are usually enough to detect infestation under optimal conditions (temperature, coupling, high density of larvae), longer durations (up to 120 minutes) may be needed to detect irregular- activity, especially in colder environments or when the density of larvae is low (Limmer & al, 2024, p.8-9; Plinke & al., 2022, p.2).

[5] Personnal communication, 30.07.2024

Signal characterization
AE signals related to insect feeding sounds generally consist of short pulses, lasting between 3 to 15 milliseconds (ms). However, rapid sequences may appear as a single burst, lasting up to 50ms (Sutin & al. 2019, p.1328)

High frequency signals (>100kHz) are typically associated with wood fracture, as well as active feeding. In contrast, low-frequency signals (<50kHz) are often associated with background noise, such as environmental vibration and friction. (Jakiela & al. 2007, p.7; Łukomski, 2020, p.12-13)

4 Objectives

4.1 Providing data for AI-based analysis

To enable faster and more accurate data analysis, a collaboration with Tom Marti, a final-year Bachelor student in Computer Engineering at the Haute Ecole Arc will take place. His work aims to train an Artificial Intelligence (AI) model to recognize signal data from infested objects.
Our goal is to provide him with a substantial data set composed of signals from both infested and non-infested wooden materials, by early June
AI-based analysis could also help with determining the optimal duration of each measurement. This approach could significantly reduce processing time when large numbers of objects are tested in the future, while also limiting potential inaccuracies.

4.2 Feasibility study on organic materials

The second objective of this project is to explore the possibility of extending the use of AE to other potentially infested organic materials such as books, textiles or leather. This will provide better understanding of the limitations of the methods, and this phase also serves to refine the IPM protocol.

4.3 Enhancement of IPM strategy

4.3.1 Heatmap

This objective was added after reviewing the IPM strategy of the Museum. The need for an improved way to register pest found in traps and present the obtained data leads us to the goal of creating an automated heatmap, allowing clear visual display and easily implementable method.

4.3.2 Acoustic emission protocol

The Museum seeks to determine whether acoustic emission use, as a program, is applicable to its collections, in what ways and under which conditions. This involves several factors such as identifying the optimal test duration, sensor placement, appropriate coupling materials and data analysis. The primary focus will therefore be the development of a protocol for the use of AE as a monitoring and detection tool, with respect to their collections and conservation practices.

5 Material and methods

All the AE equipment used is from Vallen System®:

Sensor: VS900-M (100 to 900 kHz)
Pre-amplifier: AEP5 (34 dB or 40 dB gain)
Coaxial cable: CBL-1-5M-V1 (RG-58)
Sensor-cable to preamplifier: CBL-1-1M2-V5 (microdot)
Chassis: AMSY-6 4 channels
AE signal processor: ASIP-2
Software: AE Suite R2022.0809.2
Computer: Dell IntelCore vPRO i5, Windows 10 22H2.
Hsu-Nielsen Source: 0.5mm, 2H lead. 30° angle

The available technical sheets can be found in appendix 5, technical sheet 1-2, p.48-51.

Each test was named according to the same system:
Name-of-the-institution_Test-category_number

Name of the institution:

CMH: Canadian Museum of History
NGC: National Gallery of Canada
CMSI: Ingenium / Canadian Museum of aviation and space

Test category:

AW: Attenuation on Wood. Is used for totem poles tests.
AP: Attenuation on Paper. Is used for books and paper tests.
AT: Attenuation on Textile. Is used for all kind of textiles tested.
WM: Wood moisture. Is used for tests conducted on drying wood.
ABS: Attenuation Wood surface. Is used for the sensor-object contact ratio tests.
B_N: Is used for pest detection tests on non-infested wood.
B_I: Is used for pest detection tests on wood suspected of infestation.
O_N: Is used for pest detection tests on non-infested organic material other than wood.
O_I: Is used for pest detection tests on organic material other than wood suspected of infestation.

The number take the format "000" at start at "001" for each category. "B_N" and "B_I" are considered as one category, having followings numbers. Same for "O_N" and "O_I".

Example of possible files names:
NGC_B_N_002
CMSI_O_I_004
CMH_AP_012

5.1 Collect data for AI training

The current AE protocol for pest detection aims to detect the breaking of wood fiber occurring when larvae feed on wood. As seen in literature, destructive events result in frequencies above 100kHz, while friction, considered as interference noises, shows frequencies lower than 100khZ.

For these tests, the following parameters were used:

- Continuous mode enabled
- No fronted filter.
- AE sample rate: 10MHz (100ns).
- Transient (TR) data enabled.
- TR sample rate: 2 MHz (0.5µs).
- TR max samples per set: 1024.
- Preamp gain (dB): 34.

For detailed acquisition parameter, consult appendix 4.2, fig. 4-6, p.27-28.

Those parameters were selected to maximize the quantity of data detected, without saturating the computer too quickly. We chose to not filter the background noise and register in continuous mode in agreement with T. Marti, so his AI-model could try to detect patterns and information not visible by eyes in the said background noise.

While different coupling methods and test duration were experimented, those steps stayed identical for all tests:

- 3 sensors placed on wooden object
- 1 sensor placed upside down near the object, as a reference for background noise
- Pencil lead break (PLB) near each sensor
- PLB is repeated at the end of the test when it has a duration of one full night or more, to ensure that the coupling is still efficient.

The PLB consists of breaking a mechanical pencil lead, three times, near the sensor to mimic a fracture signal. A mechanical pencil is used, equipped with a shoe guide produced by Vallen® that allows the lead to break at a 30° angle. The lead used is 0.5mm, 2H type and the length used for breaking is 3mm. This length corresponds to 3-4 clicks with the mechanical pencil but needs to be verified.

Three distinct phases were followed:

- Preliminary tests, done at Haute Ecole Arc (He-Arc), from March to April.
- Tests on wood logs found outdoors, carried out at the CMH, from May to July.
- Tests on suspected artefacts, carried out at partners institutions (NGC, Ingenium), from May to June.

The tests at He-Arc[6] were conducted on suspected logs collected in gardens and completed in a quiet non-collection storage room.
The coupling material used was solvent-free cyclododecane (CDD) in spray. The duration of tests varied between 5, 30 and 60 minutes, 6 hours and one night (usually 16 hours, from 17:00 to 9:00).

[6] Appendix 1, figure 1, p.1

The data is reviewed by visual analysis and observations on the state of the wood and the data is written down. The data and documentation are then transferred to Tom Marti.

The tests on suspected logs at CMH (figure 4) were conducted in a noisy loading bay (67 dB, spot measurement), to avoid spreading pest inside the museum. In between tests, wood samples were stored in polyethylene bags, which allowed further protection and easier visual monitoring of the state of the sample (frass, new exit holes, live or dead larvae and adults)[7]
The coupling methods tested were renaissance wax[8] and CDD, with and without cotton strings and with or without weights, from 100g to 1kg. Test duration varied from 30min to several days over weekends. Temperature (T°C) and relative humidity (RH%) data were recorded (HOBO MX1101)[9]. A dB-meter (NTI XL2) was also used to conduct spots measurements to indicate the standard noise level of the environment.

Figure 4, CMH_B_I_015 – CMH setup

The tested samples that showed signs of infestation in the AE data were frozen for one week and/or two weeks at -18°C and tested again to confirm if the detected signals could have been emitted by insects or others phenomenon such as cracking.
The data was reviewed and forwarded with T.Marti, along with observations and remarks.

The tests made in partner institutions[10] (figure 5) used different couplings methods, depending on the conservation practices of each institution. CDD, renaissance wax, or no product were tested. Cotton strings and weights (from 100g to 1kg) were used as well. The duration of the tests was limited to 30 minutes, to allow ample time to try several different objects during the site access period.
T°C and RH% were either recorded with the same device (HOBO MX1101) or communicated by the institution, as captured using building sensors.
NGC_B_I_007 NGC Setup

Figure 5 NGC_B_I_007 – NGC setup

Additionally, as the Musée National de l'Automobile (Collection Schlumpf), Mulhouse – France were carrying out AE measurement on suspected historical vehicles in the same timeframe as this project, they kindly agreed to follow our protocol and share their data with us.

[7] Appendix 1, figures 2-3, p.1

[8] Appendix 5, Technical sheet 4, p.49

[9] Appendix 5, Technical sheet 3, p.47-48

[10] Appendix 1, figures 4, p.1

5.2 Feasibility study on organic materials

Working on the feasibility of using AE on other organic materials means looking for other kinds of insects: Keratinophagous and detritivores pest that target organic materials containing molecules such as proteins, lipids, or polysaccharides. As commonly found museum pests, we can cite the clothes moth (*Tineolla bisselliella)*, the varied carpet beetle (*Anthrenus verbasci*), or the silverfish (*Lepisma saccharina*) (Museum Pests, 2025)

The tests were conducted on healthy material in order to focus on the study of wave transmission and attenuation through different materials, rather than trying to detect active pest signals without background knowledge.

For those tests, the following parameters were selected:

- Continuous mode disabled.
- No fronted filter.
- AE sample rate : 10MHz (100ns).
- Transient (TR) data enabled.
- TR sample rate: 5’000 MHz (0.5µs).
- TR max samples per set: 2’097’152.
- Preamp gain (dB): 34.

For detailed acquisition parameter, consult appendix 6, document 4, p.67.

Those parameters aim to suppress background noise to focus solely on artificially created signals by the pencil lead break test.

Note that for each of the tests cited below, PLB were conducted at various distances and in different directions, using a sticky note pocket in order to not touch the surface of the object with the lead.

Figure 6, PLB with sticky note pocket

In appendix 3, table 2, p.17, find a table that gathers all the tested objects that will be talked about in the next chapters, their ID number, corresponding test names and short descriptions.

5.2.1 Books and paper

A selection of books and paper objects, of a variety of sizes, materials and densities, were chosen to conduct a series of tests.
Different tests were performed to establish attenuation inside those materials and try to enhance it.

Wood table setup
Firstly, each object was tested raw, placed on a wood table covered with 0.2mm thin Ethafoam®, with the sensor directly on the surface of the object. Cotton ribbon weights (from 200g to 1kg) and/or clamps were used to maintain sensors into place. Each sensor was placed strategically depending on the nature and shape of the objects, to cover distance in multiples directions. (figure 7-8, p.20)
To be able to simulate a signal from within the book, cotton strings were placed at different depths and width inside the book. They are gently pulled by both ends in a forward and backward motion. The sequence is composed of one pull forward, one pull backward and a short pause, repeated for a total of three times. This test was named the “string pull test” (SPT).
Additional pictures can be found in appendix 1, figure 5-9, p. 1-2

Figure 7 CMH_AP_001 – wood table setup

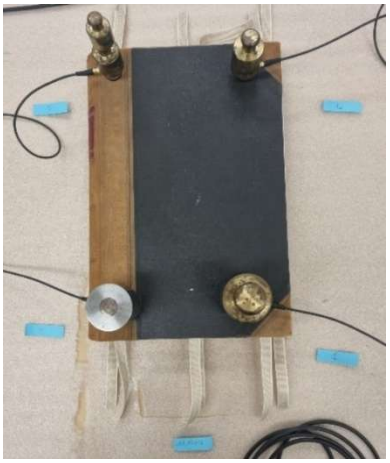


Figure 8 CMH_AP_002 – 1974.1672.1 – wood table setup

Metal table setup

The same objects were tested on an aluminum table instead of a wood table. The sensors were placed on the metal table, with renaissance wax and weights (from 0g to 1kg). PLB were conducted on the metal table and on each object (figure 9).

This test aimed to determine the possibility of testing objects in groups without placing the sensor directly on the object, reducing the constraints of coupling material and heritage objects compatibility.

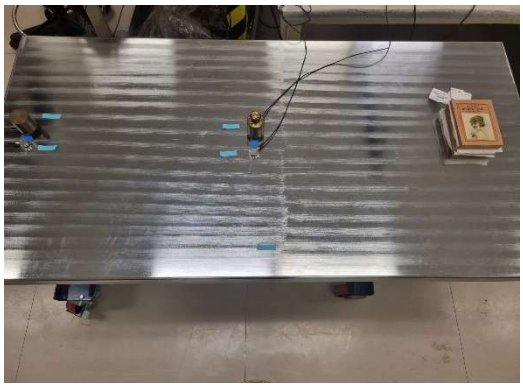


Figure 9 CMH_AP_009 – Metal table setup

Top-bottom setup

The ensemble of books used during the test CMH_AP_001 (figure 7) went under various tests to try to enhance transmission through paper. This ensemble was chosen because of its uniformity and the possibility to gradually increase the total thickness by adding other books.

The first setup (figure 10) consisted of placing a book on small wooden blocks to elevate it. Cotton ribbons are used to attach two sensors, one in the bottom and one on top. The PLB was conducted along the book (1 cm, 3 cm and 6 cm away from the sensor), then a second book was added, and the test was repeated (figure 10). The same test was conducted with CDD to compare results.

No attenuation profiles were made for this test, as a wider range of distance is necessary to establish a pertinent graph. Instead, the loss of dB per centimeter was calculated by subtracting the value obtained on the bottom sensor to the one obtained on the top sensor.

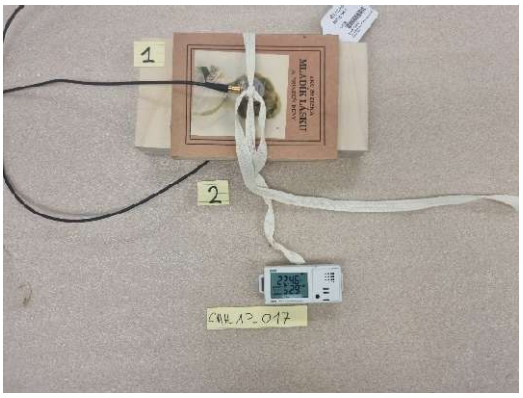


Figure 10, CMH_AP_017 – Top-bottom setup 1

Setup 2-3

Then the same test was conducted with the addition of stainless-steel plates of different thickness (0.2, 0.8 and 1.2mm) were added at the top and bottom[11]. The sensors were coupled with renaissance wax, and a metal clamp was used to apply some force to the installation.

The test was repeated, but small pads of 1 cm thin Ethafoam® were placed in between the sensors and the clamp (figure 11).

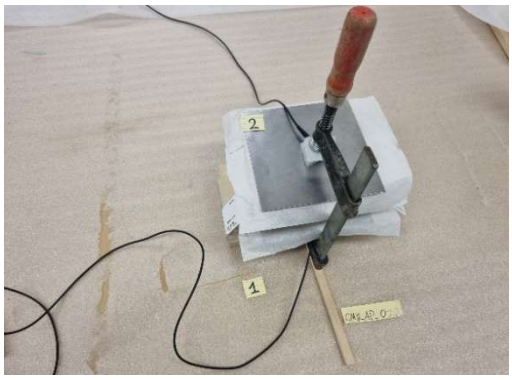


Figure 11 CMH_AP_20 – top-bottom setup 3

Setup 4-5

Another setup consisting of placing the book on the metal table with a 2mm thick stainless-steel plate on top was tested. Sensors are coupled with renaissance wax[12].

For the last setup (figure 12), a stainless plate was placed between the table and the book, aiming to reduce potential friction noises.

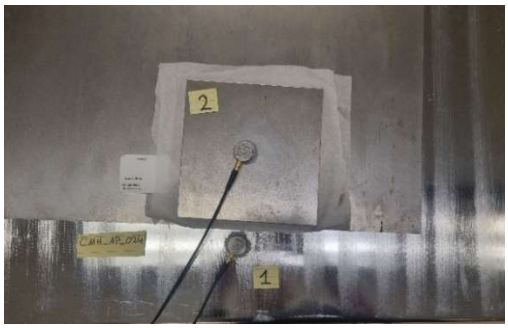


Figure 12 CMH_AP_20 – top-bottom setup 5

5.2.2 Textiles

A selection of different types of textiles objects were selected for their variety in terms of materials (cotton, silk, wool, leather), thickness and packing methods.

Storage room

The first setup consisted of testing armchairs in a standard storage room at the CMH. The chair cushions are most likely composed of cotton velvet and horsehair as stuffing. Sensors were placed on different parts of the chair, using cotton ribbons and/or weights (figure 13).

Figure 13 CMH_AT_002 – 982.14.1 – Armchair setut

[11] Appendix 1, figure 10, p.2

[12] Appendix 1, figure 11, p.2

Wood table setup

The second setup tested flat textiles on a wood table covered by 2mm thick Ethafoam® of different thickness and material, such as cotton, leather and silk. Sensors were placed using CDD and/or weights (figure 14). Additional pictures can be found in appendix 1, figures 12-14, p.2-3.

Figure 14 CMH_AT_004 D-11973 – Wood table setup

Rolled textiles

The third setup was rolled textiles. Sensors were placed on the textile, with cotton ribbons and with or without CDD. Inspired by the work of R.Mankin & D. Hagstrum "*Acoustic Monitoring of Insects*", 2011 suggesting that using a metal tube to detect pest insect in stored grain with AE is possible, we decided to place sensors on the concrete form tubes used to store the textiles.

We tested two types of tubes found in the storage rooms: non-acidic carboard 3mm thick (figure 15) and Acrylonitrile butadiene styrene plastic tube (*ABS*). Additional pictures can be found in appendix 1, figures 15-17, p.3.

Figure 15 CMH_AT_003 – 982.14.1 – Rolled textile setup

Metal table setup

In the next setup, the silk vest (ID: D-11973) was tested according to the same method as the fourth setup for books: placed in between metal plates, on the aluminum table. Sensors were coupled with renaissance wax and 1kg weight.

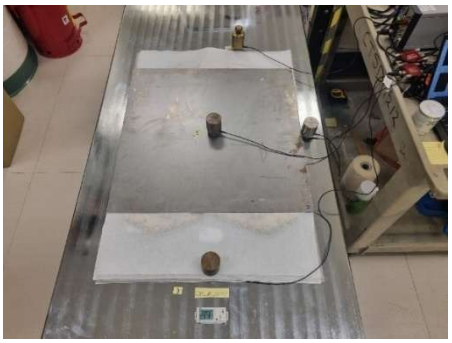


Figure 16 CMH_AT_010 – D-11973 – Metal table setup

5.2.3 Whalebone

Whalebones contain fats and oils that can continue to migrate to the surface for decades after collection. They are targeted by some insects, and some museums have had active infestation in their whalebone artefact collection (YouTube, 2024).
Testing was conducted on a large sculpture (ID: IV-C-4437 a-b) (figure 17).
As the sculpture presented different level of porosity, the sensors were placed on area from high to low porosity.
Cotton ribbons were used as a coupling method, as renaissance wax could penetrate inside the material and we did not have the solvent-free CDD in our possession yet.

Figure 17 CMH_AB_001 – IV_C-4437 a-b - Whalebone

Additional pictures can be found in appendix 1, figures 18-19, p.4.

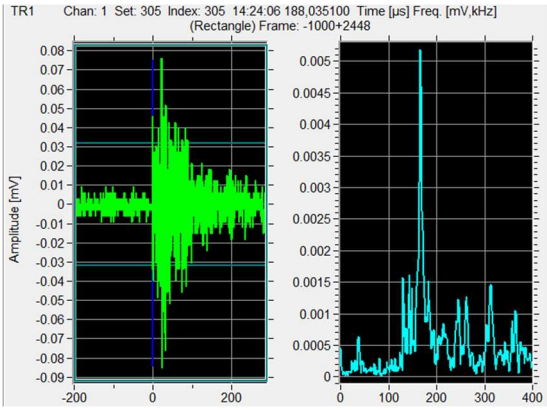
5.2.4 Attenuation profile

For each test, the collected data is used to calculate the attenuation profile in VisualAE, Vallen®. This allowed us to predict the maximal effective distance inside a material or object.

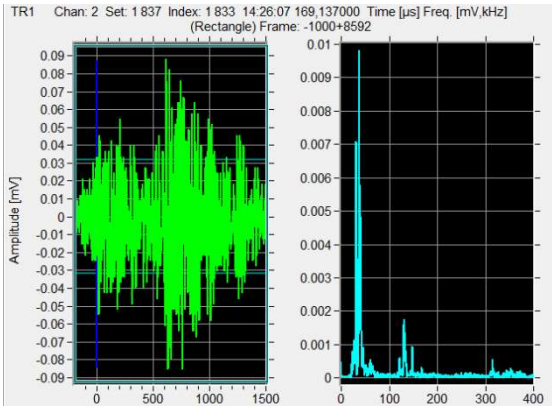
Because of the use of the sticky note pocket and of the softness of certain materials tested it is not rare to receive AE signals induced by friction, instead of cracking sound emitted by the PLB. In order to make the attenuation profile, it is necessary to take exclusively the signal emitted from the lead breaking.
To ensure that the right signals are used, we reviewed each hit according to the following parameters :

- Frequency: breaking signals are associated with greater frequencies than 100Hz and friction are with frequencies lower than 100Hz (Łukomski, 2020, p.12-13). This has been confirmed by our PLB on wood.
- Duration: cracking sounds typically heard during insect feeding activity tend to have a shorter duration than friction ones (Sutin & al. 2019, p.1328). During our tests, it has been observed that PLB signals range mostly from 100 to 200ms, while friction signals can go up to 2000ms. However, it is not rare that one hit contains distinct frequency peaks in the friction and cracking part, resulting in longer hits that can nevertheless be associated with cracking.
- Logic: apparition of hits is checked while doing PLB. We verify in real time that their placement on the graph follows the pattern of the PLB while conducting the test.

Graphs 1 & 2 below illustrate the statements discussed above, with the *Transient Diagram* (TR-Diagram) on the right (green), indicating the duration of the hit. On the right (blue), the *Fast Fourier Transform* (FFT) represents the frequency components of the hit



Graph 1, CMH_B_N_002 TR-Diagram and FFT of a PLB hit (break)



Graph 2, CMH_AP_001 TR-Diagram and FFT of a SPT hit (friction)

A. Sutin wrote in his 2019 study "*This is a well-known classification problem: a single 'strong' feature does not exist; therefore, many 'weak' features must be used in parallel for signal detection and discrimination*". Therefore, it is important to note that the different parameters cited above have been used to help sorting and analyzing the data, but do not provide an absolute guarantee of accuracy.

Once the correct signals have been picked, they are entered in VisualAE Attenuation Profile to generate the Graphs and obtained values such as maximal sensor spacing (maximal detection distance).
A *near-field* limit has to be attributed to allow calculation. As the attenuation profiles tend to create a *negative exponential curve*, the software has a different calculation process for the values placed in the near-field and *far-field.*
This value is normally determined by multiplying the thickness of the material tested by 20, but this parameter has been established with standardized metal plates, which does not correspond to our tested objects. To solve this issue, Herbert Karzel, sales engineer at Vallen® explained in a personal communication on the 11.07.25 that this value could be attributed freely in a way that fit the point on the curve beyond which it transitions from a steep decline to a more gradual decay[13].
He specified that because of the relative approximation of the near-field limit value and the less homogenous nature of tested objects, amplitudes and maximal sensor spacing distance would be less accurate compared to metal structures.

5.3 Enhancement of IPM strategy

5.3.1 Heatmap

To create a model of automated heatmap, the data from 2012 regarding the findings and location of carpet beetle[14] were collected from the paper records and trimestral report and gathered in an excel file. This file calculates the number of insects found each year, by rooms and by floor. It also shows color grade visual for a quick overview.

For each floor, the corresponding map was squared and attributed X and Y values as coordinates, allowing to indicate the precise location of each sticky trap.

[13] Appendix 2, Graph 6, p.9

[14] This specie was chosen as a rise in its population has been notified the past years and it present a risk for the collection.

With this information, the excel file was imported to Tableau Public® 2025.2 version, to create automated heatmaps, sorted by year and floor. The heatmap can be easily updated, traps can be added or suppressed, and new species can be added.
The protocol on how to use and update the heatmap is found in appendix 4.4 "use and update of the heatmap", p.38-42.

5.3.2 Acoustic emission protocol

To refine the use of acoustic emission as a detailed protocol, several tests were conducted on the following variables and setting: cyclododecane as a coupling material, sensor-object contact ratio, wood moisture and attenuation on oversized objects.
Note that two separate numbering systems are used in the annexes: one for the main report and one for the figures contained in the protocols. This ensures that the protocols and their figures remain self-contained and can be extracted and used independently of this full document.
In protocols, each figure is labeled "fig." followed by a sequential number starting from 1.
In the rest of the document, figure references are written in full and never abbreviated.

Cyclododecane
As the usual solvent-free CDD spray was out of stock until mid-June, several kinds of sprays were provided as a replacement. To determine their compatibility on heritage objects and for AE testing, documentation about each product and their composition was made by consulting technical sheets and consolidating information. The sprays in question are the Attblime® AB0, AB2, AB6 and ABP grey[15]. Attblime® AB24, the solvent-free one, was included in the documentation to allow better comparison.
After documentation, the sublimation time and potential staining were tested by using each spray on a wood log. Each one was sprayed twice, first for 1 second then 3 seconds.
The log was photographed before the intervention and at regular intervals until the complete sublimation of the product.
As the ABP spray is not a sublimating product, the following cleaning methods were tested: soft brush, hard brush, wood spatula, metal spatula, water, ethanol and isopropyl alcohol.
After this test, the adhesive properties of these sprays were tested by trying to install a sensor to a small wood sample the same way it's done with the usual solvent-free AB24 spray[16]. The wood sample was then moved at vertical position and then upside down to see if the sensor would hold correctly. This test is made again but the wood sample is moved after a 15-minute delay to let the CDD layer dry. The final test was done by using a considerable amount of CDD around the sensor to try to increase the adhesive force. The AB24 wasn't included in those tests, as it has been already used successfully in acoustic emission testing and came several weeks after the other ones.

Figure 18 CDD Attblime® sprays, 1 hour after application

[15] Appendix 5, technical sheets 5-9, p.50-57.

[16] Usual method: Spray a thin layer, quickly press the sensor into the surface, spray a thicker CDD around the sensor

Sensor-object contact ratio

Secondly, the influence of the sensor-object contact ratio was studied. In the case of small objects, or a curved surface or particularly uneven surface, the sensor might not be completely pressed into the surface.

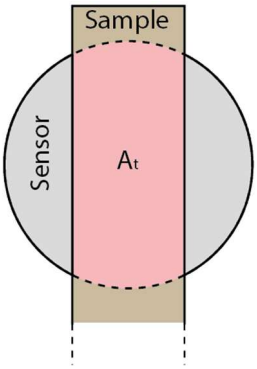
To estimate the impact of this on wave detection, several wood samples of two different species, maple and western red cedar, cut at different widths from 25mm to 2mm, a height of 25mm and a length of 150mm.

Sensors were then placed on one extremity of the surface of the sample, secured with a cotton ribbon only. No coupling material were used to simulate "worst-case" scenario (figure 20). On very thin samples, to allow it to not fall over, the sample was held by thick pieces of low-density foam. This material was selected to avoid interference due to waves travelling through the material used to hold the wood sample.

PLB was then done every 5 cm along the sample but also in the air at 3 cm away from each sensor, by manually breaking the 3mm long lead. This aims to identify a possible increase in background noise detection in case of low sensor-object contact ratio.

The attenuation of signal in each sample was then calculated using Vallen software.

To establish the sensor-object contact ratio, this equation was formulated to calculate the area of the touching surface:



$$A_t = r^2\left(2\alpha - \sin(2\alpha)\right) + 2w \cdot \sqrt{r^2 - \left(\frac{w}{2}\right)^2}$$

Figure 19, Sensor-object contact surface

Where:

r = sensor radius w = width of the wood sample $\alpha = \arcsin\left(\frac{w}{2r}\right)$

It calculates the area of the top circular segment, multiply it by two and then add the area of the central rectangle.

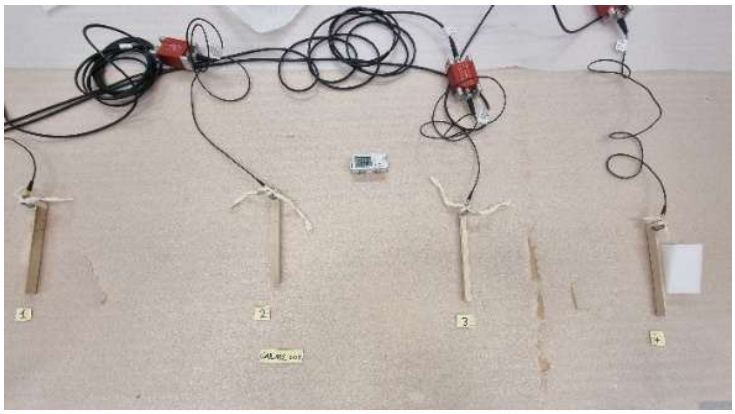


Figure 20 Sensor-object contact ratio setup

Wood moisture

Thirdly, as wood moisture has been reported to have an impact on AE signals in several studies (Jakiela & al., 2007, p.4; Nasswettrová & al., 2016, p.756; Łukomski & al., 2020, p.17), AE testing was conducted on drying wood. Three wood samples of different density and composition (maple, red western cedar and plywood) were cut according to the following length, width and heigh: 10x5x2 cm.

Their moisture level was measured with the pinless moisture meter Ligno Scanner SD from Lignomat® at 1.9 cm and 0.6 cm depth. These depth settings are standard for this instrument. Measurements were taken on both sides of the samples, and the average was calculated. This was established as the woods "dry" moisture reading. An AE test is conducted on those dry samples, using cotton ribbon as a coupling method to avoid introducing any chemicals that could have an influence on moisture or temperature of the wood. The test lasted one night.

The samples were then soaked in tap water for 6 hours, then left to begin drying in ambient air for half an hour before taking the moisture level again. The AE test was repeated, for a duration of three consecutive days (figure 21).

The moisture level was recorded at regular each day, until the wood sample were back to their original "dry" moisture level.

PLB are also made every 24h to ensure the correct response of the sensor.

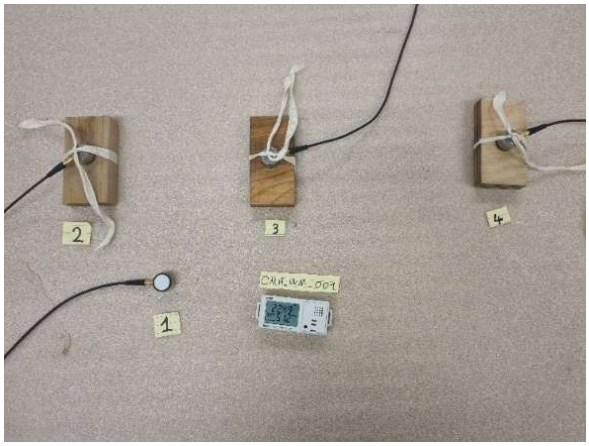


Figure 21 CMH_WM_001 – Wood moisture setup – wet wood

Attenuation on monumental heritage artwork

Lastly, as the CMH has an important collection of massive wood totem poles on permanent display, we obtained authorization to test on two of them.

The first one (ID VII-F-937 a-d Hesquiaht Pole) is a 8.07m long plain cedar pole. It is mounted on two metal rods screwed into the wood, that reach approximately the 2/3 of the total length.
The four sensors were strategically placed on one of the metal rods and around the totem pole, using CDD and cotton ribbon when necessary (figures 22-23).

PLB were made in vertical and horizontal direction, at different distances from each sensor. It wasn't judged necessary to do PLB up to the top of the totem, as the attenuation will be calculated based on the tested distances, reaching up to 1m70 high.

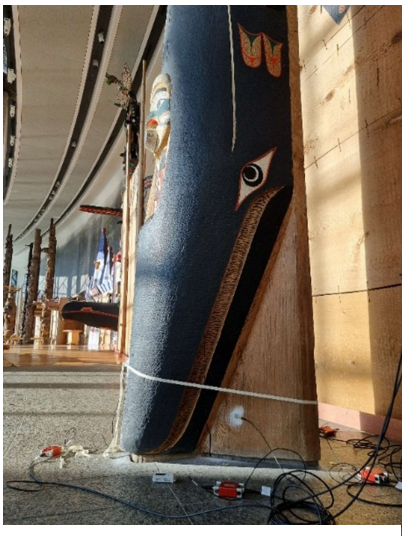


Figure 22 VII_F-937 – totem setup - side

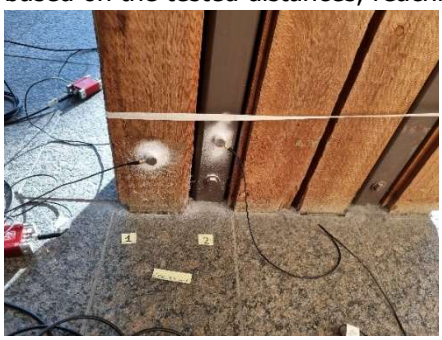


Figure 23 VII_F-937 – totem setup - back

The second one (ID VII-C-2226 Salmon Pole) is a 10.21m long red cedar pole that is carved, forming a half donut shape. It is mounted on one single rod reaching the top, with smaller horizontal rods at regular intervals, connecting the two sides of the totem pole (figures 24-25). Sensors were mounted with CDD on strategic spots: On the metal rod, in the front and one of each side of a wood edge. PLB was then performed at various distances of each sensor, both vertically and horizontally.

Figure 24 VII-C-2226 – totem setup front

Figure 25 VII-2226 – totem setup - back

6 Results

Due to the considerable size of the data collected, the results displayed here and in appendix illustrate the most representatives test for each experiment.

To have a better understanding on the following part, please consult appendix 4.1 "How to read AE Graphs", p.20-22, containing a short guide on how to read AE data.

6.1 Collect data for AI training

A total of 300GB, representing 450 hours[17] of AE data recordings have been successfully collected, described and transmitted to Tom Marti. Those data are composed of infested and healthy wood, in various ambient noises, going through active drying process and after freezing treatment.

To gather more data and ensure reproducibility of our protocol, Brice Chalançon, Manager of Conservation Workshop at the Musée National de l'Automobile (Collection Schlumpf), who is currently conducting AE testing on historic vehicles, kindly agreed to follow our protocol and share his data with us.

Tom Marti explained in personal communication of the 19th of July 2025 the following limitations of the data base:

Binary classification

Infested versus non-infested. This classification "*oversimplifies the complexity of real-world infestations by not accounting for infestation severity, developmental stages, or species diversity"* (Tom Marti, 2025). Classification can also be biased due to the absence of external review of the AE data.

GeoGraphal and temporal limitations

The dataset was collected over a four month (April-July 2025), potentially missing seasonal variations of insect activity.
Tests are limited to western institutions, omitting different climates, insect population and wood species.

Technical limitations

Variation in acoustic coupling methods across experiments introduces potential confounding factors that could affect signal transmission consistency. The use of ambient noise sensors may not provide optimal noise reference due to spatial separation from target sensors.

Imbalance

The imbalance between the recording hours on infested material and non-infested material could also introduce bias in the IA model.

Data collection constraints

AE equipment delivery was delayed for more than a week and the solvent-free cyclododecane was delayed until late June.
Partner institutions were unable to provide objects with confirmed infestation as initially anticipated, even though we are pleased to know that their collection seems safe from bugs.

[17] Appendix 2, Graph 1, p.7

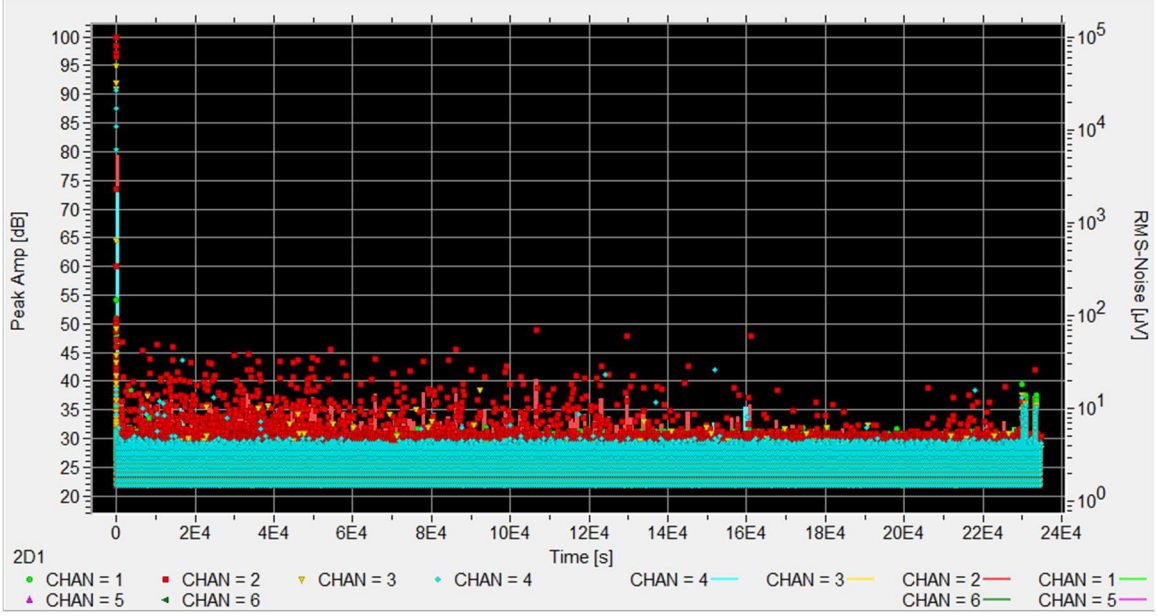
Most of these limitations could not have been fixed in this research framework.

In a personal communication of the 24th of July 2025, T. Marti wrote "*Supervised learning techniques can achieve high classification performance within single institutional contexts but cannot reliably detect infestations across different institutions. The research reveals a fundamental limitation in cross-institutional generalizability that prevents reliable deployment in practice*"

Please refer to the paper "Acoustic Emissions Signal Classification for Active Wood Infestation Detection in Cultural Heritage Objects" by Tom Marti (2025)[18] to read more about his results.[19]
The collection of objects tested at NGC has shown no signs of infestation.

An infested wood sample[20], went through two freezing treatments, one for one week at -18°C and one following the current freezing treatment protocol: one week in the freezer, one day out, one week in.

Before treatment, the infested wood is monitored by CHAN2 (red), other woods aren't infested:



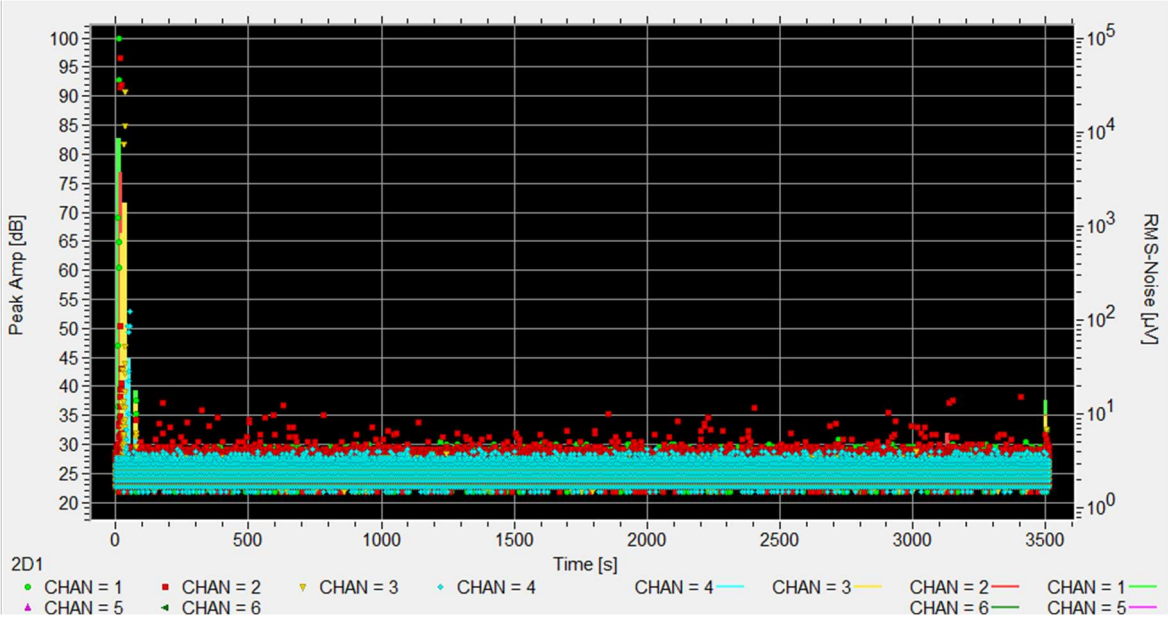
Graph 3 Infested wood (origin: CMSI_B_I_001) on CHAN2 – before freezing (CMH_B_I_017)

After one week of freezing, the same wood samples were tested again, with moderate activity remaining on CHAN2 (red):

[18] This paper is a Bachelor thesis project still being conducted at the time this paper is submitted.

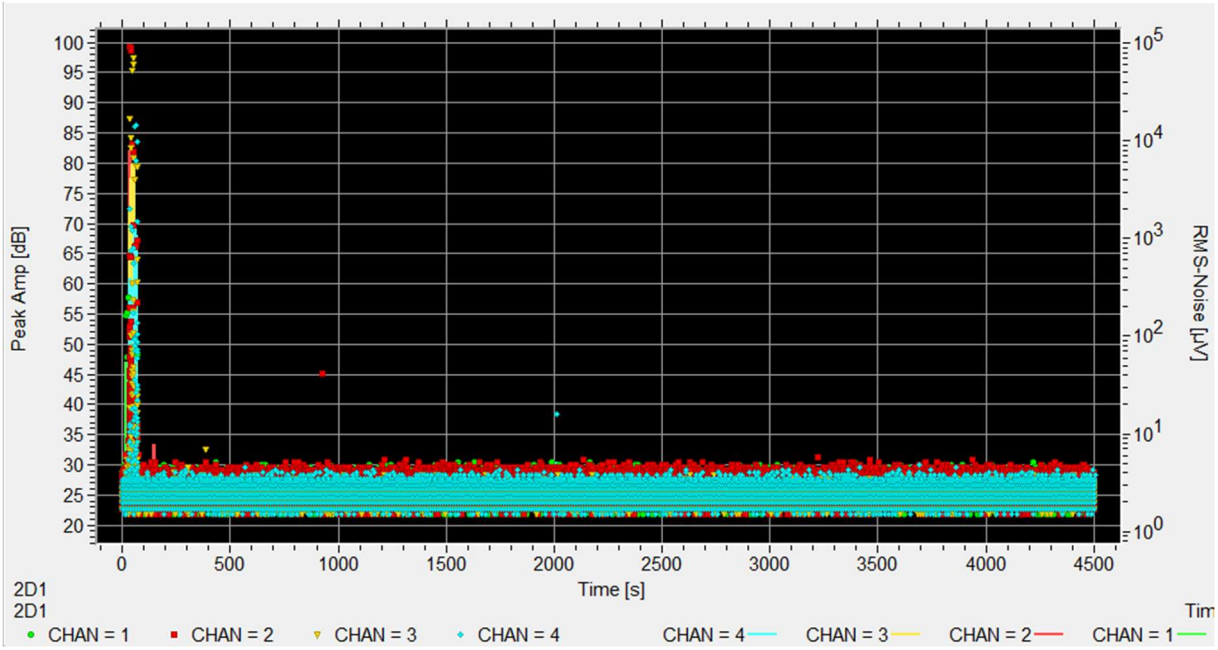
[19] T. Marti contact info: tom.marti@he-arc.ch. In case of no answer, contact ingenerie@he-arc.ch (engineering administration department of Haute Ecole Arc)

[20] Same wood sample tested several times: CMSI_B_I_001, CMSI_B_I_007, CMH_B_I_017, CMH_B_N_034, CMH_B_N_035.



Graph 4 Infested wood (origin: CMSI_B_I_001) on CHAN2 - after one week freezing treatment (CMH_B_N_034)

After the second freezing treatment, following the protocol stopped all signs of activity:



Graph 5 Infested wood WHICH ONE (origin: CMSI_B_I_001) – after two-week cycle freezing treatment (CMH_B_N_035)

This result highlights the efficacity of the current treatment method and the importance of following the two-week cycle method, as one week only hasn't shown conclusive results.

All the other pieces of wood that were showing signs of infestation got freeze and tested by AE again, with a successful stop of AE signals.

6.2 Feasibility study on organic material

6.2.1 Books and paper

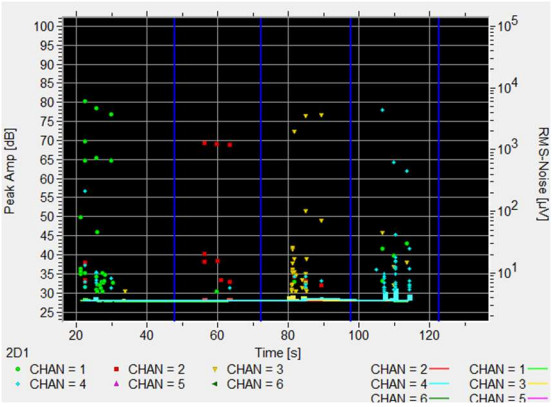
Wood table setup

The results obtained can be divided into two categories:

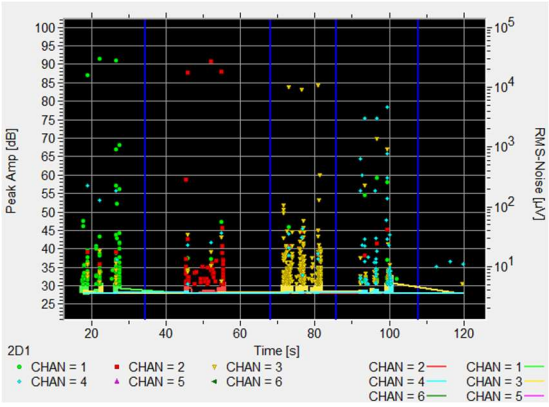
- Standard book: tests CMH_AP_001-004.
- Boxes: CMH_AP_005-007.

Refer to appendix 3, table 2, p.17 for ID numbers.

The boxes have shown no communication between sensors. The few detected signals were identified as friction noises. The use of clamps on didn't show amelioration and increased parasitic noises.



Graph 6, CMH_AP_005, postal art box, without clamps



Graph 7 CMH_AP_006, postal art box, with clamps

The books have shown more interesting results. The one with paper cover showed close results, with a maximum sensor spacing distance of 65 cm and 55 cm. Books with a thicker carboard cover (ID 1974.1672.1, 1974.1663.1) showed more attenuation, with an average of 49 cm as a maximum sensor spacing distance for 3 mm thickness and 33 cm for 6mm thickness[21].

The use of different weights, ranging from 0g to 1kg did not show a clear tendency. Others attenuation factors seem to be more influent than weight[22].

The hits detected from the string pull test (SPT) were characterized as expected by frequencies below 100Hz (Graphs 11-12). While this could give some information about wave transmission inside the material, it cannot be used to assess the possibility of using acoustic emissions on books to detect feeding activities from larvae. The SPT test is also not reproductible, as the strength and speed used to pull the string and the length pulled, can introduce important variations.

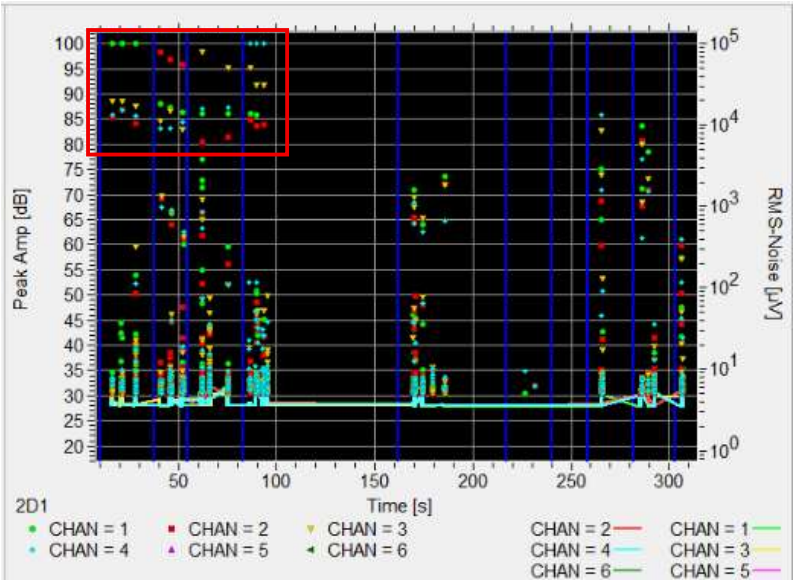
To ensure the signals we were detecting were actually passing through the entirety of the book and not simply sounds of friction, we proceeded with further tests on the metal table.

[21] Appendix 3, tables 3-6, p.14.

[22] Appendix 2, Graphs 2-5, p.7-9

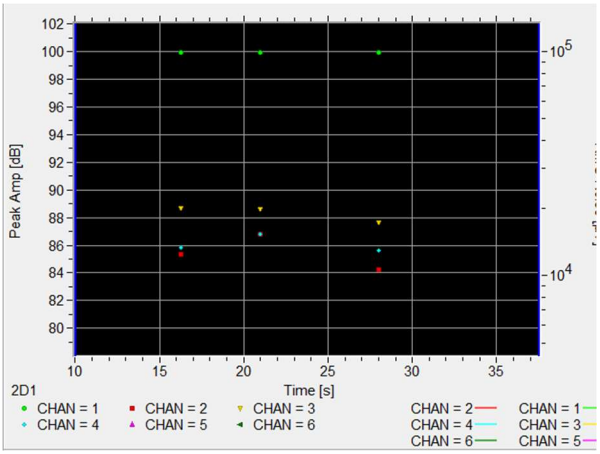
Metal table setup

All the objects tested on the standard table setup have been tested again on the metal table.
At first PLB was made 1 cm away from each sensor, placed on the metal table. Then the PLB were made on the object placed on the table.
While the result looked conclusive at first glance, having various responses from all the sensors when executing the PLB on the object, a quick analysis on the characteristics of the hits showed us otherwise. On Graph 8 below, the first half on the left shows PLB made close to the sensor on the metal table. The other half on the right shows PLB conducted on the object.

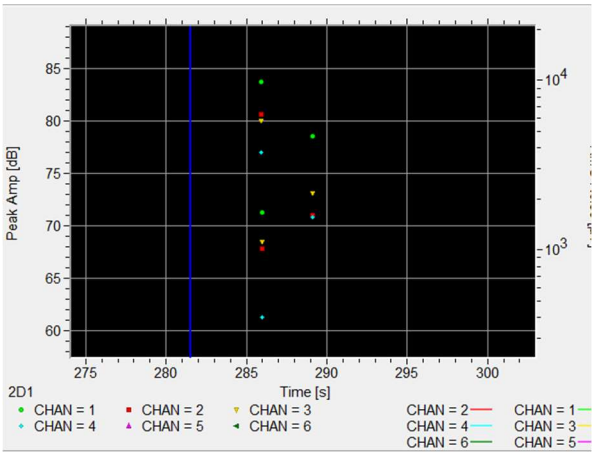


Graph 8, CMH_AP_009 Metal table setup

The hits coming from PLB on metal table are regular (Graph 9). In each of the three pencil lead breaks, we can notice a hit from all four sensors appearing at the same time, at different dB levels. It forms three distinctive lines, each composed by the four hits coming from the four different channels (Graph 8, red square) and additional low-dB noise.
In the PLB test made on the book, the hits are disorganized (Graph 10). On this example below there are only two lines and some channels appear more than once on the same line. This suggests that we detect the friction of the objects slightly moving on the metal while doing the PLB instead of the cracking sound of the lead breaking.

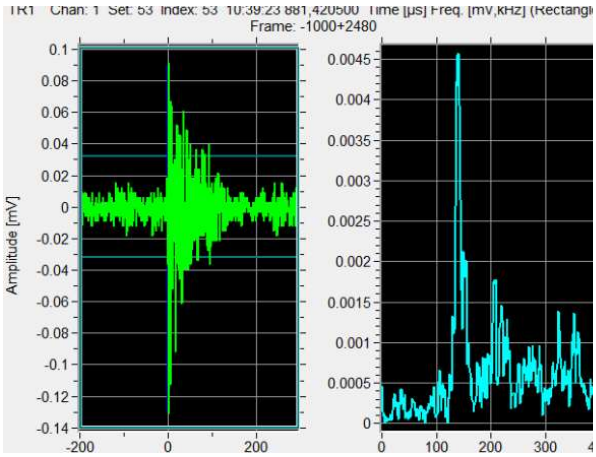


Graph 9 CMH_AP_009, Metal PLB at CHAN1, zoomed

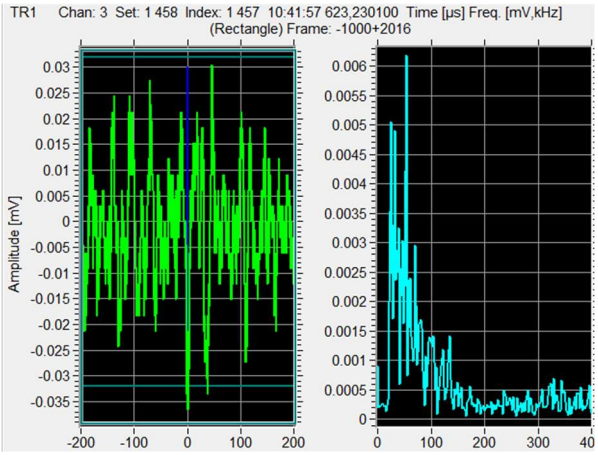


Graph 10 CMH_AP_009, Object PLB at CHAN1, zoomed

By looking at the frequency response of some hits obtained, we noticed that most of them presented little to no frequencies above 100Hz, the frequencies usually associated with cracking (graph 11). Instead, they showed dominant frequencies under 100Hz, usually associated with friction (graph 12).

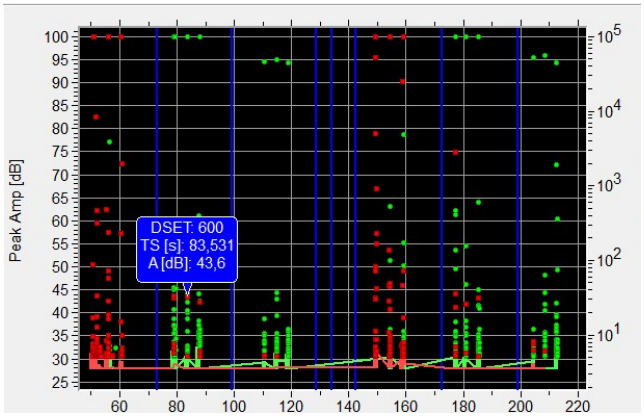


Graph 11, CMH_AP_009, TR-diagram and FFT of a hit from metal PLB (destructive event).

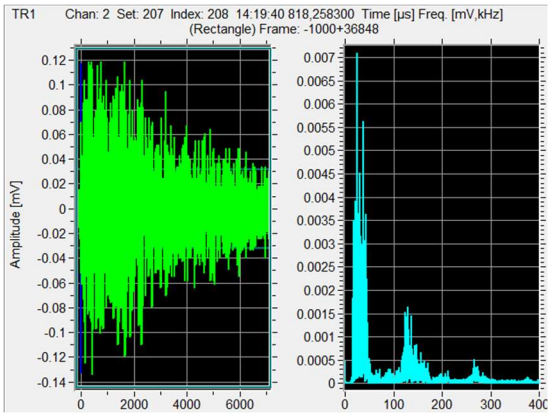


Graph 12, CMH_AP_009,TR-diagram and FFT of a hit from object PLB (friction event).

To ensure that the detected data were truly from the PLB and not from possible friction of the book on the metal table while executing the PLB, the test was conducted again on the book 997.22.330 from the 5-books ensemble (CMH_AP_001). It was held between two 0.2 cm thick metal plates and then placed on the aluminum table. A sensor was placed on top of the book (CHAN2, red) and one on the table, 1 cm away from the book (CHAN1, green). PLB were made 1 cm from CHAN2, then 1 cm and 6 cm away from CHAN1.



Graph 13, CMH_AP_025 Double metal table setup



Graph 14, CMH_AP_025 Double metal table setup. Tr-diagram and FFT of hit DSET 600 (Graph 13).

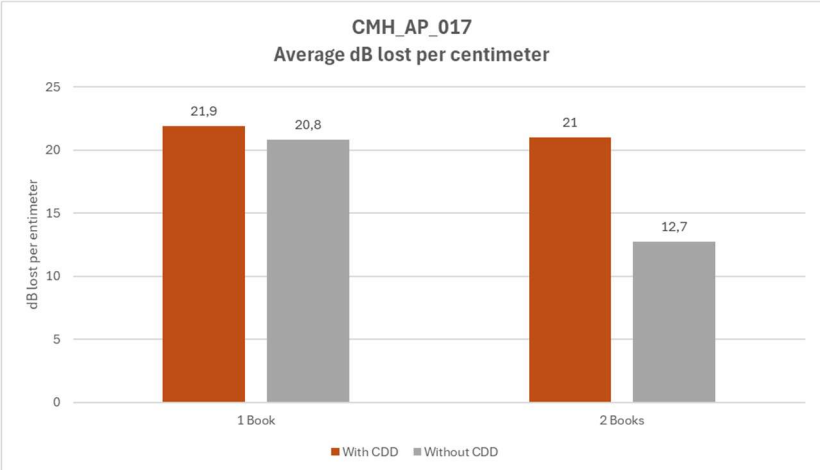
Graph 13 illustrates the results obtained. The first three series on the left represent the test without weight and the last three series on the right is the result after adding weights.

What can be seen is that without weights, the PLB conducted on CHAN1 (green) were not detected by CHAN2. The only detected signals were mostly characterized by frequencies below 100kHz (Graph 14). Adding weight showed a positive impact, as both channels were able to hear each other. However, the average loss of dB between the hit detected by one channel end and the same one detected by the other channel end is still 61 dB. Knowing that CHAN1 and CHAN2 are 4.2 cm apart, this results in a loss of 14.5 dB/cm.

To put that in perspective, a decrease of 15 dB per centimeter means that a hit of 90 dB would fall under the detection threshold (30.1 dB) after just 4 cm[23].

Top-Bottom setup

The tests for the setup having two sensors placed on the top and bottom of books, with and without CDD, showed the following result[24] :



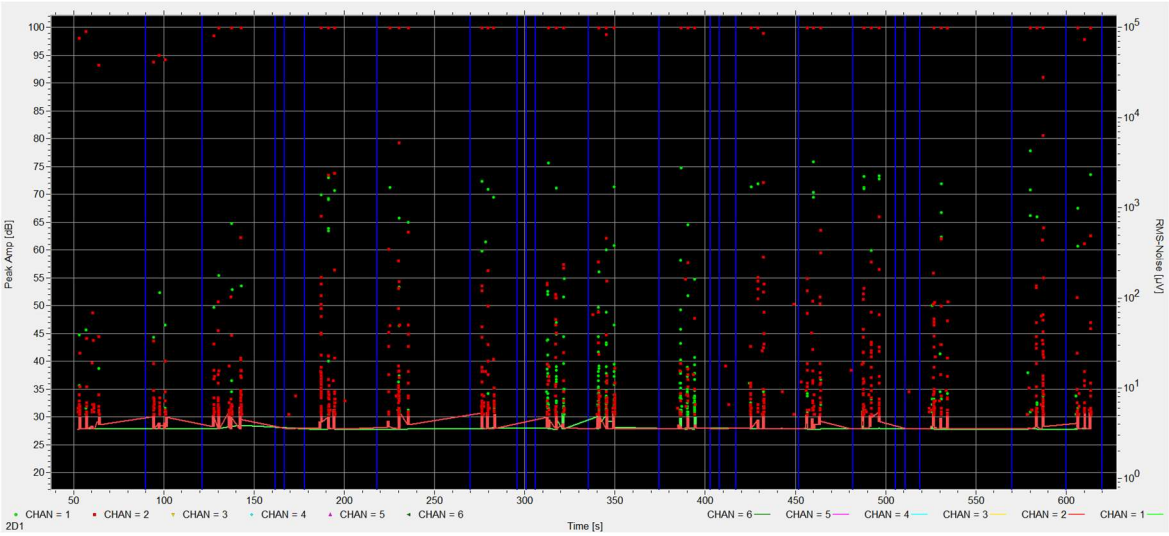
Graph 15 CMH_AP_017 Average dB lost per centimeter

[23] Appendix 1, table 7, p.14

[24] Appendix 3, tables 8-11, p.15-16

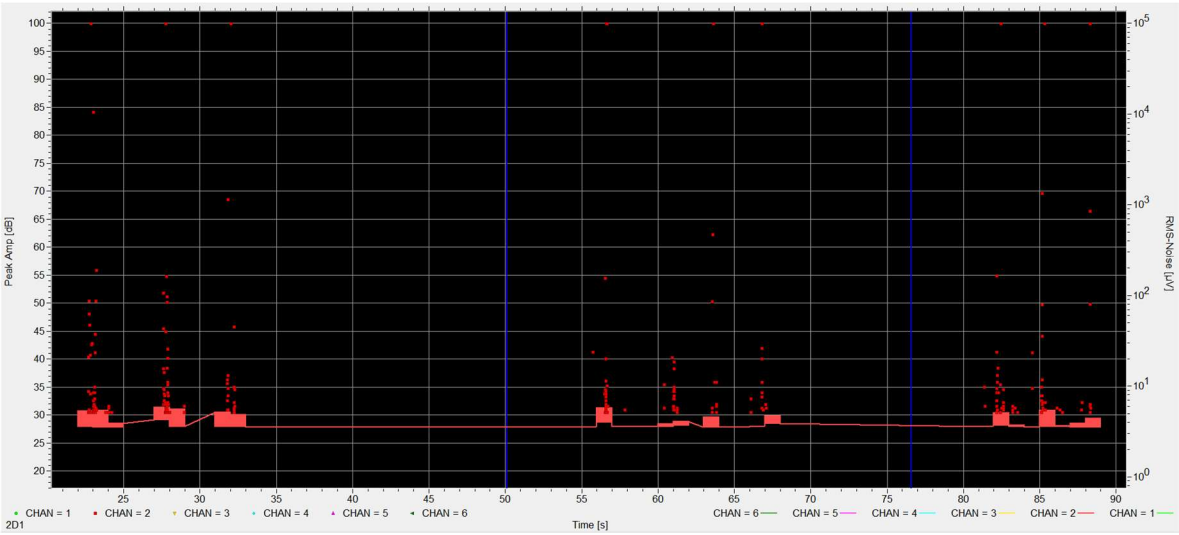
As it might seem surprising to notice a decrease in the average dB lost per centimeter with the second test (2 books), this is explained by the attenuation profile being a negative exponential curve. The dB loss is strong in the first centimeters (near-field) and decreases, forming a less steep curve (far-field). See the reference attenuation profile in appendix 2, Graph 6, p.13 for visual details.
The cyclododecane seems to have prolongated that near-field section, causing less efficiency at deeper level.
As the result presented unconclusive result with just one and two books, no more than two books were tested at once and no further research on the impact of CDD in that context was carried out.

The graph 16 below show the results of a test conducted with the same book, in between two stainless steel plate, the sensor being held by renaissance wax and a clamp. The differents sizes of plates were all tested in the same experiment, by pausing the measurement to modify the setup.



Graph 16, AP_018 Top-bottom setup with metal plate and clamps

While this test shows promising results, with the bottom sensor (CHAN1, green) being able to detect the PLB made on the top sensor (CHAN2, red) in the next experiment offers a different answer:



Graph 17, AP_020 Top-bottom setup with foam pad

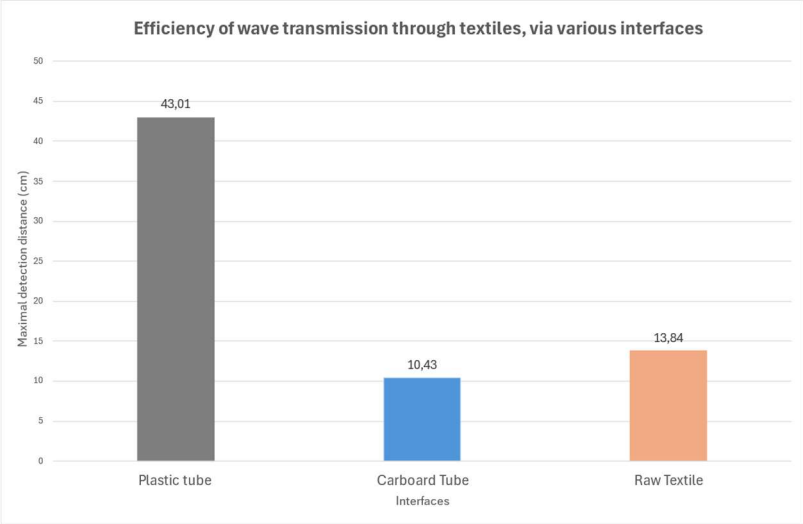
This test was conducted with the same book and the thinnest metal plate (0.2 cm), as it seemed to offer the best results during AP_018. The difference lies in the use of small Ethafoam® pad (1 cm) between the clamp and the sensor. While the results of the PLB on CHAN2 (red) are still similar, CHAN1 did not detect any AE data.

The supposition is that the soundwave emitted by the PLB was travelling through the metal clamp used to secure the sensor, instead of going through the book. When foam was introduced, it acted as an efficient wave insulator due to its low density, ensuring that the soundwaves emitted by the PLB were not travelling through the metal clamp.

Based on the current experiments, and despite some small amelioration obtained, using AE for pest detection in books and paper is not recommended because of the low maximal sensors spacing distance and important difficulty on obtaining signals through the books.

6.2.2 Textiles

The tests conducted on raw textile and rolled textiles showed an important attenuation. The rolled textiles tested had a museum standard support core of either acid-free cardboard or ABS plastic. The maximal detection distance on carboard tubes and raw textiles did not exceed 15 cm.

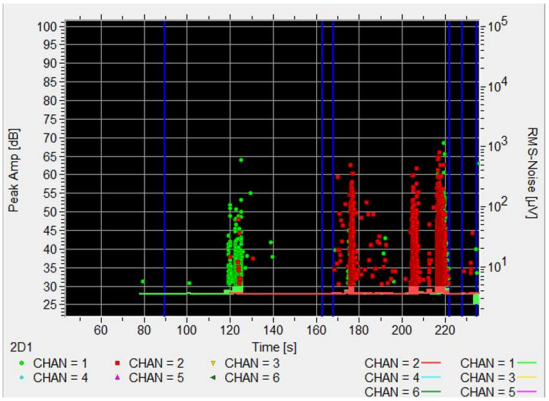


Graph 18 Maximal sensor spacing distance in tested textile

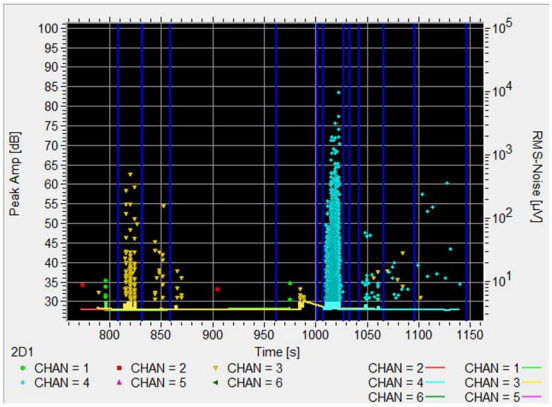
The results on ABS plastic tube were significantly better. This difference can be supported by the physical characteristic of ABS versus carboard. It is a very rigid plastic, with higher density (1.06-1.08 g/cm^3) than most carboard, allowing better waves transmission than in softer materials (Wikipedia, 2025). Carboard on the other hand is more porous and additionally is more sensitive to relative humidity changes and this could induce interferences in the case of longer measurements.
Even with a maximal detection distance of more than 40 cm, this distance is still weak compared to wood, where the distance can, in the right conditions, reach several meters.
Additionally, for both tests conducted on ABS plastic tube, there was one of the sensors who failed to detect PLB hits, without pattern as to which sensor was affected. The efficiency of the method is therefore still unsure and would require further testing.

After these experiments, which demonstrate significant signal attenuation in all types of textiles tested, no classification on which type has the best7worst wave transmission levels has been made.

The experiment made on the armchairs (ID: 982.14.1 and D-2583) in storage showed great difficulties placing the sensor correctly and conducting a PLB, because of important bending of the soft surface. This created a lot of interferences, making the data difficult to read and analyze.



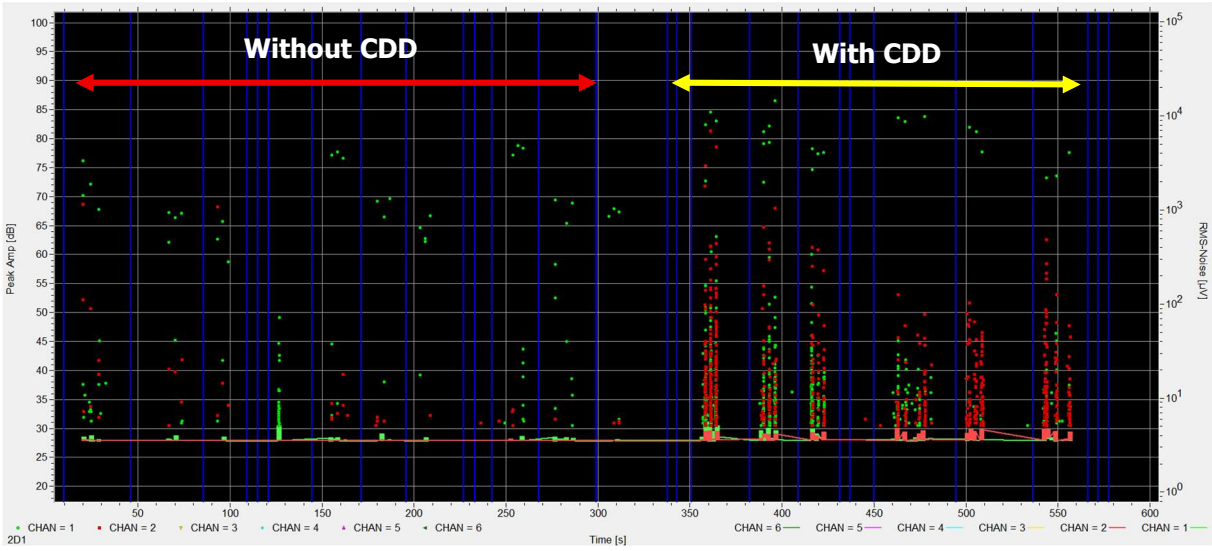
Graph 19 CMH_AT_001 Armchair ID:982.14.1



Graph 20 CMH_AT_001 Armchair ID: D-2583

Based on the results reported above on the raw textile and rolled textile, we can assume that the important attenuation of soundwave through softer material will be similar in the case of armchairs, without being able to quantify it precisely.
Even without quantifying it, visual analysis of the data demonstrated that despite some hits having a high dB value, the sensors do not seem to be able to hear activity from each other's.
The method used to sort hits between cracking noises and friction involving to look at each hit individual characteristics, it has been decided to not conduct this deeper analysis because of the important number of hits.

The use of CDD as a coupling material on textiles tends to create more parasitic noises while conducting PLB. The CDD layer cannot deform along with the bending on the object surface and cracks:



Graph 21 Difference of PLB signals detected with and without CDD, on the same cotton textile

Based on the current experiments, using AE for pest detection for textiles of any kind is not recommended, because of the low maximal sensor spacing distance and the high risk of interferences.

6.2.3 Whalebone

The results on the whalebone (Inventory number: IV-C-4437 a-b) showed maximal sensor spacing distance ranging from 10.6 cm to 27.6 cm, which is very low.

	Max. distance (cm)	Density
CHAN1	10,6	low
CHAN2,0	26	very high
CHAN2,1	21,6	very high
CHAN3	23,3	high
CHAN4	27,6	very low

Table 2 Maximal sensor spacing distance – Whalebone

However, the lowest density spot tested shows the highest maximal distance, which is contrary to what we could expect.
As a hypothesis, it can be suggested that the structural aspects of the object had a greater impact than the density. For example, if there are holes, bumps, edges or anything else that could impact the straightforward movement of the wave, the attenuation would be more important[25].

As we don't possess more precise knowledge about the density and inside structure of this object, no precise diagnostic can't be established.

Based on the current experiments, using AE for pest detection in whalebone is not recommended because of the low maximum sensors spacing distance and the fact that insects are not directly feeding on the bones

[25] Appendix 1, figures 18-19, p.4

6.3 Enhancement of IPM strategy

6.3.1 Heatmap

The automated heatmap was successfully built, using Tableau Public® 2025.2 and an Excel sheet.
The protocol on how to update the heatmaps with future data is in appendix 4.4 "Use and update of the heatmap", p.42-46.

The map below (figure3,4) shows an example of the visual obtained using the data for carpet beetles in 2020 and 2024, at the 5th floor of the Museum's storage building. Each trap is labelled by its room and trap number and possesses an associated circle that grows and gets darker as the number of insects increases.
The scale goes from 0 to 5, as this was the highest number of insects, per single trap, ever registered in one year, but this number can easily be adapted if needed.

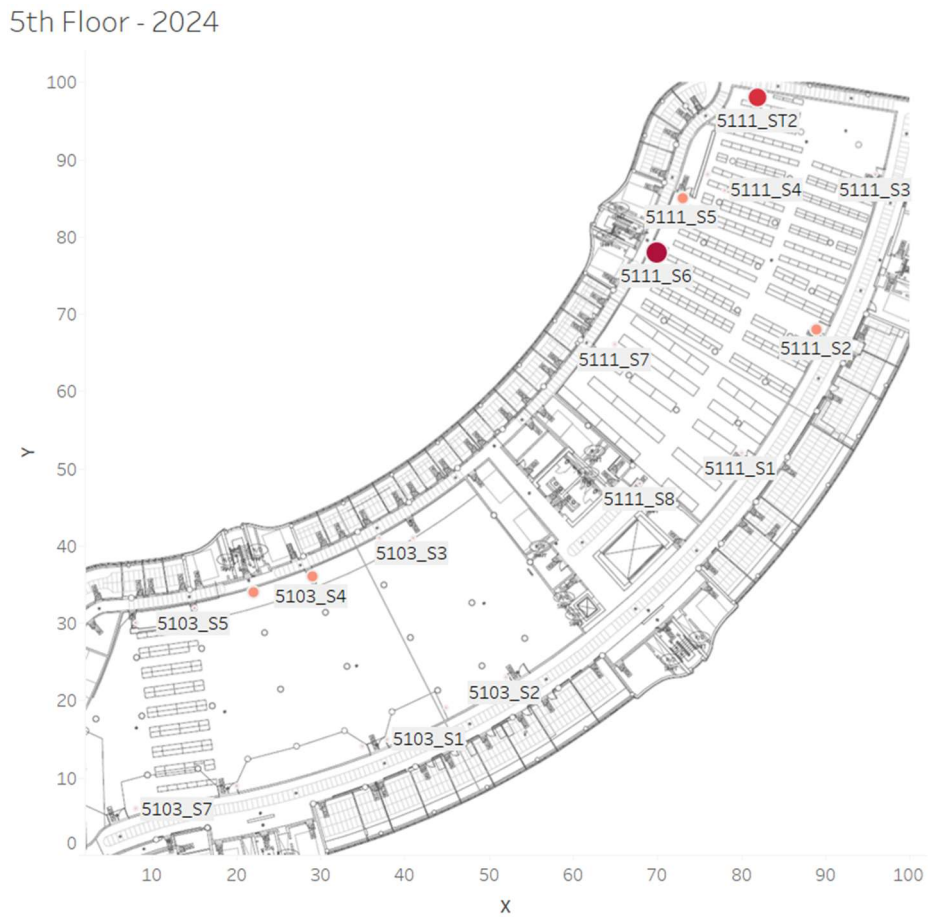


Figure 26 Heatmap, 5th floor, 2024

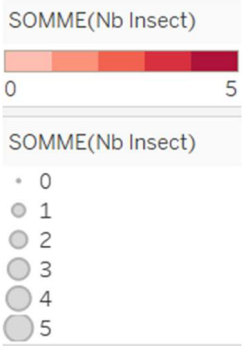


Figure 27 Heatmap captions

6.3.2 Acoustic emission

Cyclododecane

In the table below, the composition and characteristics of the different Attblime® sprays are listed.

Attblime spray	AB Zero	AB 2	AB 6	AB 24	AB P
Active ingredient	Cyclododécane	Cyclododécane	Cyclododécane	Cyclododécane	Rice starch + CaCo3
Solvant	Ethanol	Isopropyl Alcohol + C7-C9	Isopropyl Alcohol / C7-C9	None	Isopropyl Alcohol
Propellent	Propane + Butane	Propane + Butane	Propane + Butane	Propane + Butane	Propane + Butane
Effective analyse Time	<1 hour	12 hours	2 - 6 hours	12-24 hours	permanent
Sublimation time	12 hours	24 hours	6-10 hours	24-48 hours	does not sublimate
Pigments	None	None	None	None	Yes - food grade
Film formation	60 seconds	30 seconds	Instant	Instant	15 seconds

Table 3, Characteristics summary of five type of Attblime® spray

The Attblime® AB 2 and AB 6 use isopropyl alcohol as solvent and another compound of the C7-C9 solvent category[26], without any more specification. Those two sprays have been considered unusable on heritage objects as the second solvent isn't known.

The Attblime® AB P does not contain cyclododecane but rice starch, calcium carbonate and grey pigment. It does not sublimate, and cleaning methods tested to remove it were not conclusive[27]. This product is not suitable as a coupling material on heritage object.

The Attblime® AB Zero has greater penetration in porous material like wood due to its lower concentration of CDD. This results in considerably slowed down complete sublimation, as the asperities of the surface get less air ventilation. The advertised sublimation time was 12 hours. It took 10 days to completely sublimate on an untreated wood plank.

The adhesive power of the AB0, AB2, AB6 and ABP were very low. The sensor fell from the surface before it being completely turned upside down.

Sublimation time for all products tested was longer than the one advertised[28]. This duration varied greatly depending on the thickness of the coat applied[29]. Therefore, when using CDD on heritage object, it should be kept in mind that sublimation could take several days to weeks.

[26] Appendix 6, document 2, p.59

[27] Appendix 1, figures 22-28, p.5-6

[28] Appendix 3, table 12, p.18

[29] Appendix 1, figures 29-32, p.6

Sensor-object contact ratio

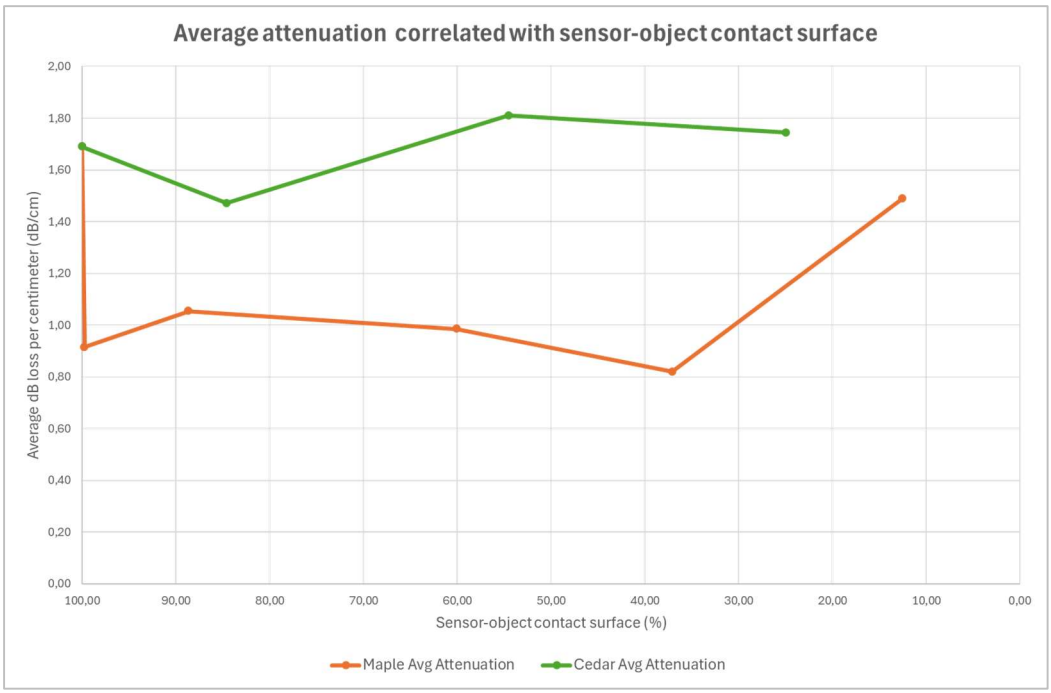
The Graph below (Graph 22) showed a surprising tendency to rise for the maximum sensor distance when the surface in contact was decreasing.

Graph 22 Maximal sensor spacing distance correlated with sensor-object contact surface

Due to the way the test was conducted, it is supposed that efficiency increased, not because of the decrease of the contact ratio, but rather because of the size of each wood sample. In a larger wood sample, waves can spread out more and be more attenuated in longer distance. While in very thin wood sample, the waves cannot disperse as much, resulting in higher efficiency.

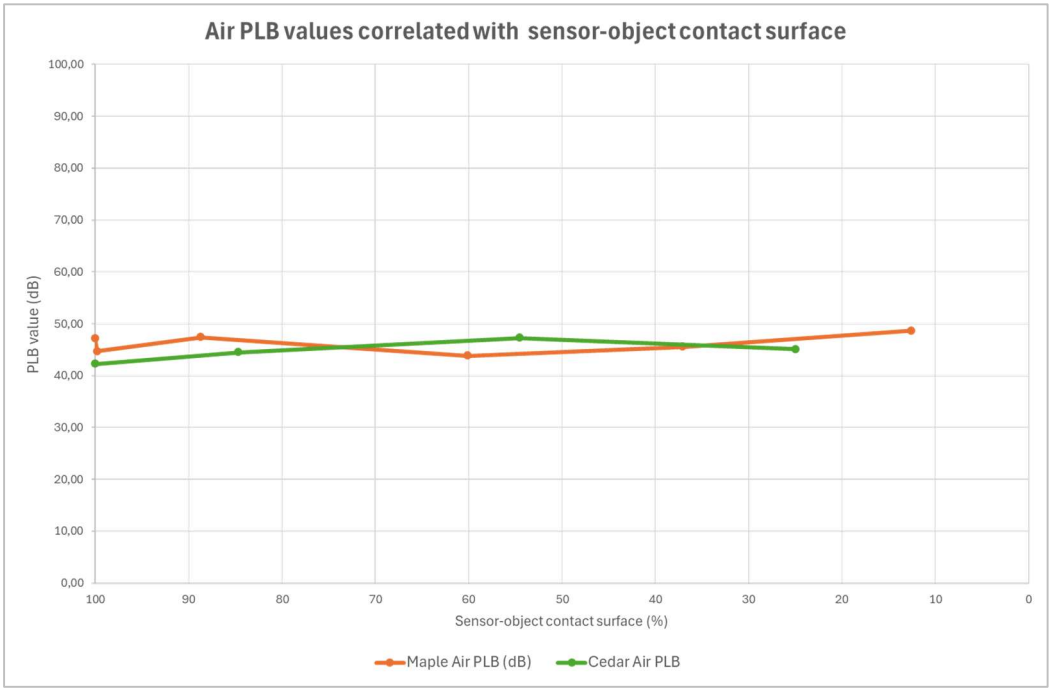
For this reason, this result does not allow us to determinate the impact of the sensor-object contact ratio on sensor efficiency.
However, as a decrease initially was expected when contact ratio is lower, we can emit the hypothesis that the shape and size of the tested object have a greater impact on the detected AE signals than the sensor-object contact ratio

Additionally, the Graph below (Graph 23) display the average attenuation, calculated with the near-field and far-field attenuation, allows us to notice the higher attenuation in western red cedar wood. This wood has a lower density (380 kg/m^3) than maple wood (620-900 kg/m^3) (Engineering toolbox, 2025) and therefore should have a higher attenuation level, which correlates with the obtained data.



Graph 23 Average attenuation correlated with sensor-object contact surface

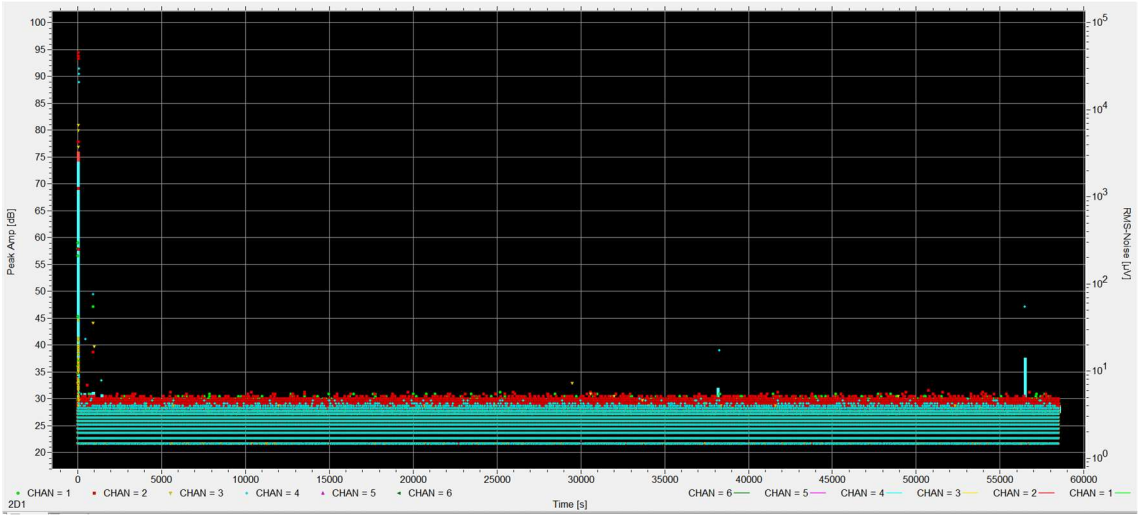
Air PLB have shown only little differences between sensors with a maximal and minimal contact surface The values are ranging from 42.25 dB to 48.63 dB, with an average of 46.20 dB for maple wood and 44.75 dB for western red cedar. This result suggests that environmental noise is not a more problematic parameters in case of incomplete contact with the surface.



Graph 24 Air PLB value correlated with sensor-object contact surface

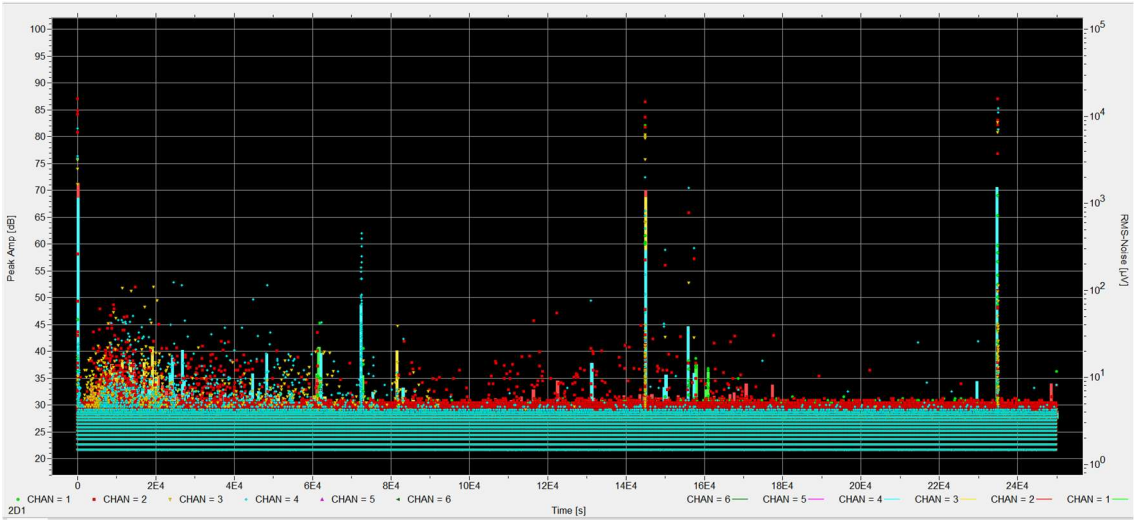
Wood moisture

Before being soaked, the wood samples did not show sign of activity, as expected. The Graph (Graph 25) below shows the AE measurement, ran during a night.



Graph 25 CMH_WM_000 Before soaking.

After being soaked, the samples were monitored with AE during 3 consecutive days and showed intense activity from the beginning, each channel slowing down at a different rate:



Graph 26 CMH_WM_001 After soaking.

The three highest peaks are the PLB, showing consistent efficiency of the coupling method (cotton ribbon).

The others smaller peaks, mostly from CHAN4 (blue) and CHAN1 (green) have been reported to be staff members doing work next to the setup.

CHAN1 (green) is the reference sensor.
CHAN2 (red) is placed on maple.
CHAN3 (yellow) is placed on western red cedar.
CHAN4 (blue) is placed on plywood.

As seen in appendix 3, table 13, p.23, maple absorbed the most water and has undergone the most daily variations.
Cedar absorbed less water than maple, despite being a softwood, because it is naturally rich in resins and oils, which confer hydrophobic properties to the wood (Wagner meters, 2025).

Plywood absorbed the least water overall, but certain measurements taken over the days appeared inconsistent with the expected drying behavior of wood. Moisture levels on the back side increased drastically during the drying process. Since the wood sample is measured across its full depth, even if water were trapped at one precise point, the average value should remain stable, which is not the case here. Despite proper device cleaning and calibration, as well as cross-checking with a pin-type moisture meter on another wood sample, the anomaly could not be explained. The wood couldn't be weighed either, as the AE equipment was installed on the wood samples during the drying process.
The data from CHAN4 are therefore considered erroneous and won't be discussed further.

Cracks and deformation were observed on plywood and maple samples after complete drying, corroborating that the signals observed are due to cracking. Maple presents the most intense deformation, while cedar did not suffer from visible cracks.

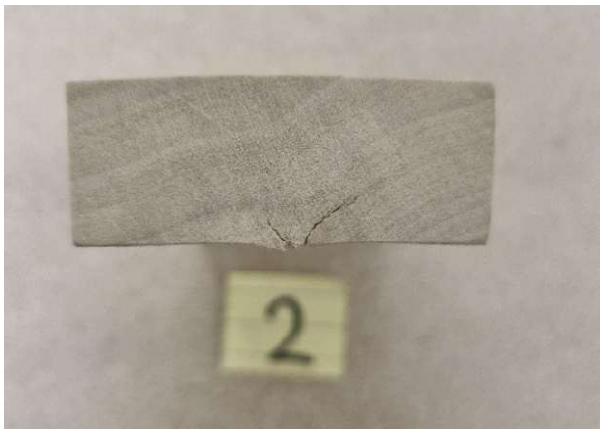


Figure 28 CMH_WB_001 Maple wood after drying

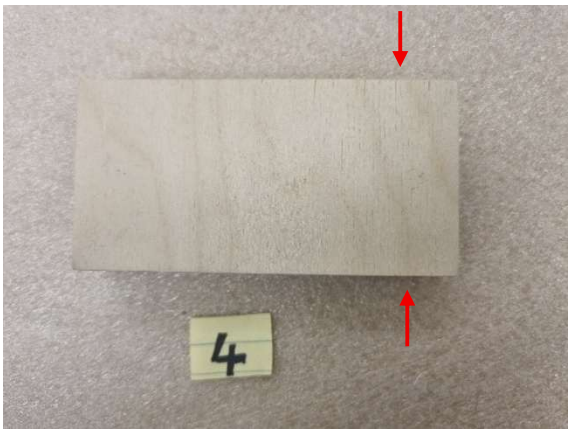


Figure 29 CMH_WB_001 Plywood after drying

The duration and intensity of the signals observed on Graph 27 seems to corroborate with that statement. CHAN2 (red: maple), emitted signals for a longer time and at a higher intensity, while CHAN3 (yellow: cedar) emitted signals for the first 24hours and at a lower intensity.

As the signals detected are emitted from cracking, they are defined by frequencies above 100Hz, which correspond as the 100-300kHz frequency range expected for moisture variations (Jakiela & al., 2007, p.2)

Attenuation on monumental heritage artwork
Two totems were tested:

The first (ID: VII-F-937) is plain and mounted on two vertical metal rod, going up to the 2/3 of the pole. Sensors were placed strategically around the pole, with one on the metal rod. The schema to the right illustrates the sensors (green half circle) on the totem pole, viewed from above. Greys squares are metal rods.
PLB were made horizontally (against grain orientation) and vertically on all sensors, except CHAN2 (red), as we aren't looking to determine attenuation inside of metal.

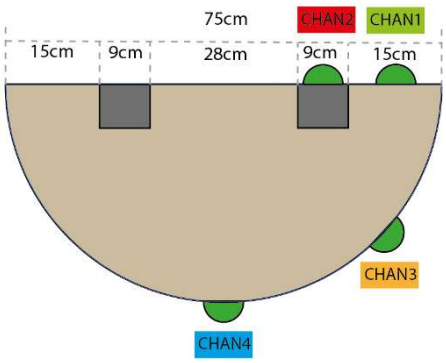
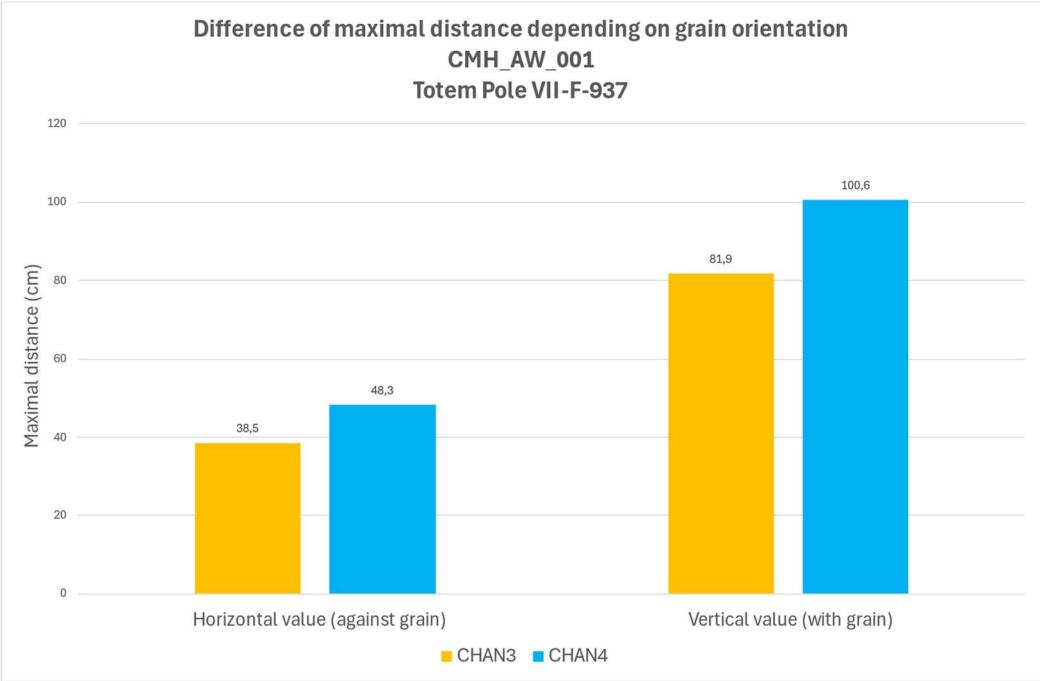


Figure 30, CMH_AW_001 sensors placement, from above

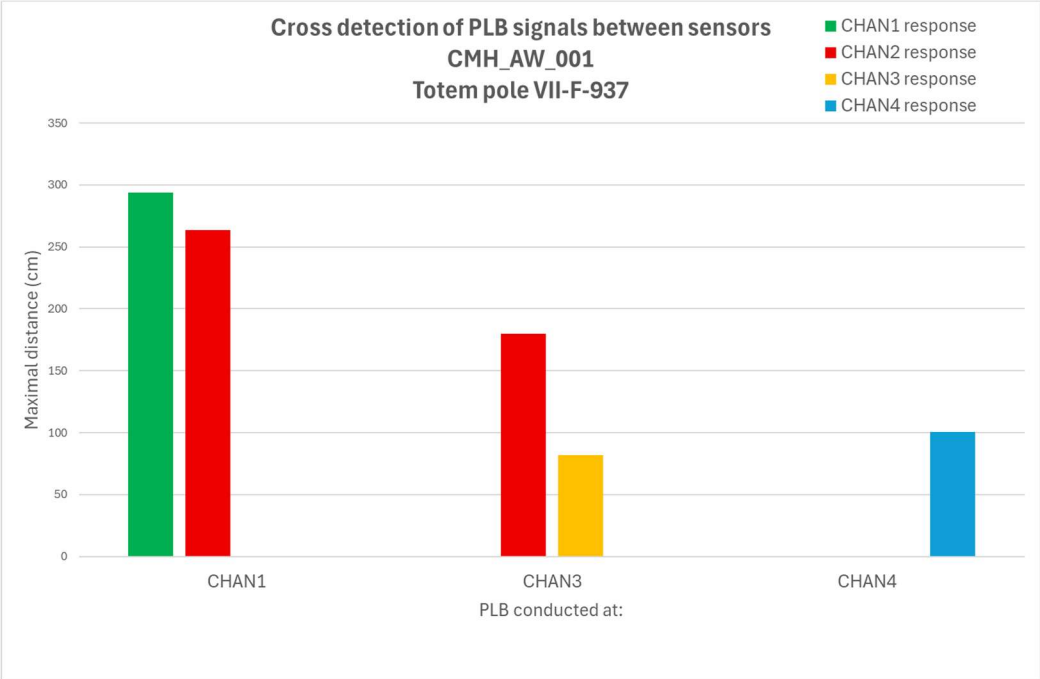
The graph below (Graph 27) shows the difference between horizontal and vertical attenuation for CHAN3 and CHAN4. It highlights the drastic diminution of efficiency when going against grain orientation.



Graph 27 CMH_AW_001 VII-F-937 Attenuation correlated with grain orientation

The difference between the two channels can be explained by their placement. CHAN4 is located on a relatively flat part of the totem, while CHAN3 is placed near important prominences.
CHAN1 wasn't included in this Graph, as the back of the totem shows major cracks and empty interstices between the metal rods and the wood. This results in almost no signals detected when going horizontally. In appendix 2, Graph 7, p.14 is found the attenuation profile of CHAN1.

The second graph (graph 28) is meant to highlight the sensors response to PLB carried out close to a neighboring sensor.



Graph 28 CMH_AW_001 VII-F-937 Cross detection of PLB signals between sensors

This Graph demonstrates that the three channels are too far away from each other to hear signals coming from the same event (PLB), no matter if the PLB is made vertically or horizontally.
CHAN2 (red, placed on the metal rod), showed good results with PLB made vertically on CHAN1. More interestingly, it detected signals emitted close to CHAN3 (yellow) better than CHAN3 itself.
As CHAN3 has the lowest maximal distance due to its placement on a bumpier area, this could mean that the metal rod screwed inside the wood is able to detect signals in a better way than sensors placed on the surface, attenuating the negative impact of a contoured surface.

The second one (VII-C-2226) is hollow and mounted on one vertical metal rod, going to the very top of the pole. Smaller horizontal rods are placed at 60 cm from the ground and then every ~2m.
For this pole, a sensor was placed on the main metal rod, at the cross with the horizontal ones. Another sensor is placed in front of the totem. The two last are placed
The schema on the right illustrates the totem pole and sensor placement, viewed from above.
PLB were made horizontally and vertically from each sensor, except for CHAN4 (blue) who is placed on the metal rod.

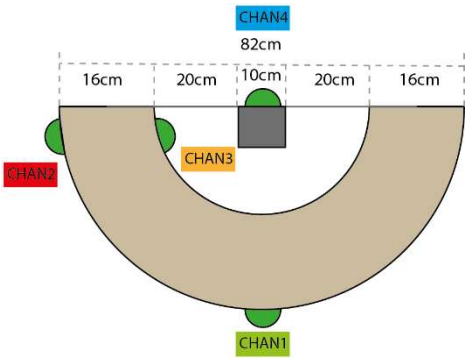
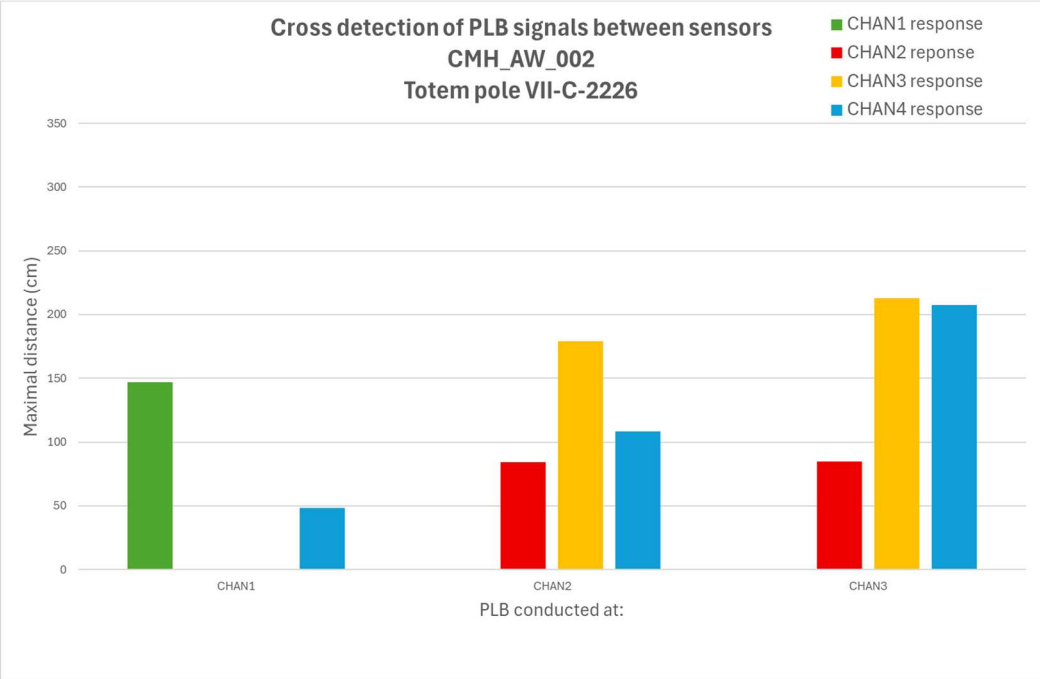


Figure 31, CMH_AW_002 sensors placement, from above

The Graph illustrates the sensors response to PLB carried out close to a neighboring sensor:



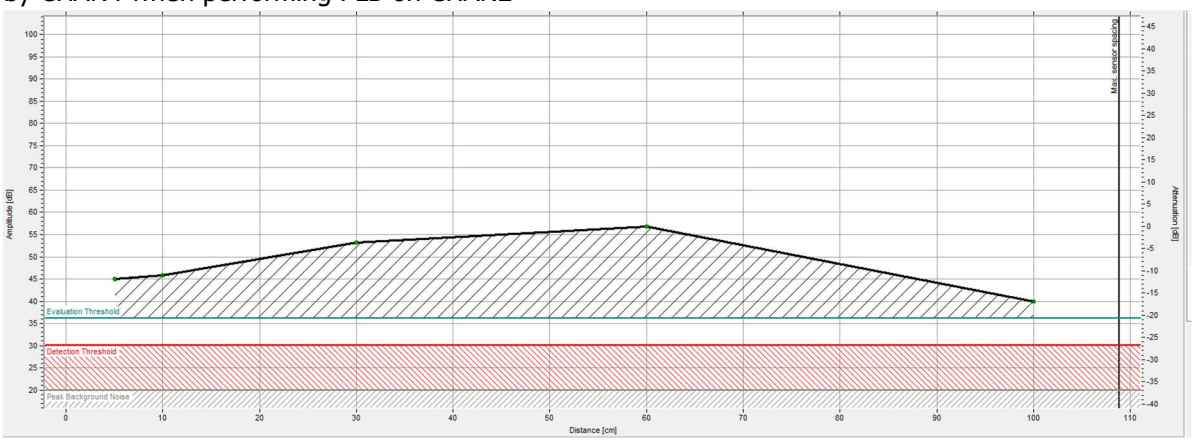
Graph 29, CMH_AW_002 VII-C-2226 Cross detection of PLB signals between sensors

Similar to the first test, there is no communication between CHAN1 and the distant sensors (CHAN2 and 3).

CHAN2 obtained lower results than CHAN3, which can be explained by the contoured surface on the outside of totem, where CHAN2 is placed, versus the more surface on the inside of the totem, where CHAN3 is placed. These two sensors communicated well through 16 cm thick wood, against grain orientation.

CHAN4, placed on the metal rod, showed again interesting results, being able to detect PLB signals made at every sensor, including CHAN1. The best result of CHAN4 was obtained with PLB made at CHAN3, which is the closest.

Even more interesting; the graph below shows the attenuation curve obtained using the signals detected by CHAN4 when performing PLB on CHAN2



Graph 30, CW_AW_002, Attenuation curve of signals detect at CHAN4, from PLB performed at CHAN2

Standard attenuation curves present a *negative exponential curve*[30]. However, this one presents a *unimodal curve*. This can be explained by the schema on the right. PLB made on CHAN2 start 1 cm away from it and gradually increase the distance by going up. This means that PLB distance begins further away from CHAN4, get closer and then get further again. The signals detected by CHAN4 follow the same pattern, starting low and gradually getting stronger as coming closer to the horizontal metal rod, then decreasing again.

Similar curves can be observed when PLB are made from CHAN1 and 3, see appendix 2, Graph 8-9 p.10-11

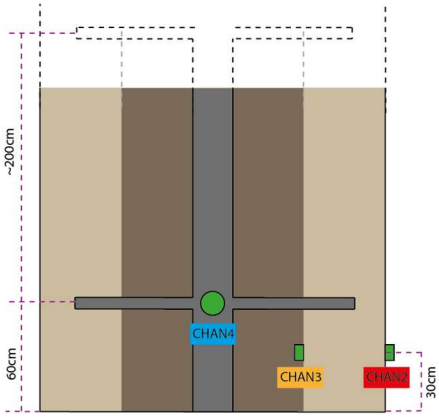


Figure 32, CMH_AW_002 sensor placement, from behind

7 Discussion

Collecting data

While being the first objective to complete, in order to send Tom Marti data in a timely manner for the collaborative research, the delivery delay of the AE equipment and solvent-free CDD compounded with the difficulties encountered in finding an active infestation in a wood sample and collection prolongated the intended hours spend on this part of the project.
The relatively cold climate of Canada in May may have played a part, as insects may not have been very active at the beginning of the testing[31].

The collected data set has been used for T. Marti's work and is now pending validation for publication, with the aim of providing valuable data for future large-scale research.

Sensor-object contact ratio

This experiment aimed first, as its name indicates, to determine the impact of lower sensor-object contact on the detection of AE signals. While the experiments conducted could not achieve this objective, the experiments provided valuable information to put the relative importance of different parameters such as surface shape, grain orientation, density and coupling method into perspective. The impact of said parameters was then observed on results from tested objects such a totem pole and whalebone.
Deeper knowledge on that matter will facilitate more mindful sensor placement, increasing the quality of future tests.

Attenuation of AE signals

<u>General</u>

The results highlighted four major parameters that can increase or decrease attenuation when testing on wood objects. They are listed below in order of influence, based on the results obtained:

- Grain orientation: going against grain orientation results in a more significant decrease, while following it results in better signal transmission.
- Shape and size: if the objects present bumps, recess or assembled parts, the signal attenuation will be higher.

[30] Appendix 2, Graph 6, p.9

[31] Appendix 2, Graph 10 p.11

- Density: the denser the material the higher the transmission
- Coupling method: the nature of the chosen coupling material and the condition of the surface (rounded, cracks, uneven, smaller than sensor) influence the results as well.

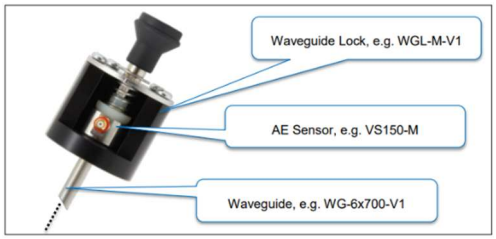
As the influence of these parameters is clear, further research is needed to confirm the current suggested ranking, in order to their importance in achieving the cleanest, most conclusive and repeatable data collection.

The results displayed by attenuation profiles indicate the maximal detection distance, based on the PLB test. It is important to note that sounds emitted by feeding activity of insects can be lower, which will result in a shorter maximal distance range. The obtained result serves as an indicator to help choose an adequate sensor spacing distance for pest detection.

J. Creemers advises a maximum 50 cm sensor spacing distance on wood to ensure good coverage, but that recommendation will need to be adapted to include the recommendations above.

<u>On totem pole</u>

The result in totem illustrated the interesting possibility to use the metal mount as a waveguide.
Waveguides are a small proposal by Vallen®, allowing to use AE on particularly hot or cold surfaces that do not allow direct coupling. The waveguide is a stainless-steel rod that is inserted into the surface. In heritage collection, the use of waveguide is not possible as it would require to pierce the object, but using an existing mount (Vallen, 2024).



©Vallen
Figure 33 Vallen® Waveguide

When that level of intervention into a object is not possible, such as inserting a screw into the body of the material, taking advantage of the way certain artwork are mounted to increase the maximal sensor spacing distance, has promise as an option.
To increase the precision of the results obtained, more research would be needed, by conduction PLB test on the whole length of the tested totem for example. This was not possible during the time period of this research, due to the location of the objects within the museum, combined with it being the visitor high season.

<u>Books and textiles</u>

The setups using metal plates on top and bottom of objects in both paper and textiles allowed us to reduce the parasitic signals caused by the bending of the soft surface when executing PLB directly on them. It demonstrated that although a certain maximal sensor spacing distance could reach more than 50 cm in books when doing PLB along the surface, this distance was considerably reduced when trying to obtain signals that had gone through the whole book or textile, and not just those travelling at the surface level.
This can be explained by the layered (pages/layers of textiles) composition of the tested objects in comparison to grain orientation in wood. Even when compressed a bit between metal plates, there is still more air in between pages/layers of textiles than in between the fiber of the same layer/page. Additionally, it must be considered that some values used to calculate attenuation were from friction and parasitic noises due to the bending of the surface, despite the careful examination of the parameters of each signal hit before including them in the calculation. This could have falsely increased the results obtained.

As we want to be able to listen to activity from within the materials, these results are too low to suggest an efficient use of AE on those materials with the AE equipment and setup tested.

The use of various weights did not show consistent amelioration through the different tests. Even if looking for cases where it did decrease the attenuation, the difference was not significant and repetitive enough to obtain a conclusive result. Applying considerably heavier weight could result in a difference, however this technique would result in less compatibility with fragile objects.

Some variations in the results might have been introduced while conducting PLB. Even if using the same type of lead and guide shoe, slight variation in the resulting sound is possible, for example the lead sometimes cracks instead of snapping.

Lastly, it is necessary to keep in mind that the results obtained on maximal sensor spacing on both wood, textiles and paper possess a margin of approximation due to their non homogenous structure, impacting how calculations are made in VisualAE when creating attenuation profiles, as explained by H. Karzel.

Protocols

AE protocols are constituted by a total of three documents. The first one, appendix 4.1 "How to read AE Graphs", p.24-26, is a short guide on how to read basic data displayed in Visual AE. The second one, appendix 4.2 "Detailed AE procedure – infestation detection", p.27-40, is a detailed document on the use of AE for pest detection containing information that can be used when discovering AE and needing complementary information about coupling method, data analysis and visual example. The last one, appendix 4.3 "AE protocol – infestation detection" p.41, is a short version containing the primordial steps.
It can be printed and laminated to be stored with the AE device, for easy and quick test setup, for a staff member with some previous AE experience.

Ideal AE test duration, as sensor spacing distance in wooden object, cannot be defined by one precise value. Many different parameters have to be taken into consideration for the successful monitoring of an object. In case of doubt regarding the obtained results, tests can always be run over longer time period and with smaller sensor spacing distance.
As a reminder, this non-exhaustive list cites parameters that have an influence on AE signals:
<u>Larvae:</u> species, population density, size of individuals, adequate climatic condition, activity cycles
<u>Coupling:</u> partial contact of the sensor, high/low transmission by the chosen coupling method
<u>Wood:</u> moisture content, shape, size, grain orientation, density, condition.
<u>Background noise:</u> human activities producing vibrations, machine noises, wind.

With these documents, any conservator at the museum should be able to apprehend AE technology for pest detection, without previous background knowledge. If needed, detailed information can be found in this report and in the articles cited in bibliography.

Pest monitoring

In appendix 4.2, the protocol "Detailed AE procedure – infestation detection" indicates how data can be visually analyzed to confirm or negate an infestation. However, as we noticed with the drying wood experiment, some tests can be visually confusing. As we listen to larvae breaking the wood fiber while feeding, if cracking events happen as a non-isolated event but rather as relatively continuous events, it could be confused with insect infestation. Therefore, using AE for pest detection on actively drying wood is not recommended.

False negative could happen too, but the risk can be reduced by ensuring the following points:

- Adequate temperature: not below 10°C.
- Good coupling method: PLB test to verify.
- Well considered sensors placement.
- Measurements duration of a minimum of 30 minutes.
- Complementing AE testing with visual monitoring of the objects: look for holes, frass, live or dead adult beetles

In case of doubt, doing more measurements in other spots of the objects and increasing the test duration could help clear any uncertain situation.

As an adequate temperature is needed to ensure larvae activity, we recommend conducting AE monitoring in the late spring and summer.

Limitations

This study experimented with several aspects and limitations of AE testing for pest detection. Due to the limited time, the current data obtained yields an initial understanding and highlights new perspectives but requires a greater amount of data to ensure validation and broader applicability.

Outlook

<u>PLB</u>

With the difficulty encountered for conducting PLB on softer surfaces, Joseph Mkalaf, engineering student and summer intern at CMH, came up with a concept of "PLB machine", a small device to place on the surface of the tested object. It aims to break the lead at the same 30° angle, consistent 3mm length and apply force directly into the lead from above, reducing the force applied and reducing the potential for variations in sound produced into the material itself. This device is still being constructed at the current time.

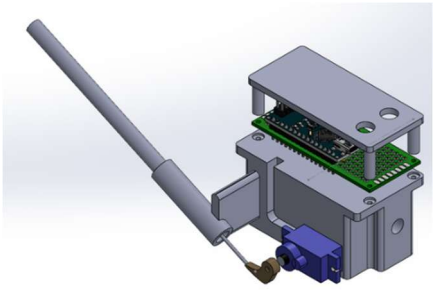


Figure 34 PLB machine ©Joseph Mkalaf

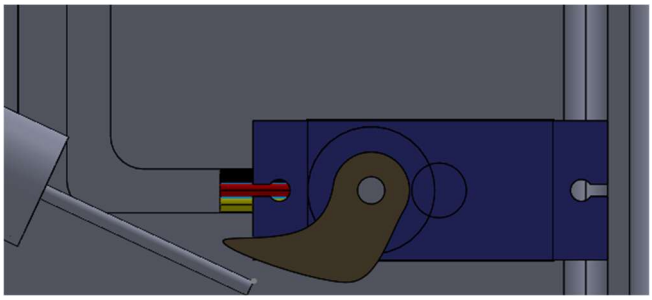


Figure 35 PLB machine, lead breaking part detail ©Joseph Mkalaf

Coupling methods

Having a great variety of functional coupling method allows AE testing on a wider range of objects. In heritage, coupling methods that provide the most optimal result often have to be sacrificed for material compatibility and risk reduction in terms of object safety.
During a personal communication on the 1st of July with Jos Creemers, Project Manager at SHR (Netherlands), he explained a new coupling method, compatible with certain museum artefacts.

This method consists of putting a screw in a small pine wood block, 1.5 cm thick, then glueing the wood block to the artefact using a Japan paper and hare glue for easier reversibility. The sensor is then magnetically fixed to the screw.
J. Creemers reported conclusive results with this technique.
This method couldn't be put to the test during this research due to time restriction, but it represent a valuable new perspective and has potential for incorporation into future research

J. Creemers also reported using cracks on wood artefacts to mechanically fasten a small metal tool inside and then fixing the sensor to the metal tool, with conclusive results. This information could support the obtained data on totem poles, using the metal rod mount as a kind of waveguide.

Detection of activity in organic material

As seen in text, destructive events such as wood fiber cracking result in frequencies above 100kHz. Focusing on this kind of event and therefore frequencies is commonly used for wood infestation detection and was the strategy employed during this study.
However, in addition to the attenuation being more important in softer material, the signals emitted from feeding activity will not result in a loud clear crack, as will happen with wood, because of the higher plastic deformation that is capable in textile objects. For that reason, aiming to detect breaking sounds in textiles is far from ideal.

For whalebone, it is important to highlight that insects will not feed on the bone itself, but on the fats and residues that it can contain. No breaking sound will be emitted from feeding activity.

Paper could be more ambiguous. The rupture of cellulose fiber could generate cracking sounds, depending on the type and condition of the paper. Signals of both low and high frequencies could be detected.

These hypotheses represent a general statement, but it is important to acknowledge that considerable differences will be observed depending on the characteristics of each textile or paper type, as well as the species of insects involved. Deeper analysis on low frequencies signals transmission in textiles and paper is needed to support the hypothesis and achieve better understanding on wave transmission through these materials

The SPT test that was trialed during this project could, despite its flaw of difficult reproducibility, could be a starting point to compare different low frequencies friction sounds.

Generally, the extension of AE to a wider range of material would require further research on optimal coupling techniques, methods to verify the performance of sensors, and on aiming to detect lower frequency signals emitted during the movements of insects and to differentiate them from potential interferences noises.
As testing during this project focused on healthy materials, research on infested material could provide valuable insights.

8 Conclusion

The project was conducted at the Canadian Museum of History from May to July, with the primary focus being opening new IPM perspectives for the museum, after the ban of CO2 treatment.

The first objective, collecting a substantial data set, has been successful.
On a personal communication on the 19th of July 2025, Tom Marti wrote "*The dataset is comprehensive for the research framework discussed earlier, it contains a lot of different ambiences following the protocol determined between C.Costa and me. The quantity of data given meet the expectation I had despite the fact that there is a lot of infested samples rather than non-infested (balanced dataset are better for machine learning) but that's what I asked for*".
Despite the limitations described in point 6.1, the data were suitable for use in his project.

The second objective, exploring the feasibility of the use of AE on various organic materials, has been successful. A variety of materials were tested using different setups, and despite the current results being negative for IPM implementation across multiples collection materials, it highlighted several elements that could be a starting point for further research, such as the use of dense plastic tube to detect infestation in textile or the differentiation of AE sounds emitted by feeding activity versus the signals created during insect movements.

The third objective, enhancement of IPM strategy, is successful.
The heatmaps offer retrospective visuals on the past 13 years of pest detection record. Completed with a protocol on how to use and complete it with news data, it introduces for the Museum a new way of tracking pest population through time and storage spaces, gaining time and offering easily understandable visuals. Based on this map, targeted treatment or monitoring can be enacted.

Several documents about acoustic emission were produced in order to allow the Museum staff to understand the concept of AE, how to read and visually analyze the obtained data in Vallen® software, to perform AE testing while making mindful choices on coupling method, sensor placement and duration of the test.
The research on sensor-object contact ratio, wood drying monitored by AE and monumental highlighted some important parameters to keep in mind while using AE, such as the dominant importance of structural shape of the tested object and grain orientation, the possible confusion between AE signals obtained by drying wood and the potential of using the metal rod mount as a waveguide to monitor infestation.

Overall, this project allowed parallel research on AE signals classification by AI, offered news perspective in terms of IPM and AE monitoring for the museum, and opened news perspective in terms of AE research in museum context.

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11 List of abbreviations

AE: Acoustic emission

ABS : Acrylonitrile butadiene styrene

AI: Artificial Intelligence

dB: Décibel

CCWG: Canadian Cooperative of Wool growers

CDD: Cyclododecane

cm: centimeter

CMH: Canadian Museum of History

Hz: Hertz

IPM: Integrated pest management

M: Moisture

ms: milliseconds

NGC: National Gallery of Canada

PLB: Pencil lead break

PZT : Lead zirconate titanate

r: radius

RH%: relative humidity in percentage

SPT: String pull test

T°C: temperature in Celsius degree

w: width

12 Glossary

ABS plastic: thermoplastic polymer with high impact and strain resistance, and thermal stability (Polycase, 2021).

Coupling material: product used to facilitate acoustic transmission by ensuring good contact between the sensor and the tested surface. It should not interfere with the signal transmitted nor with the surface (Corrosionpedia, 2024).

Near-field / Far-field: in the context of waves attenuation in material, the separation between the near-field and far-fild is characterized by the modification of the slope of the negative exponential curve, changing from steep to more gradual.

Fast Fourier Transform: Computational technique that decomposes a signal into its constituent frequency components, allowing frequencies analysis and monitoring (NTI, 2025).

Mineral spirit: petroleum-derived solvent. Volatile (Dictionary, 2025).

Negative exponential curve: also known as "exponential decay". Decrease of a value at a rate directly proportional to its current magnitude. Values can't be negative number (Study, 2023).

Transient diagram: use transient signal (short and non-repetitive event, characterized by sudden energy release) to create a Graph correlated with amplitude (microvolt) (Lauro & al., 2014, p.79)

Unimodal curve: distribution having one clear peak. Can be symmetrical or asymmetrical (AnalystPrep, 2021).

13 Credits

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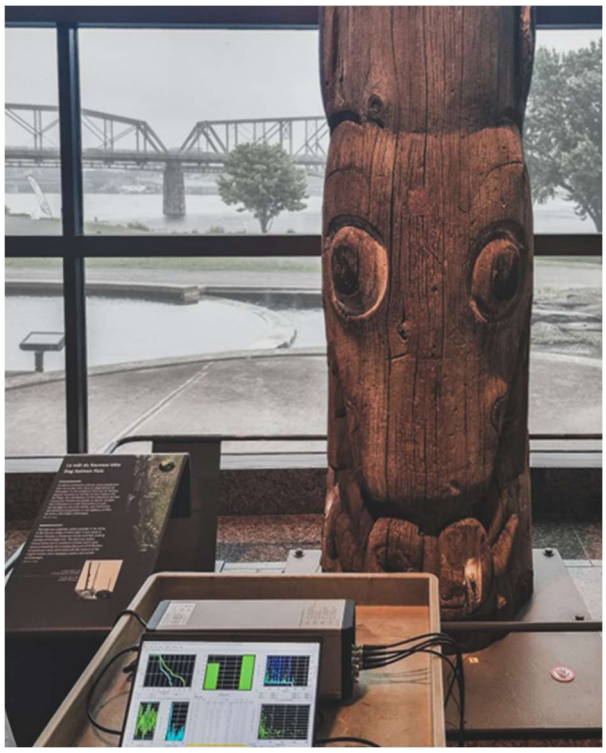
Appendix

Acoustic Emission for active pest detection. Enhancement and integration into IPM strategy

Bachelor's thesis presented by:

Costa Cécile



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Bachelor of Arts HES-SO en Conservation

Objects scientifiques, techniques et horlogers

Academic year 2024-2025

Submitted: 25.07.2025

Jury: 26.08.2025

Page count: 67

MUSÉE CANADIEN DE L'HISTOIRE

Hes·so

"*Bugs thrive on carnage, Tiger. They consume, infest, destroy, …*"

- MIB, Agent K

1 Figures

Figure 1 HEARC_018 - He-Arc setup

Figure 2 living adult woodboring insect

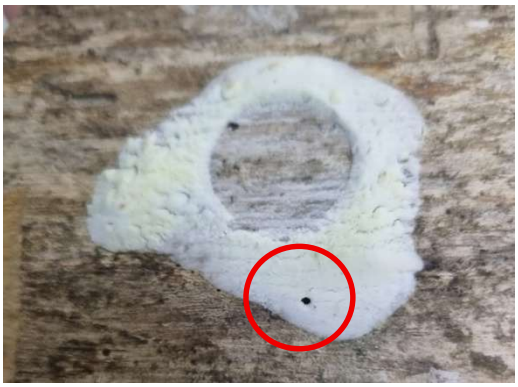


Figure 3, New exit hole after application of CDD

Figure 4 CMSI_B_I_008 CMSI setup

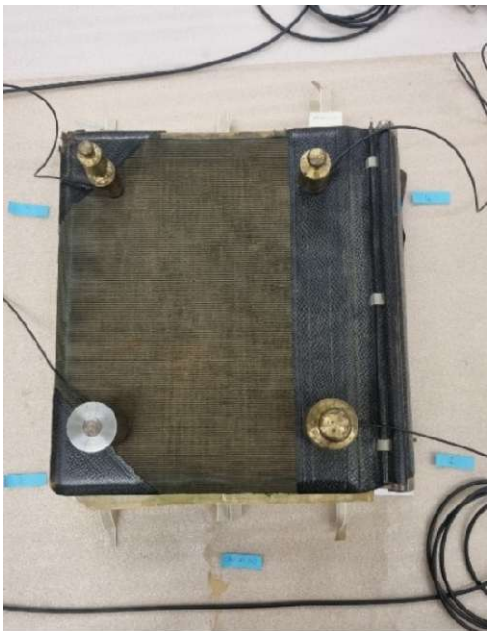


Figure 5 CMH_AP_003 – 1974.1663.1 – wood table set up

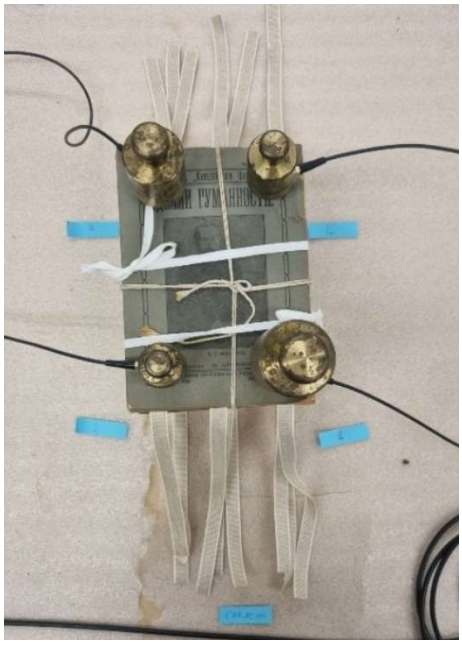


Figure 6 CMH_AP_004 – 997.22.140 – wood table set up

Figure 7 CMH_AP_005 – wood table set up

Figure 8 CMH_AP_006 – wood table set up

Figure 9 CMH_AP_007 – 19501.10.2 to 195 – wood table set up

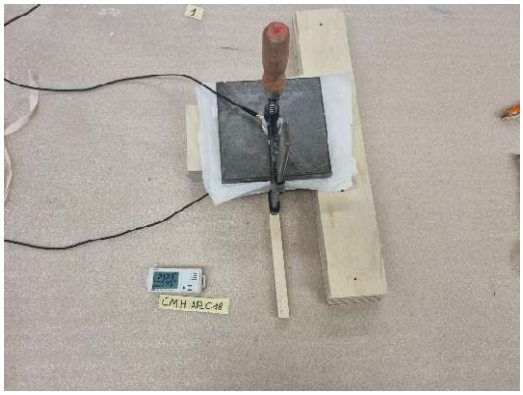


Figure 10 CMH_AP_018 -Top-bottom setup 2

Figure 11 CMH_AP_024 - Top-bottom setup 4

Figure 12 CHM_AT_007 – A-4102 - Wood table setup

Figure 13 CMH_AT_005 – A-4102 - Wood table setup

Figure 14 CMH_AT_003 – D-2296 b - Wood table setup

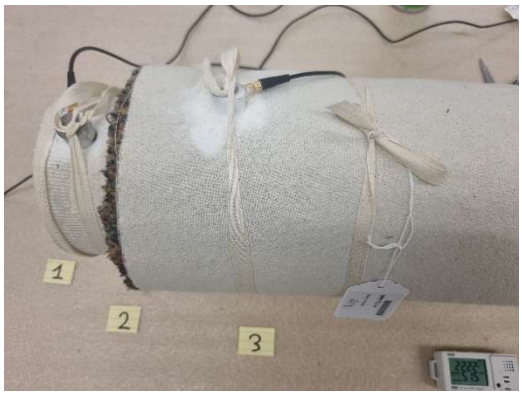


Figure 15 CMH_AT_004 – 78.1-4 - Rolled textile setup

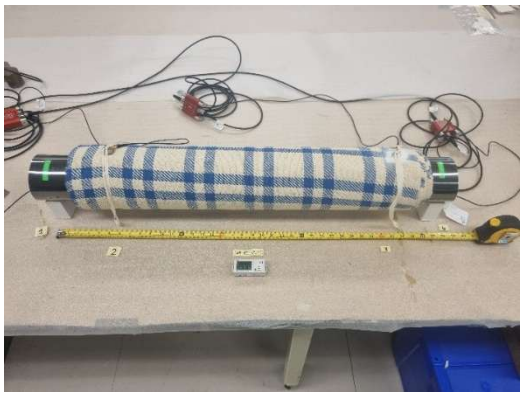


Figure 16 CMH_AT_008 – A-3350 – Rolled textile setup

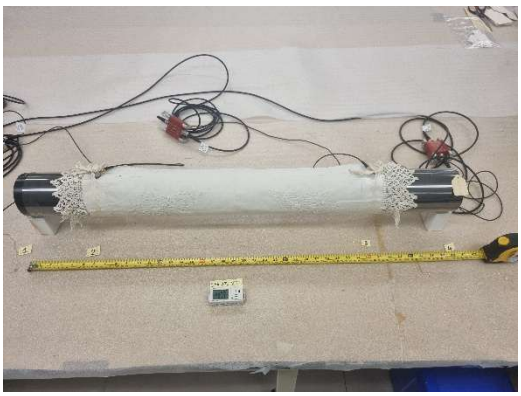


Figure 17 CMH_AT_009 – D-3150a – Rolled textile setup

Figure 18 Whalebone - IV-C-4437 a-b - high density zone - bumpy

Figure 19 Whalebone - IV-C-4437 a-b - low density zone - flat

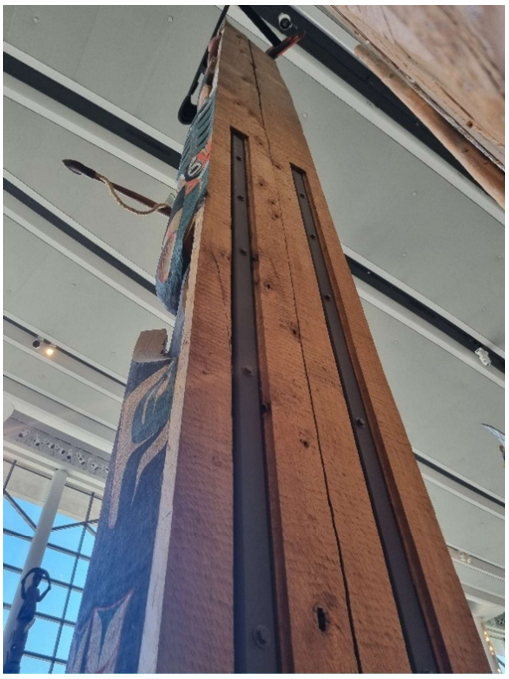


Figure 20 VII-F-937 – totem - back

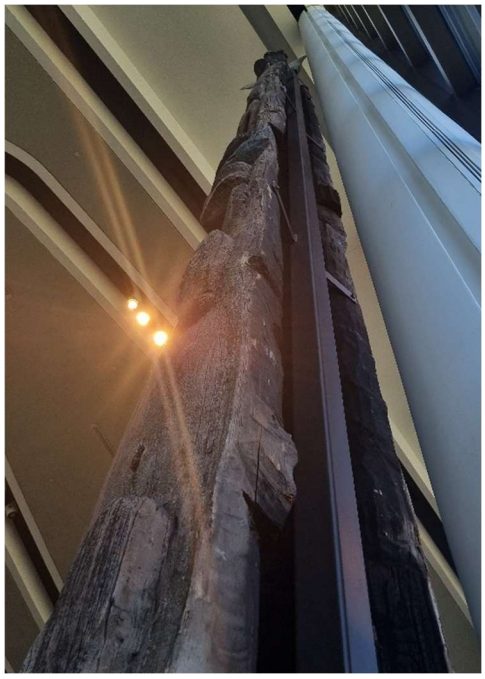


Figure 21 VII-C-2226 – totem - back

Figure 22 AB P, before cleaning

Figure 23 AB P, after soft brush cleaning

Figure 24 AB P, after hard brush cleaning

Figure 25 AB P, after wood spatula cleaning

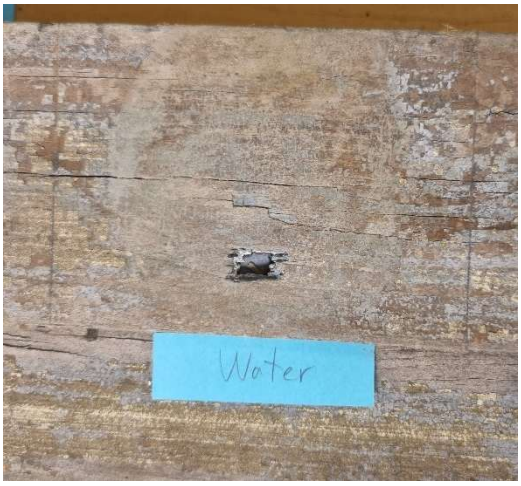


Figure 26 AB P, after water cleaning

Figure 27 AB P, after ethanol cleaning

Figure 28 AB P, after isopropyl alcohol cleaning

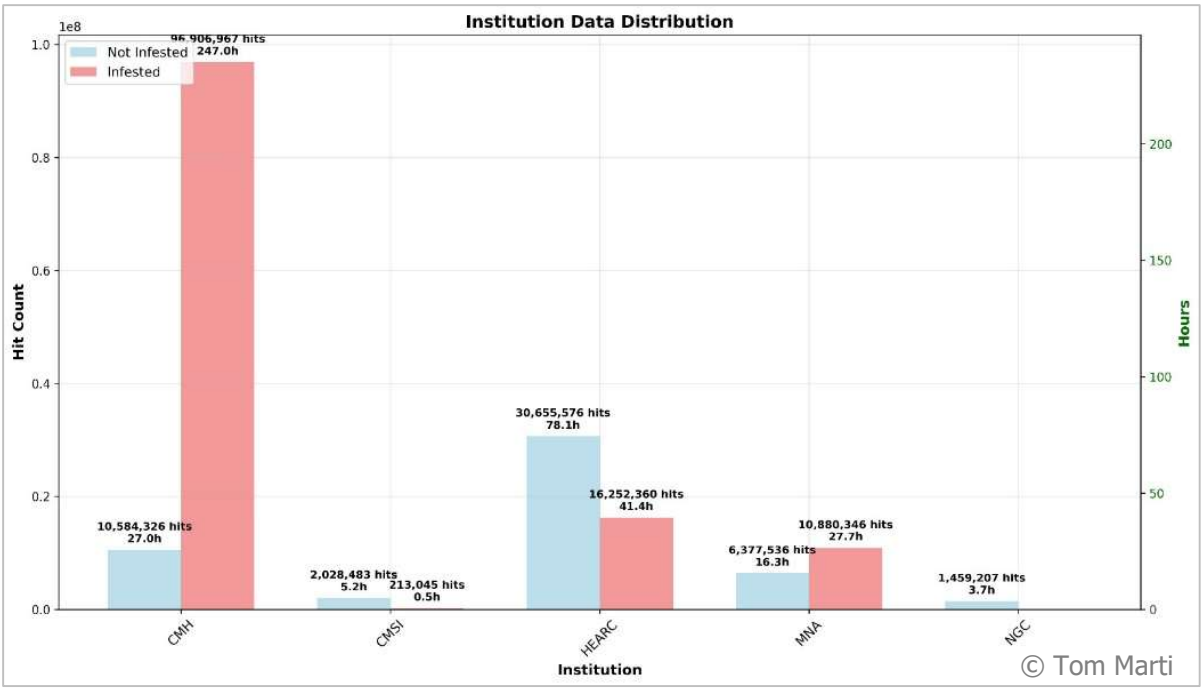
Figure 29 CDD spray, after 6 hours

Figure 30 CDD sprays, after 24 hours

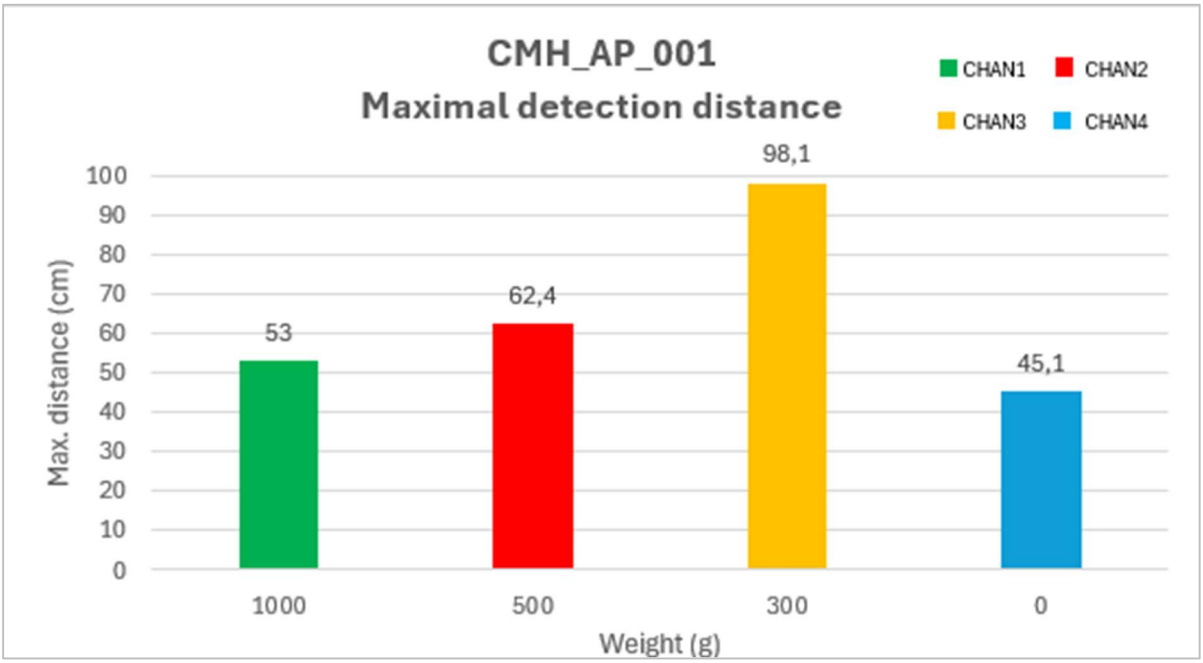
Figure 31, CDD sprays, after 2 days

Figure 32 CDD sprays, after 7 days

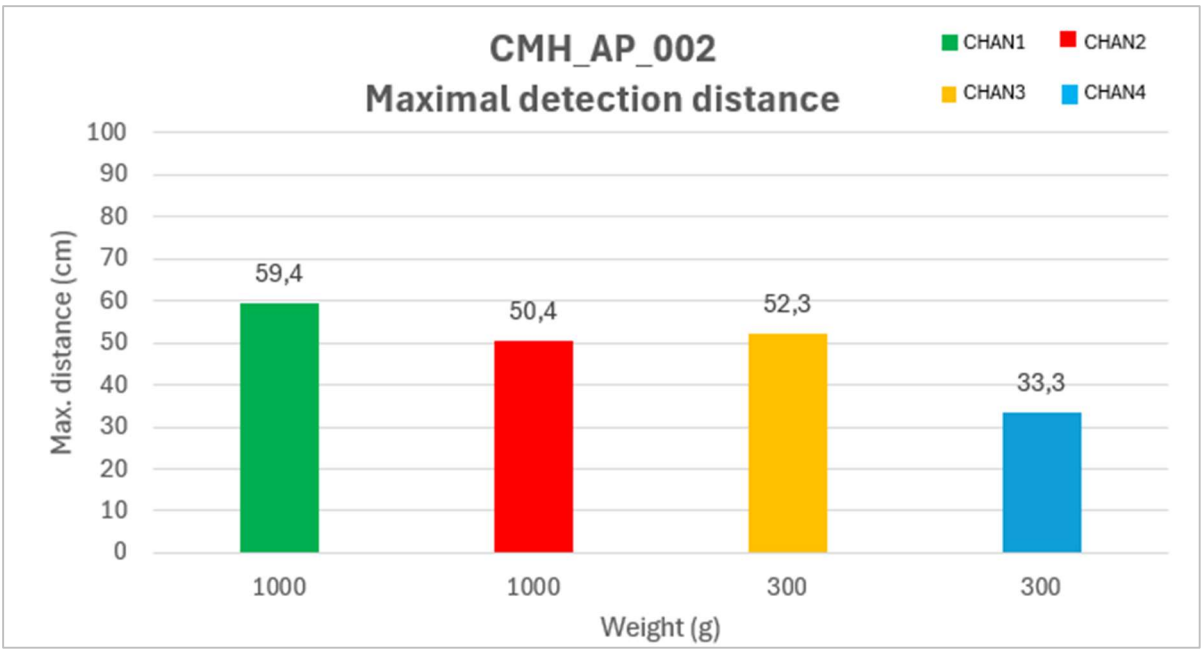
2 Graphs



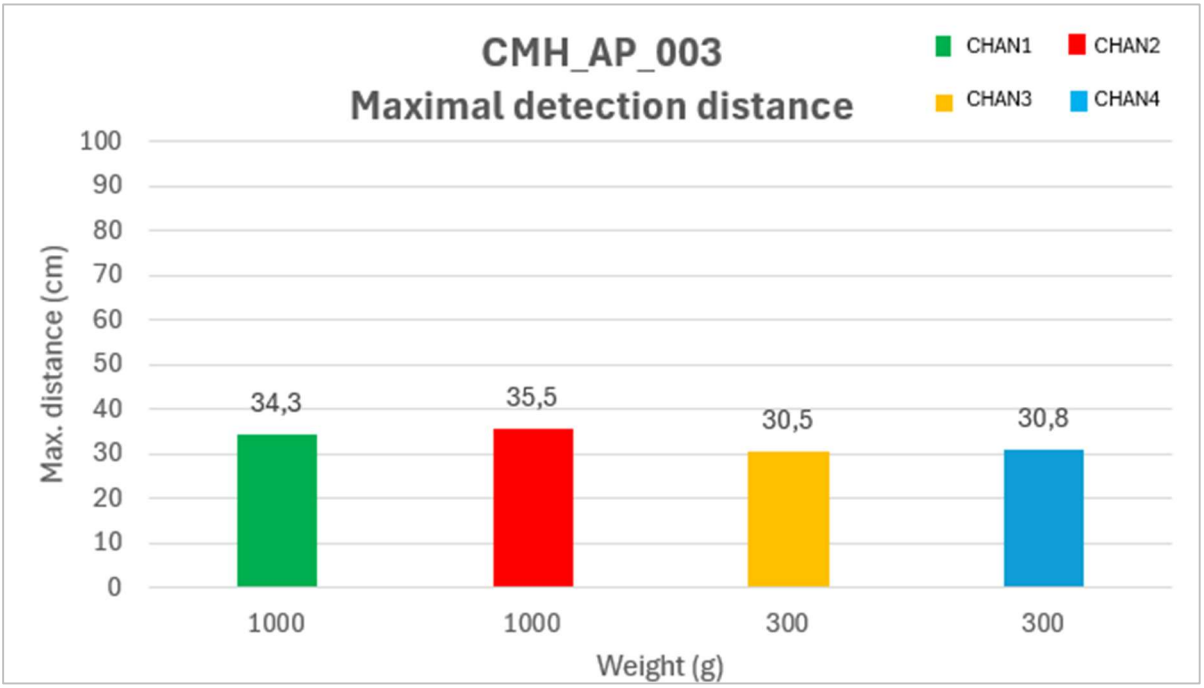
Graph 1 Institution data distribution



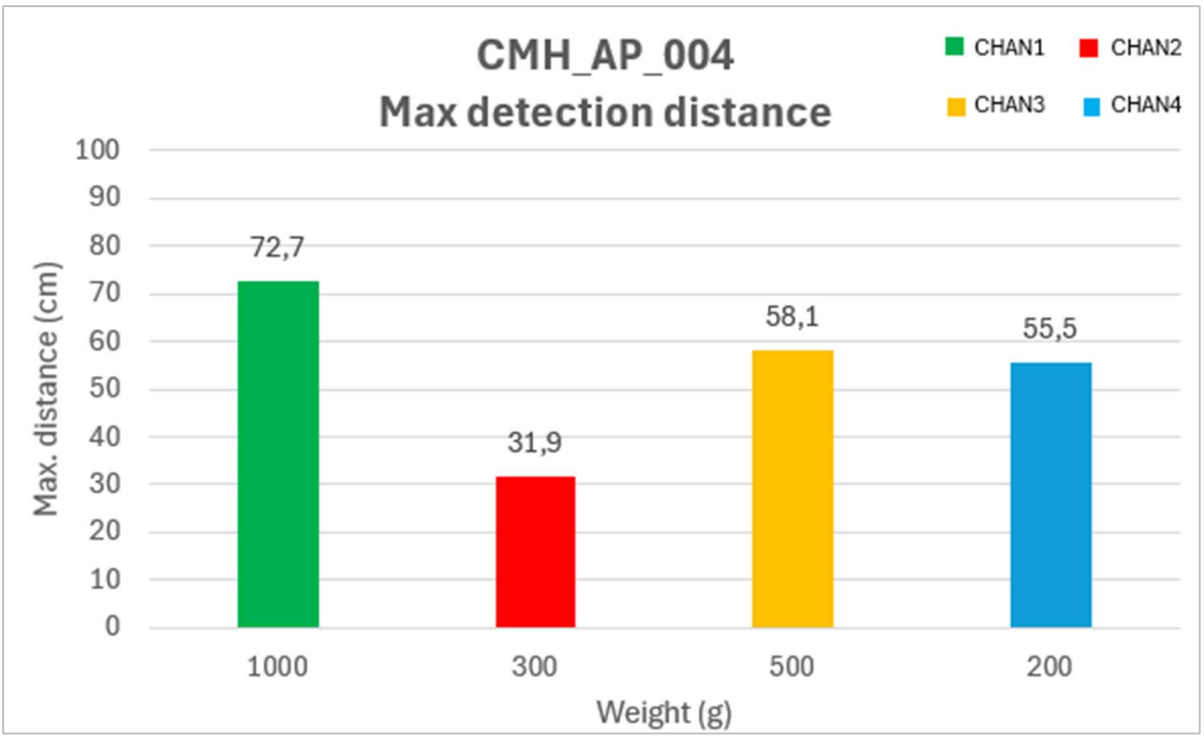
Graph 2 CMH_AP_001, Attenuation



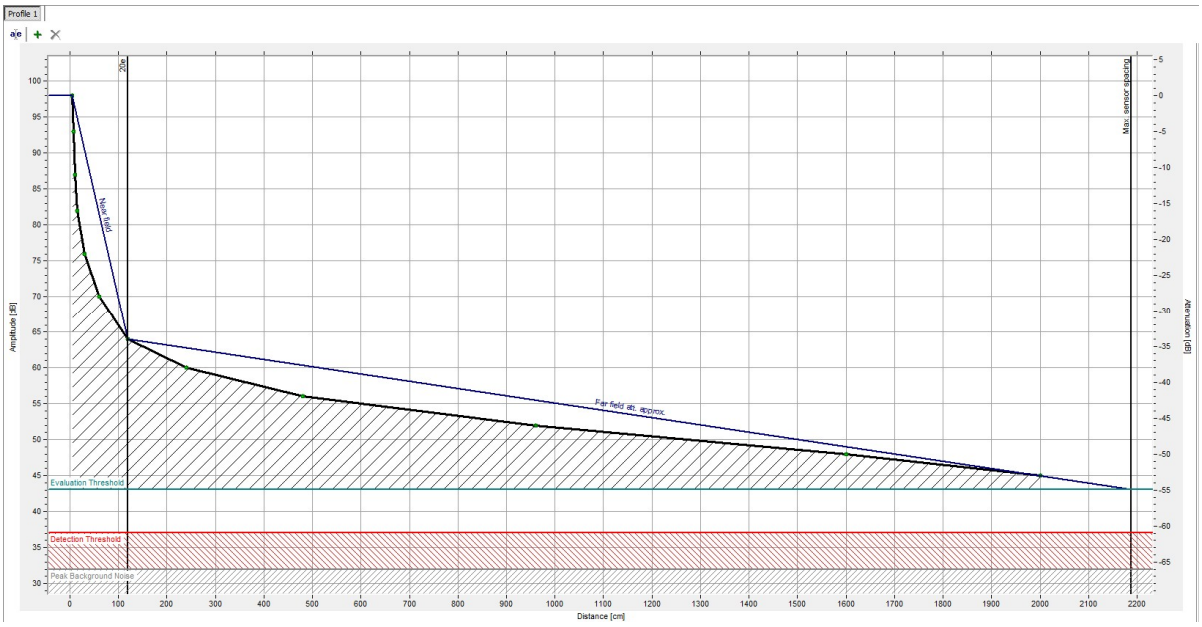
Graph 3 CMH_AP_002 Attenuation



Graph 4 CMH_AP_003 Attenuation



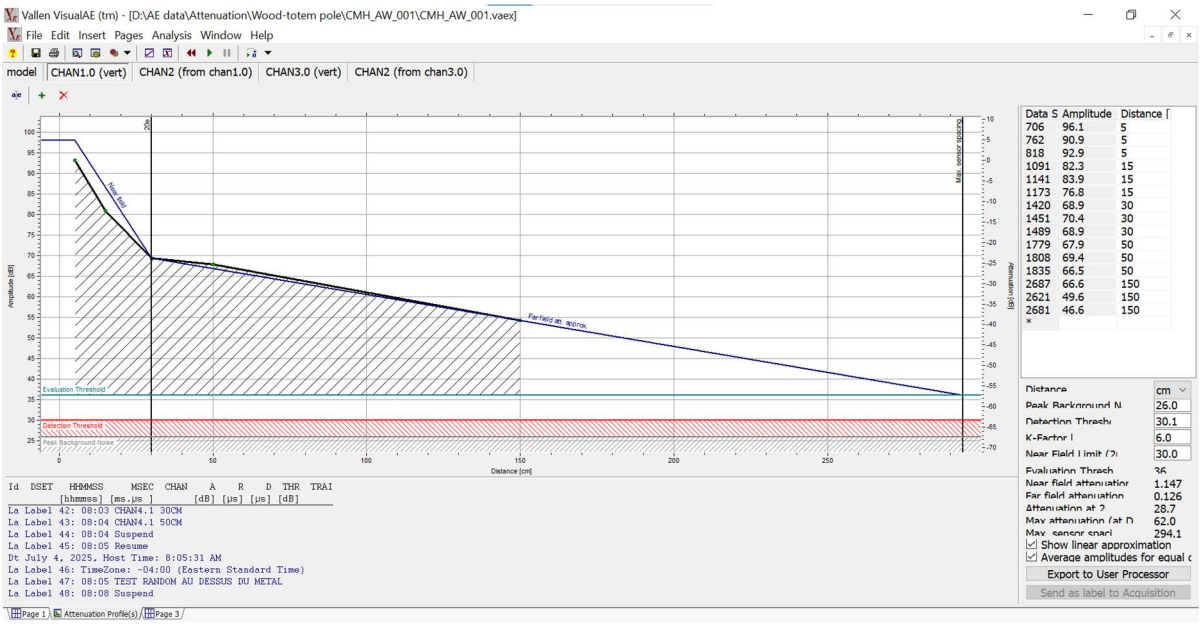
Graph 5 CMH_AP_004 Attenuation



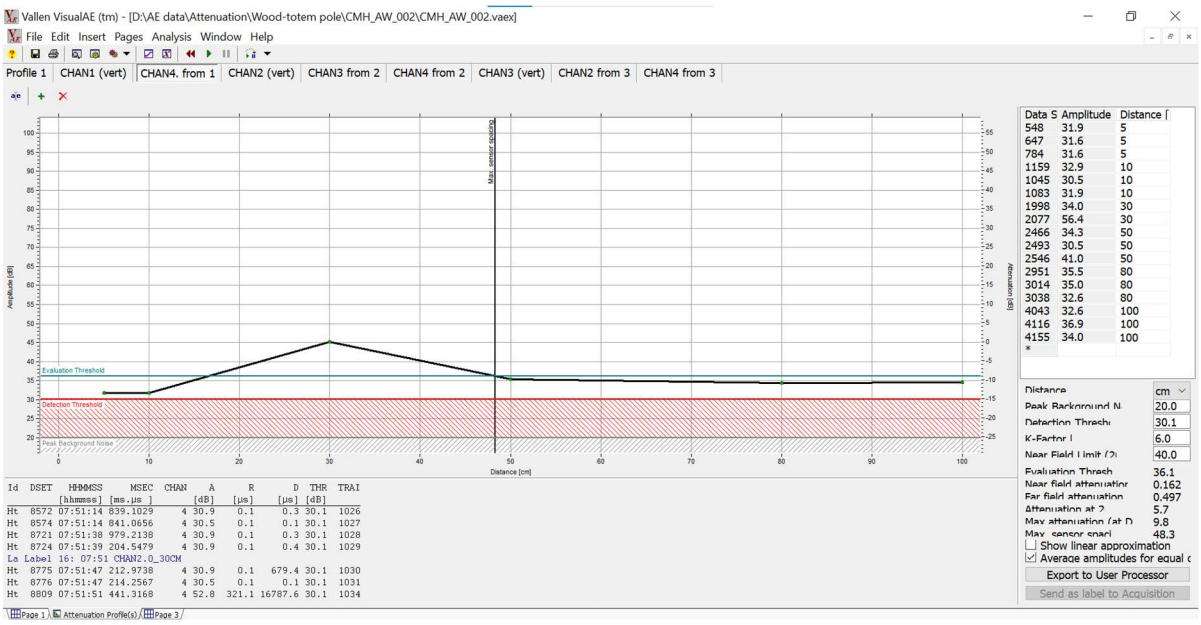
Graph 6, Attenuation profile, example provided by Vallen®

© Vallen

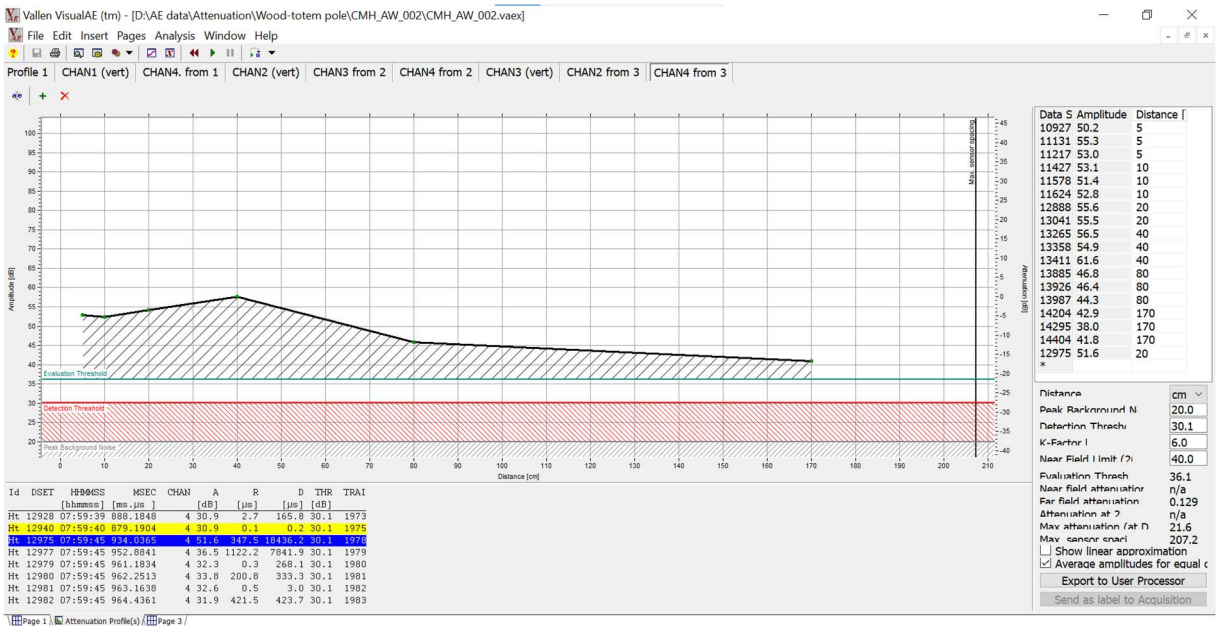
This attenuation profile provides a clear example of the negative exponential curve it forms, as well as the delimitation of the near-field and far-field.



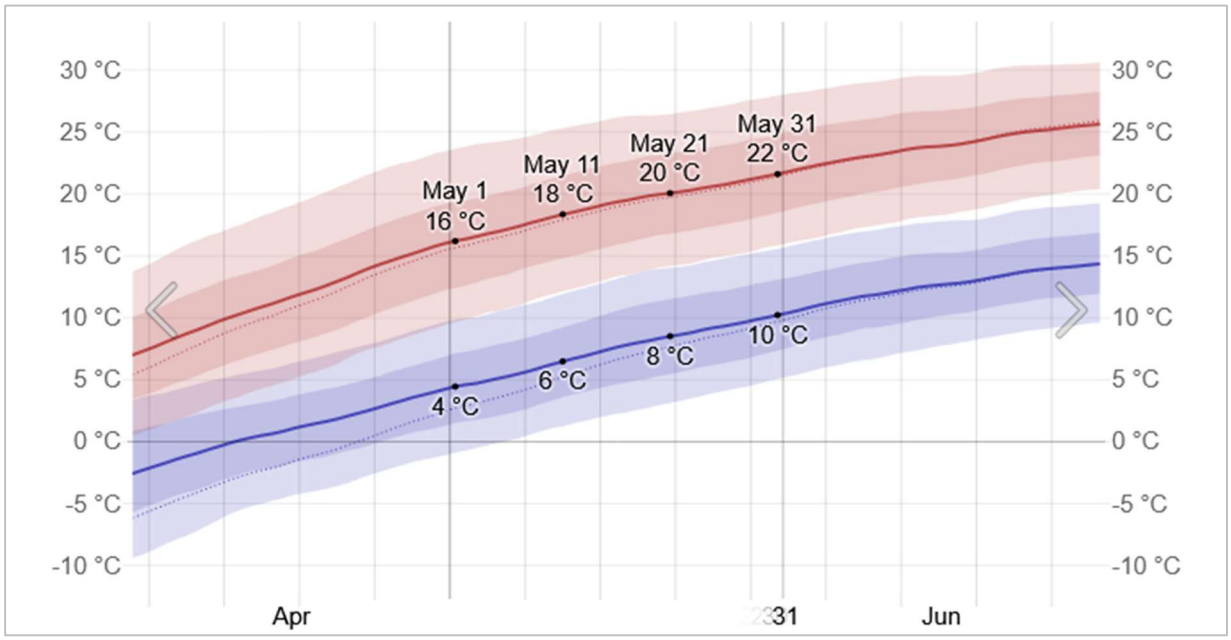
Graph 7 CMH_AW_001 VII-F-937 Attenuation on CHAN1, vertical



Graph 8 CMH_AW_002 VII-C-2226, Attenuation on CHAN4, PLB at CHAN1



Graph 9 MH_AW_002 VII-C-2226, Attenuation on CHAN4, PLB at CHAN3



Graph 10 Average high and low temperature in Gatineau in May 2025

3 Tables

Insect species	Sensor sensitivity (kHz)	Activitiy Pattern	References
Hylotrupes bajulus	0.0004 – 60 25 - 80 25 -500	Intermittent activity	Krajewski & al., 2024 Limmer & al., 2024 Creemers, 2015
Anobium punctatum	25 – 80 175 – 1000 25 - 500	Burst of activity	Limmer & al., 2024 Le Conte & al., 2015 Creemers, 2015
Lyctus brunneus	25 – 500	Drop activity below 4°C	Creemers, 2015
Xestobium rufovillosum	25 – 500	Strong decrease below 10°C	Creemers, 2015

Table 1, Sensors used for successful detection of several woodboring species

	ID number	Description	Test Name	Test method
Totem pole	**VII-F-937**	Hesquiaht Pole (black)	CMH_AW_001	CDD + cotton ribbon
	VII-C-2226	Salmon Pole	CMH_AW_002	CDD
Paper	**997.22.330** **997.22.331** **99720.753** **997.20.754.1** **997.20.754.2**	Paper books ensemble (5pcs)	CMH_AP_001 CMH_AP_009 CMH_AP_017-025	Weights (001) // metal table setup (009;017-020) // top-bottom setup (021-025)
	1974.1672.1	Hard cover book	CMH_AP_002 CMH_AP_010	Weights // metal table setup
	1974.1663.1	Hard cover book	CMH_AP_003 CMH_AP_011	Weights // metal table setup
	997.22.140	Paper books ensemble	CMH_AP_004 CMH_AP_012	Weights
	1995.81.2 **1995.81.3** **1995.81.6** **1995.81.7** **1995.81.9** **1995.81.13** **1995.81.23** **1995.81.24** **1995.81.25** **1996.4.1** **1996.18.1** **1996.46.1** **1996.61.4** **1996.157.1** **1998.126.3** **1998.126.4** **1998.126.5** **1998.126.6** **1999.278.1** **2000.25.1** **2006.89.2**	Book holder with 21 hard cover modern books	CMH_AP_005 CMH_AP_006 CMH_AP_013	Conservator blue tape // Clamps // metal table setup
	1950.10.2 to .195	Box of postal art	CMH_AP_007 CMH_AP_014	Clamps // metal table setup
Textiles	**D-2583**	Armchair	CMH_AT_001	Weights + cotton ribbons
	982.14.1	Parliament armchair	CMH_AT_002	Weights + cotton ribbons + clamps
	2002.125.1670 // D-2296 b	Belt - rolled (carboard) // glove	CMH_AT_003	Rolled textile setup (CDD, ribbons, weights) // CDD, weights
	78.1-4	Rug - rolled (carboard)	CMH_AT_004	Rolled textile setup (CDD, ribbons, weights)
	A-4102	Cotton bag - flat	CMH_AT_005	CDD
	D-11973	Silk vest - flat	CMH_AT_006 CMH_AT_010	Weights // metal table setup
	A-1768	Cape - flat	CMH_AT_007	Weights
	A-3350	Rug - rolled (ABS)	CMH_AT_008	Rolled textile setup (CDD, ribbons, weights)
	D-3150a	Lace - rolled (ABS)	CMH_AT_009	Rolled textile setup (CDD, ribbons, weights)
Whalebone	**IV-C-4437 a-b**	Whalebone statue, 2 parts	CMH_AB_001	cotton ribbons + cushion weight

Table 2 Collection objects tested

CMH_AP_001 5 books ensemble			
	weight (g)	max distance (cm)	surface
CHAN1	1000	53	paper
CHAN2	500	62,4	paper
CHAN3	300	98,1	paper
CHAN4	0	45,1	paper
Average		64,65	

Table 3 CMH_AP_001 Attenuation

CMH_AP_002 ID: 1974.1672.1			
	weight (g)	max distance (cm)	surface
CHAN1	1000	59,4	coated bookcloth
CHAN2	1000	50,4	suede
CHAN3	300	52,3	suede
CHAN4	300	33,3	coated bookcloth
Average		48,85	

Table 4 CMH_AP_002 Attenuation

CMH_AP_003 ID: 1974.1663.1			
	weight (g)	max distance (cm)	surface
CHAN1	1000	34,3	faux leather
CHAN2	1000	35,5	corderoy
CHAN3	300	30,5	corderoy
CHAN4	300	30,8	faux leather
Average		32,775	

Table 5 CMH_AP_003 Attenuation

CMH_AP_004 ID: 997.22.140			
	weight (g)	max distance (cm)	surface
CHAN1	1000	72,7	paper
CHAN2	300	31,9	paper
CHAN3	500	58,1	paper
CHAN4	200	55,5	paper
Average		54,55	

Table 6 CMH_AP_004 Attenuation

CMH_AP_025					
1 Book, thickness:	1,2cm				
Metal plate thickness:	0,1cm	0,1cm			
Metal table	3kg on plate + 1kg on sensors				
	CHAN2	CHAN1			
PLB	dB	dB	dB lost	dB loss in cm	Average
	100,0	0,0	100,0	23,8	
1cm, from CHAN2	100,0	63,2	36,8	8,8	
	100,0	78,7	21,3	5,1	12,5
	44,2	100,0	55,8	13,3	
1cm,from CHAN1	41,9	100,0	58,1	13,8	
	43,3	100,0	56,7	13,5	13,5
	33,5	95,5	62,0	14,8	
6cm, from CHAN1	31,6	95,8	64,2	15,3	
	0,0	94,4	94,4	22,5	17,5
Total average (dB)			61,0		14,5

Table 7 CMH_AP_025, Average dB lost per centimeter

CMH_AP_017					
1 Book thickness :	1,2cm	No CDD			
	CHAN1	CHAN2			
PLB	dB	dB	dB loss total	dB lost per cm	Average
	76,2	52,2	24,0	20,0	
1cm	72,2	39,4	32,8	27,3	
	67,8	41,7	26,1	21,8	23,0
	62,1	40,2	21,9	18,3	
3cm	67,1	43,0	24,1	20,1	
	66,3	41,8	24,5	20,4	19,6
	62,7	32,3	30,4	25,3	
6cm	65,7	37,8	27,9	23,3	
	58,7	34,0	24,7	20,6	23,1
Total average (dB)			**26,3**		**21,9**

Table 8 CMH_AP_017 – 1 book, no CDD

CMH_AP_017					
2 Books thickness	2,4cm	No CDD			
	CHAN1	CHAN2			
	dB	dB	dB loss total	dB lost per cm	Average
	77,2	34,3	42,9	17,9	
1cm	77,8	32,6	45,2	18,8	
	76,6	39,4	37,2	15,5	17,4
	69,2	31,9	37,3	15,5	
3cm	66,5	31,3	35,2	14,7	
	69,6	0,0	69,6	29,0	19,7
	64,6	0,0	64,6	26,9	
6cm	54,9	0,0	54,9	22,9	
	65,8	0,0	65,8	27,4	25,7
Total average					**21,0**

Table 9 CMH_AP_017 – 2 books, no CDD

CMH_AP_017					
1 Book thickness:	1,2cm	CDD			
	CHAN1	CHAN2			
	dB	dB	dB loss total	dB lost per cm	Average
1cm	82,4	59,2	23,2	19,3	
	84,5	61,4	23,1	19,3	
	83,1	61,9	21,2	17,7	18,8
3cm	81,2	50,7	30,5	25,4	
	82,2	59,0	23,2	19,3	
	86,5	68,0	18,5	15,4	20,1
6cm	78,2	51,4	26,8	22,3	
	77,4	49,5	27,9	23,3	
	77,6	47,7	29,9	24,9	23,5
Total average					**20,8**

Table 10 CMH_AP_017 – 1 book, CDD

CMH_AP_017					
2 Books thickness :	2,4cm	CDD			
	CHAN1	CHAN2	dB loss		
	dB	dB	dB loss total	dB lost per cm	Average
1cm	83,6	53,0	30,6	12,8	
	82,9	47,7	35,2	14,7	
	83,8	49,7	34,1	14,2	13,9
3cm	81,9	51,7	30,2	12,6	
	81,2	45,3	35,9	15,0	
	77,7	46,5	31,2	13,0	13,5
6cm	73,3	49,2	24,1	10,0	
	73,6	53,1	20,5	8,5	
	77,6	45,8	31,8	13,3	10,6
Total average					**12,7**

Table 11 CMH_AP_007 – 2 books, CDD

Spray name	**AB Zero**		**AB 2**	
Spray duration (s)	1	3	1	3
After 15min	dry	dry	dry	drying
After 30min	slowly sublimating	No visible changes	slowly sublimating	dry
After 1 hour	"	"	"	no visible changes
After 2 hours	"	slowly sublimating	"	slowly sublimating
After 3 hours	half sublimated	"	half sublimated	"
After 4 hours	almost sublimated	"	small residues	"
After 5 hours	small residues	"	fully sublimated	"
After 6 hours	fully sublimated	"	-	"
After 7 hours	-	"	-	half sublimated - tiny air bubble holes
After 24 hours	-	Clear delimited circle with small holes from escaped air bubbles	-	"
After 26 hours	-	"	-	"
After 31 hours	-	"	-	"
After 2 days	-	Almost sublimated	-	Almost sublimated
After 3 days	-	"	-	Fully sublimated
After 7 days	-	"	-	-
Complete sublimation	**6 hours**	**10 days**	**5 hours**	**3 days**
Anounced time (Attblime)	12 hours		24 hours	

Spray name	**AB 6**		**AB P**	
Spray duration (s)	1	3	1	3
After 15min	dry	drying	drying	drying
After 30min	No visible changes	dry	dry	"
After 1 hour	"	No visible changes	-	dry
After 2 hours	"	"	-	-
After 3 hours	Slowly sublimating	"	-	-
After 4 hours	"	Slowly sublimating	-	-
After 5 hours	"	"	-	-
After 6 hours	"	"	-	-
After 7 hours	half sublimated	"	-	-
After 24 hours	fully sublimated	"	-	-
After 26 hours	-	"	-	-
After 31 hours	-	"	-	-
After 2 days	-	"	-	-
After 3 days	-	Almost sublimated	-	-
After 7 days	-	Fully sublimated	-	-
Complete sublimation	**8-24 hours**	**7 days**	**dry in 30min**	**dry in 1 hour**
Anounced time (Attblime)	6-10 hours		-	

Table 12 Drying and sublimation time of various Attblime® sprays

07.07.2025	**Maple**		**Cedar (red western)**		**Plywood**	
17:10:00	front	back	front	back	front	back
1/4 inch	9,9	8,8	8,2	7,6	13,7	13,9
3/4 inch	9,2	8,1	7,9	7,6	13,7	13,9
Average	**9**		**7,8**		**13,8**	
08.08.2025	**Maple**		**Cedar (red western)**		**Plywood**	
18:00:00	front	back	front	back	front	back
1/4 inch	47,4	16,8	28	25,6	17,1	16,7
3/4 inch	59,5	20,9	37	25	21,1	21,6
Average	**36,15**		**28,9**		**19,1**	
09.09.2025	**Maple**		**Cedar (red western)**		**Plywood**	
16:40:00	front	back	front	back	front	back
1/4 inch	9,7	25,9	7,9	21,2	16,3	21
3/4 inch	11,8	21,4	12,7	16,3	20,1	29,8
Average	**17,2**		**14,5**		**21,8**	
10.07.2025	**Maple**		**Cedar (red western)**		**Plywood**	
17:22:00	front	back	front	back	front	back
1/4 inch	9,2	20,9	8,9	9,7	15,9	35,8
3/4 inch	10,7	15,2	9,5	10,6	18,8	45,1
Average	**14**		**9,7**		**28,9**	
11.07.2025	**Maple**		**Cedar (red western)**		**Plywood**	
16:00:00	front	back	front	back	front	back
1/4 inch	9,1	15,4	8,6	8,4	15,4	34,8
3/4 inch	10,3	12,3	8,7	8,5	17,7	42,8
Average	**11,775**		**8,6**		**27,7**	
14.07.2025	**Maple**		**Cedar (red western)**		**Plywood**	
10:15:00	front	back	front	back	front	back
1/4 inch	8,9	10	7,9	8,3	14,1	15,2
3/4 inch	9,1	9,6	7,6	8	14,4	15,1
Average	**9,4**		**8,0**		**14,7**	

Table 13 Drying rates of CMH_WM_001

4 Protocols

4.1 How to read AE graphs

The graph below llustrate a basic AE graph obtained from a healthy wood sample, as it is shown in VisualAE by using the parameters for pest detection.

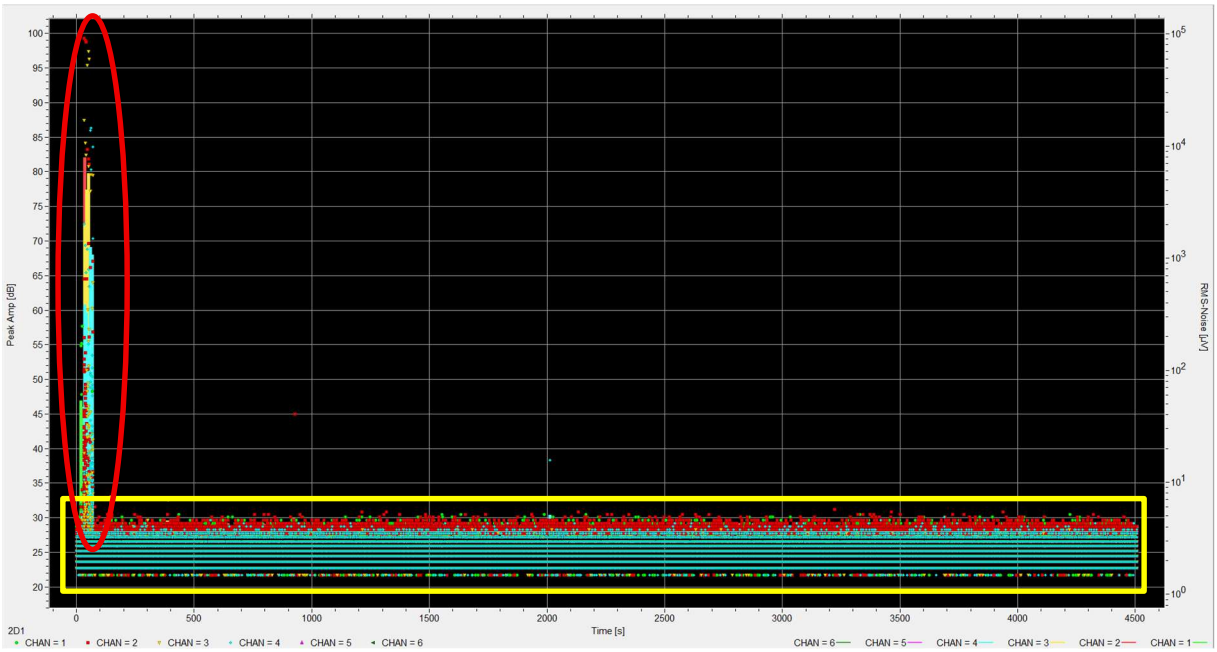


Fig. 1, AE recording - healthy wood sample

The yellow rectangle highlights the background noise. It is constituted by dense and regular hits from all sensors. The average maximum of background noise will depend on the environment, but it tend to be around 30 dB.
The red circle highlights the pencil lead break (PLB) tests made at the beginning of the test.
If hits (small dots) appear above the background noise line, that means the tested object present some kind of internal activity (PLB, infestation, cracking, vibrations from nearby activity getting through the object)

The graph next page represents the PLB done near each sensor.
Each PLB is constituted of three distinct hits of high decibel values (red arrow) and a few interference hits at lower decibels levels. The bars (yellow arrow) can appear once the measurement has been stopped. It aims to highlight clusters of concentrated high intensity hits.

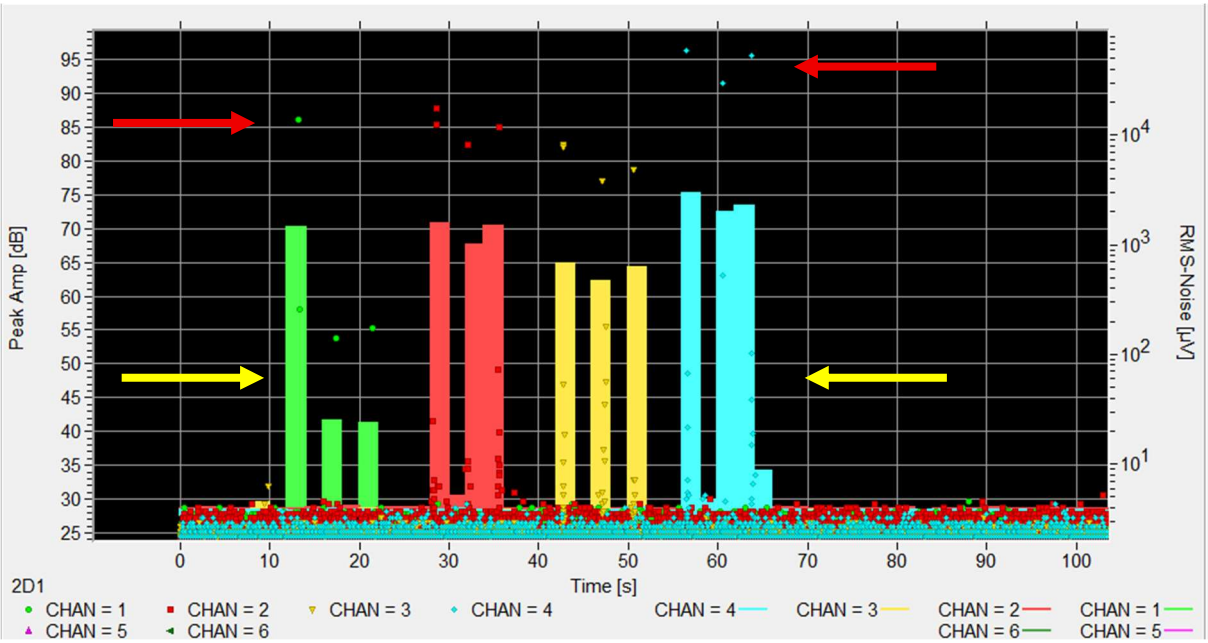


Fig. 2, Details of PLB test

Graphs with the parameters used for attenuation testing have a similar look, without the background noise. On the graph below, the blues lines represents "labels". Each label, created by a simple "ctrl + l" command, has its own title that can be shown by double-clicking on it in the graph. During attenuation testing, we created a label for each new PLB test, allowing us to differentiate more easily each test. By writing the distance at which the PLB is conducted, data analysis is greatly facilitated. The blue and green hits represent the PLB test. As the x-axis (time [s]) display bigger values than in fig. 2, the three distinct lead break are less visible and have a more compacted look

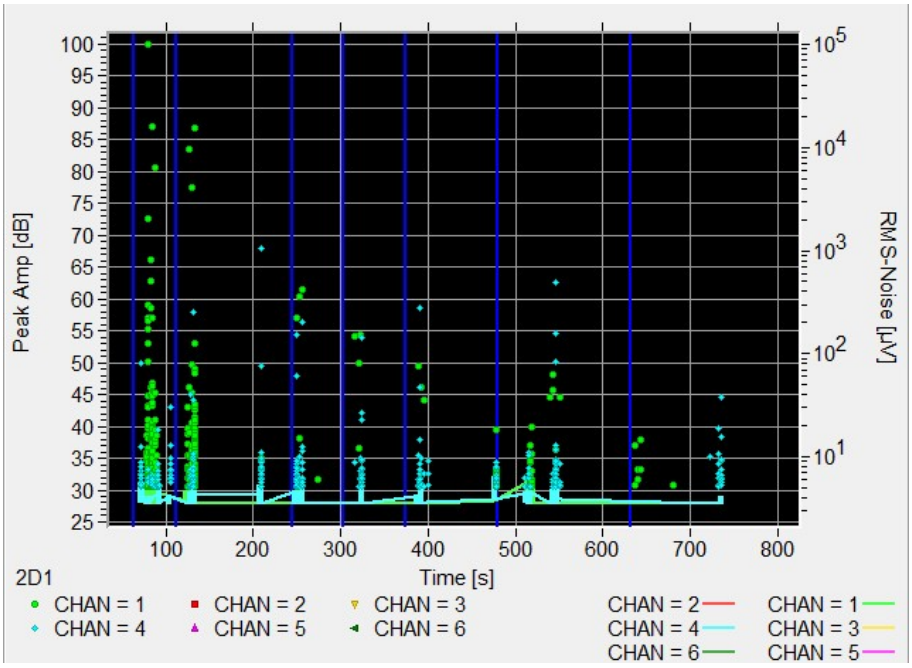


Fig. 3, AE recording – labels and hits

This graph also allows quick visual analysis. As PLB are done from a close distance to a further one, the decrease in decibels level can be seen immediately.

4.2 Detailed AE procedure – infestation detection

This protocol can be used to conduct AE testing to detect an on-going infestation in a wood object.

Equipment used:
All the AE equipment is from Vallen System® company.

Sensor: VS900-M (100 to 900 kHz)
Pre-amplifier: AEP5 (34 dB or 40 dB gain)
Coaxial cable: CBL-1-5M-V1 (RG-58)
Sensor-cable to preamplifier: CBL-1-1M2-V5
Chassis: AMSY-6 4 channels
AE signal processor: ASIP-2
Software: AE Suite R2022.0809.2
Computer: Dell IntelCore vPRO i5, Windows 10 22H2.
Hsu-Nielsen Source: 0.5mm, 2H lead. 30° angle

Acquisition parameters:
These are the general settings used:

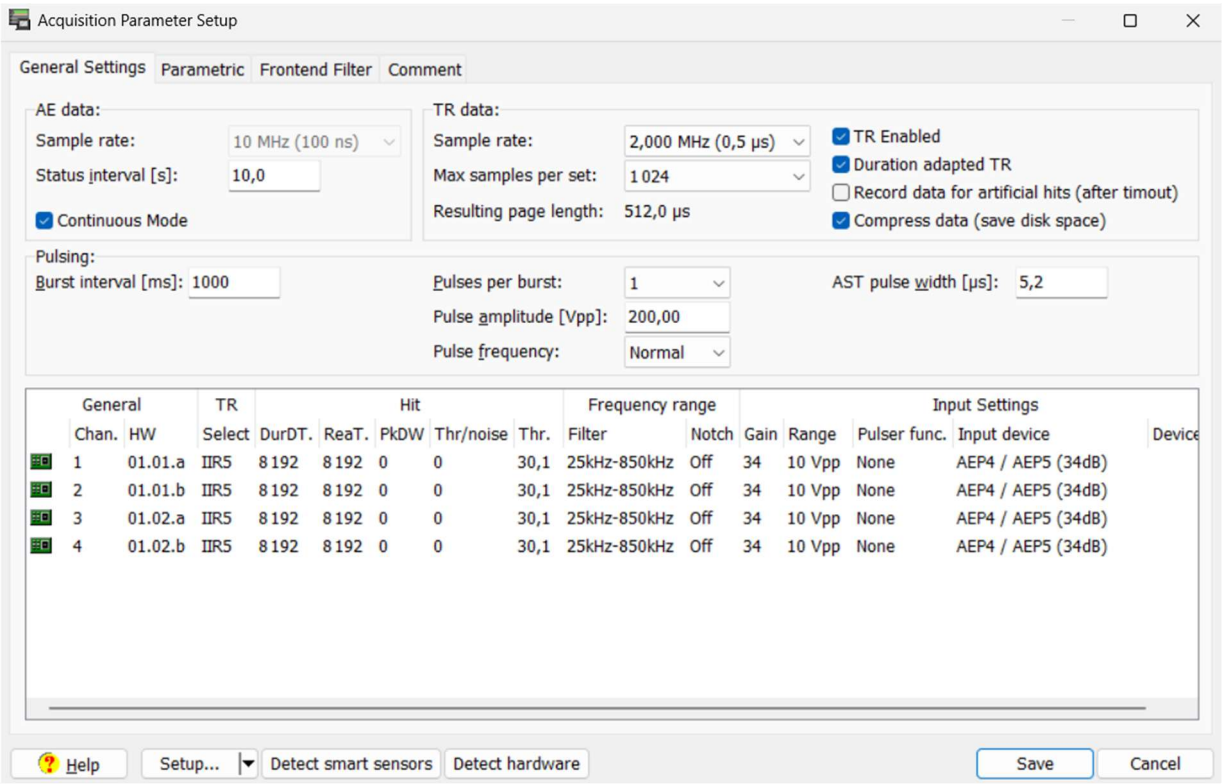


Fig. 4, General settings – pest detection testing

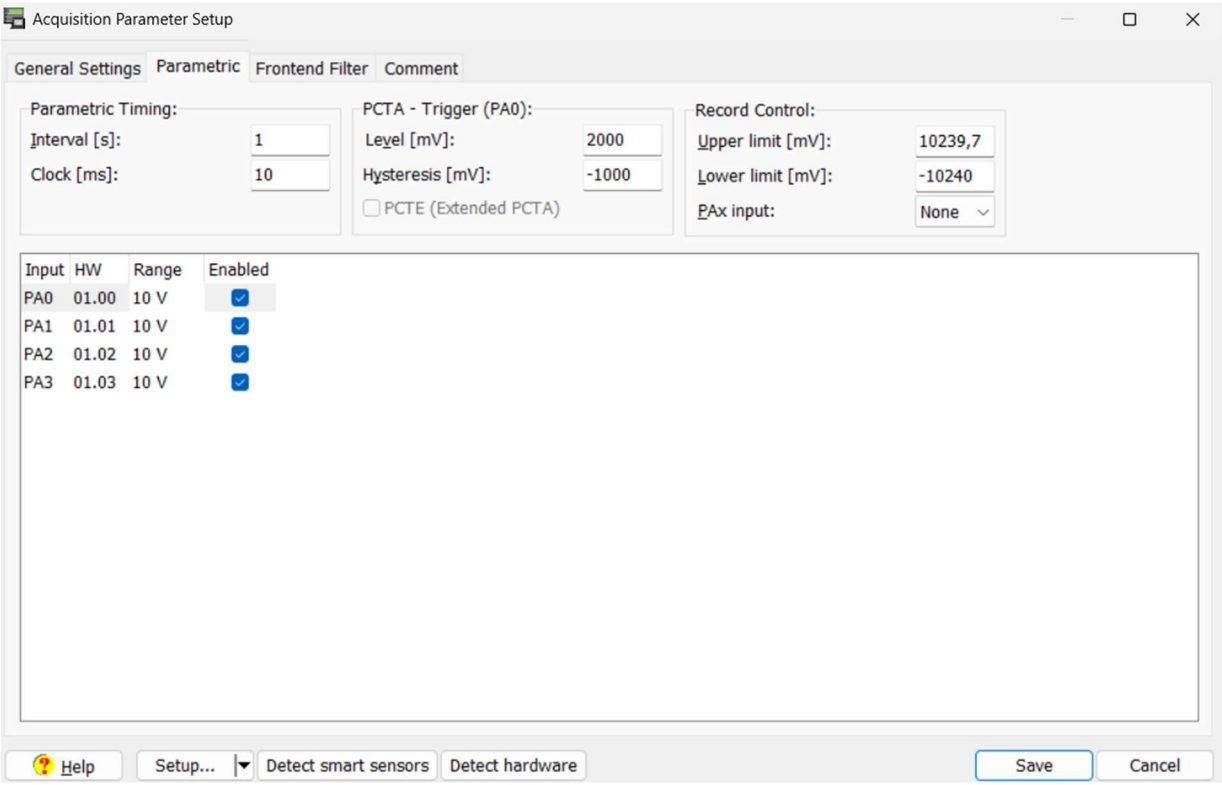


Fig. 5, Parametric settings - pest detection testing

Frontend filters aren't enabled.

The following channel-specific parameters were selected:

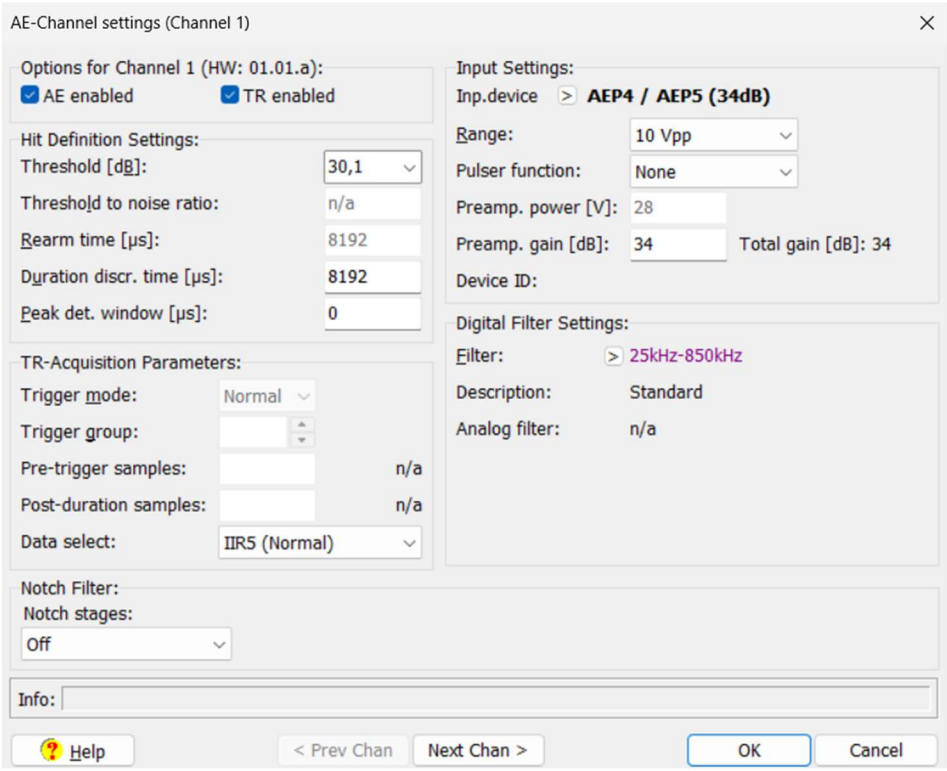


Fig. 6 Channel settings – pest detection testing

Acquisition set up:

One sensor is used as a reference for background noise. It is placed upside down near the tested object, the ceramic plate facing up.
The other sensors are placed on the object.
Each sensor is labelled by its number and the name on the test is indicated on a label, allowing easier understanding of the test's picture.
The datalogger is placed near the objects for the whole duration of the test.

Fig. 7 Example of a typical acquisition set up

Coupling methods:

Before using any coupling materials, make sure to do a spot test in a discreet area to ensure that the material chosen is not staining or leaving residues.

Dry clean with a soft brush the tested area before placing the sensors.

Renaissance wax

Renaissance wax is a microcrystalline wax solubilized in *mineral spirit*. It can be used on materials compatible with that kind of spirit. It is not advised on particularly porous or raw wood, because of the risk of stain.

To use it as a coupling material, apply a thin layer of wax directly on the sensor and wait for approximately 5 minutes. In particularly hot environment, waiting longer will be required. This aims to obtain firmer (dryer) wax for better adhesive properties, which is needed especially when placing the sensor on a vertical surface. If the wax is too soft (not dry enough), the sensor might move a bit or slip entirely.
Once the wax is the right consistency, press and lightly twist the sensor into the surface to squeeze the excess of wax.
If the surface you are placing the sensor on present important cracks or is uneven, use a thicker layer of wax to begin with before pressing the sensor into the surface to have enough wax to fill the irregularities.

After the test is completed, you can clean the sensor and surface by simply wiping it with a cotton swab. For longer tests (several hours), excess wax will have dried up and using mineral spirit to clean it will be necessary.

Fig. 8 Example of sensor installation using renaissance wax

Cyclododecane

Solvent-free cyclododecane (CDD) can be used on most materials and surfaces, as it sublimates itself without leaving traces nor interacting chemically with the surface. However, it is not advised to use CDD on very friable surface as the removal of the sensor could detach small flakes.

To use it as a coupling material, spray a thin layer of CDD on the surface you want to test and quickly press the sensor into it. Hold it in that position and spray a thicker layer around the sensor. This ensures good adhesion and wave transmission. However, for longer tests (24 hours or more), be aware that the CDD is sublimating and the adhesion will weaken. While it is not a problem in most cases, when a sensor is placed on a surface facing downwards, it may end up falling. If a long test requires CDD on an upside surface, secure the sensor with ribbons, clamps or other methods.

While CDD presents no risk for human health, it is recommended to use nitrile gloves and FFP2 mask to avoid inhaling fine particles and having to deep clean your hands afterwards.

Be aware that CDD will not be able to hold the sensor correctly on a very irregular surface.

There is no need to clean CDD. It will sublimate in a few days or weeks, depending on the thickness of the layer, the ventilation of the room, and the type of surface it was applied on.
However, if getting a clean surface right after the test is required, it can be brushed off with a hard brush or dissolved with ethanol, if methods won't degrade the object. Brushing off the CDD generates a lot of fine particles, so wearing a FFP2 mask is recommended as well.

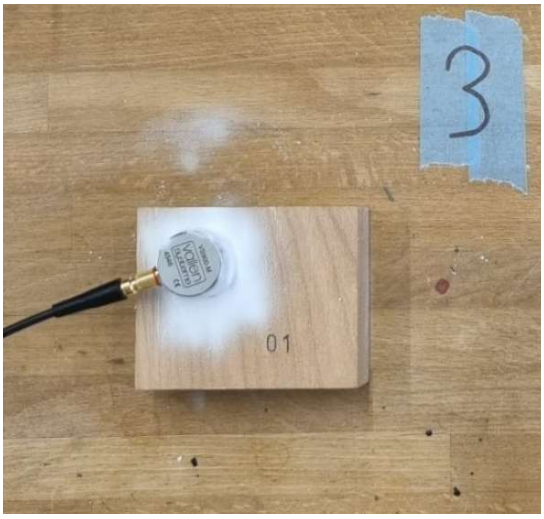


Fig. 9 Example of sensor installation using CDD

Non-chemical coupling methods

This includes methods such as cotton ribbons and weights. These can be used in addition to wax and CDD to increase the force applied to the sensor and stability of the installation, or alone in cases where no coupling material can be used.

Cotton ribbons can be tied around the object to maintain sensor into place. In case of fragile surfaces, foam pads can be placed to avoid applying direct force and friction into the object.
This method allows you to put some force into the sensor, but it can't be quantified. On larger or fragile objects, two people might be required to install the ribbons correctly.

Weights can only be used on horizontal surface. They are placed directly on top of the sensor. They add stability and force but can't exceed 1kg most of the time because of the size of the weight compared to the size of the sensor. It is important to make sure the weight is stable on the sensor and doesn't risk falling or slightly oscillating, which could cause interferences in AE signals.

Fig. 10 Example of sensor installation using cotton ribbon only

Fig. 11 Example of sensor installation, using 500g weight and cotton ribbon

<u>Step by step guide for AE testing on wood</u>

Before anything, do not forget to document your test. Take notes about the inventory number of the tested object, his state (dry/humid/wet, degraded, well preserved), size, material and surface finish. Take pictures before, during and after your intervention. Indicate specifications about background noise (noisy/quiet/specific activities) and any other relevant indications.
It is recommended to do a 24h-test on heathy object to document precisely background noise of the environment where the test is conducted

Firstly, ensure that every piece of equipment is correctly plugged in. Hardware must be connected to a power supply source and to the computer. Each sensor must be connected to the preamplifier by the sensor-cable to preamplifier cable. The preamplifiers must be connected to the chassis by the coaxial cable. Be aware to plug the sensor to the "Sensor IN" part of the preamplifier and to plug the chassis to the "Sig OUT" part of the preamplifier.

Fig. 12, Preamplifier, with "Sensor IN" and "Sig OUT" indications

To avoid interference, it is important to place the chassis on another surface than the one containing the tested objects. We used a cart to put the computer and chassis, while the tested objects were on the ground or another table.

The second step is to determine where to place the sensor on the object. Ideally, choose a flat area that covers the whole area of the sensor. Avoid friable surface or extremely fragile ones. Sensors spacing shouldn't exceed 50cm.

Fig. 13, Reference sensor

To be used as a reference, one of the sensors have to be placed near the tested object, with the ceramic plate facing up. Use a tag to quick identification of the sensor.

Depending on the surface you have chosen and the nature of the tested object, use the right coupling material and method according to point "coupling methods".
To document better the environment, you can place a datalogger to register temperature and relative humidity. If the room you are doing the test in is already equipped with one, collect the data after your test is done.

Open Vallen Control Panel app :

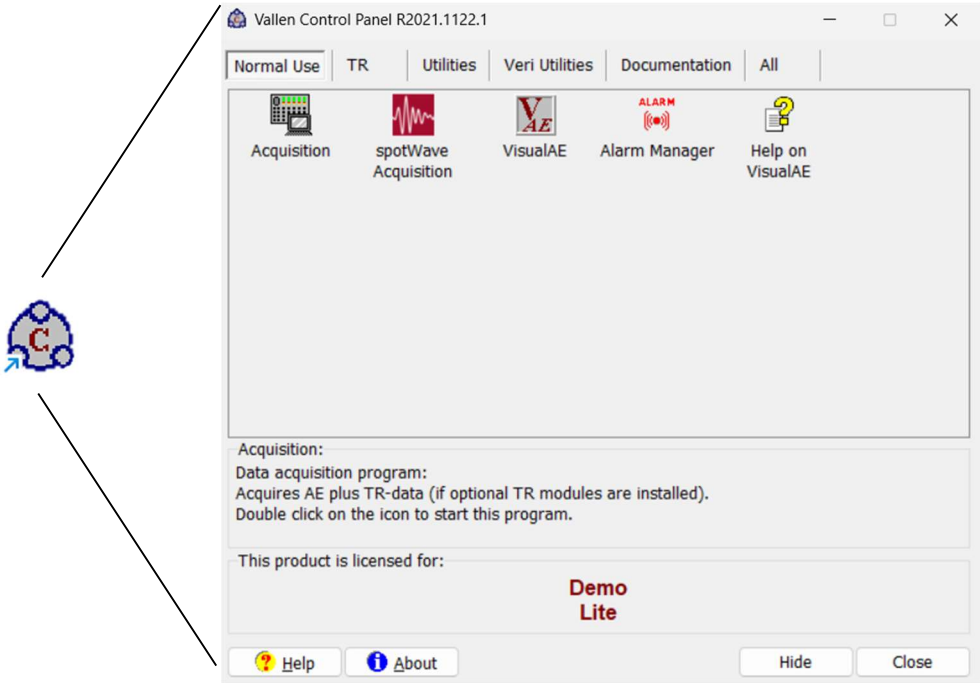


Fig. 14 Vallen Control Pannel

Go to "Acquisition". If the AE hardware is connected, it will be detected automatically.
A new window, "Acquisition Setup" will open.
If no hardware was detected yet, press "skip" to access that window.

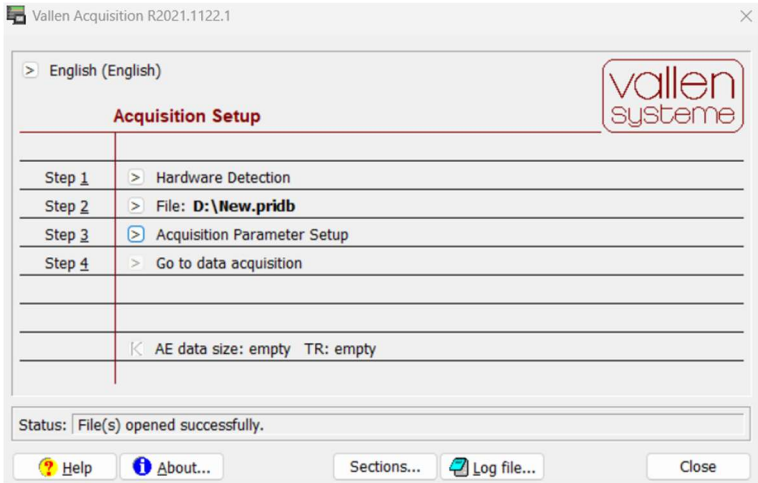


Fig. 15 Vallen Acquisition Panel

"Step 1" allow you to detect the AE hardware if its wasn't plug in yet.
"Step 2" allow you to choose a .pridb file. Choose the file corresponding to your test. If you don't have any pre-existing .pridb file, you can create one by writing a new name in "name of file" and then click "open". Remember to use a logical way to name your files for you and your coworkers to understand easily.

"Step 3" allow you to modify acquisition parameters (see parameters windows at fig. 1-3) With a pre-existing file, check that the parameters are correct. With a new file, enter the correct parameters.

To smooth the process, we created a .pridb file, named "source", with the correct parameters. This file is then copy pasted and renamed to correspond to the current test. This allows faster set up and reduced risk of using the wrong parameters.
When everything is done, proceed to "step 4". This will open a new window:

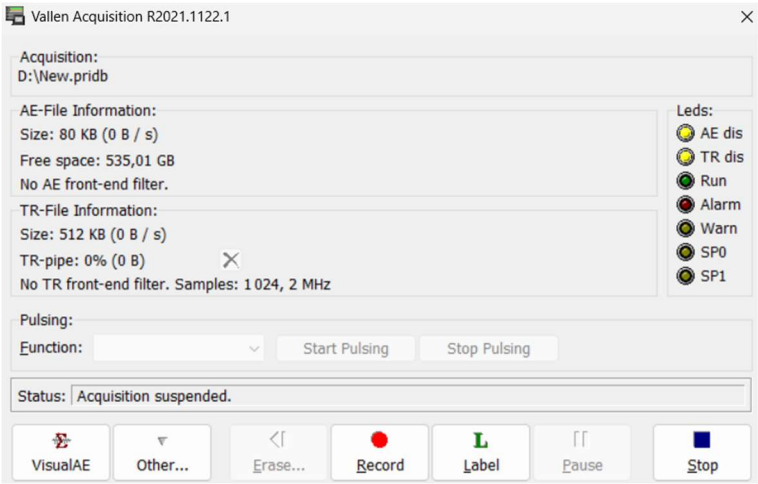


Fig. 16 Vallen Acquisition panel, when ready to record data

On this window, press "record" to start recording.
Go back to the control panel, open "VisualAE", select the file of your ongoing test and open it. You will be asked if you want to browse a set up file. Unless you already have a specific set up you want to use, select "no".
This window will open :

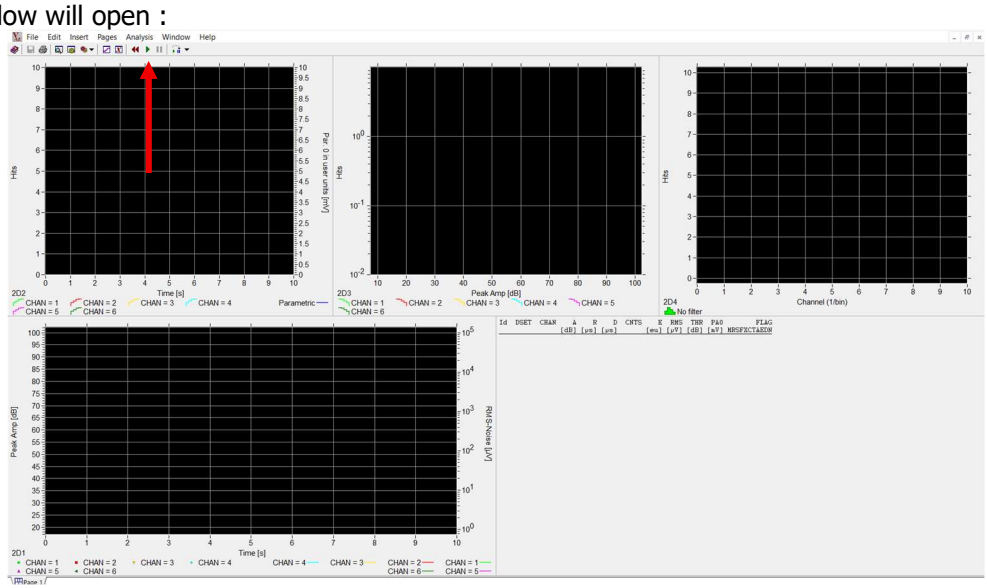


Fig. 17 Vallen® VisualAE, default set up

If you browsed a specific set up file, it might look slightly different, but the menu to the top left will be identical.

Press play (red arrow to read the data in real time. Data will start appearing on the different graphs and background noises, thick and continuous hits, will accumulate on the bottom graph. The background noise may look slightly different from on environment to another.

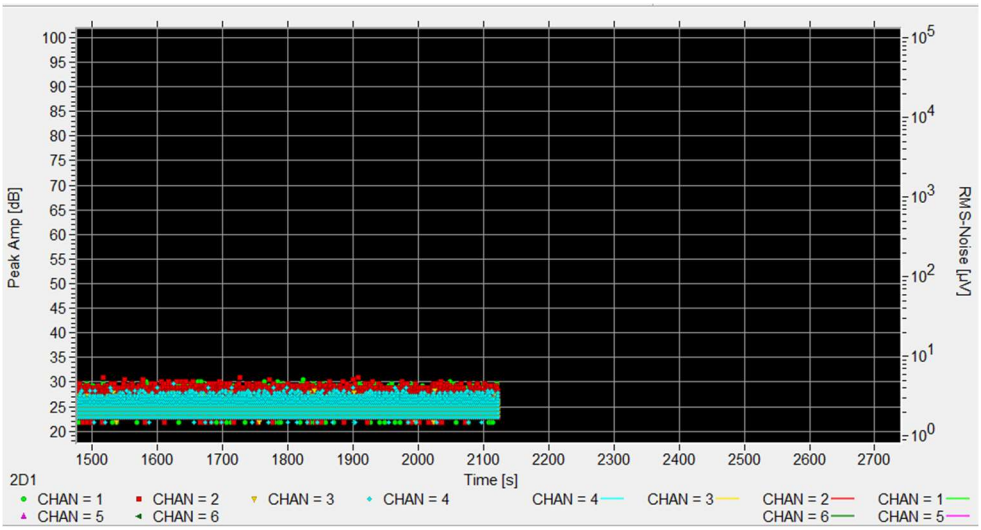


Fig. 18 Vallen VisualAE, ongoing background noise

To ensure that sensors are working correctly, use the Hsu-Nielsen Source, a mechanical pencil with a guide shoe to perform a pencil lead break test (PLB).
The lead used is a 0.5mm, 2H carbon lead. The extension is 3mm, which corresponds to 3-4 clicks. Verification with a measurement instrument is needed.
The guide shoe allows to break the lead at a 30° angle.

Fig. 19 Mechanical pencil equipped with guide shoe. Used for PLB

Break the lead 3 times 1cm away from the sensor and repeat for each sensor, including the reference one. When testing on a heritage object, it is important to protect the surface of the object and not press the lead directly into the surface and to avoid having lead break flying around. To prevent that, a simple sticky note is folded to create a pocket. The lead is broken inside of this pocket, allowing to collect the lead inside. The ones that rebound and might fall off the pocket get stuck to the sticky part of the paper.

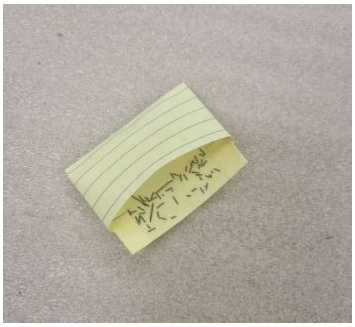


Fig. 20 Sticky note pocked (trapped leads)

Fig. 21 PLB inside the pocket

PLB will appear on the bottom graph as very high dB hits. The lower the value, the less efficient the coupling. The PLB should have a significantly lower value on the reference sensor, as it is not coupled to any surface.

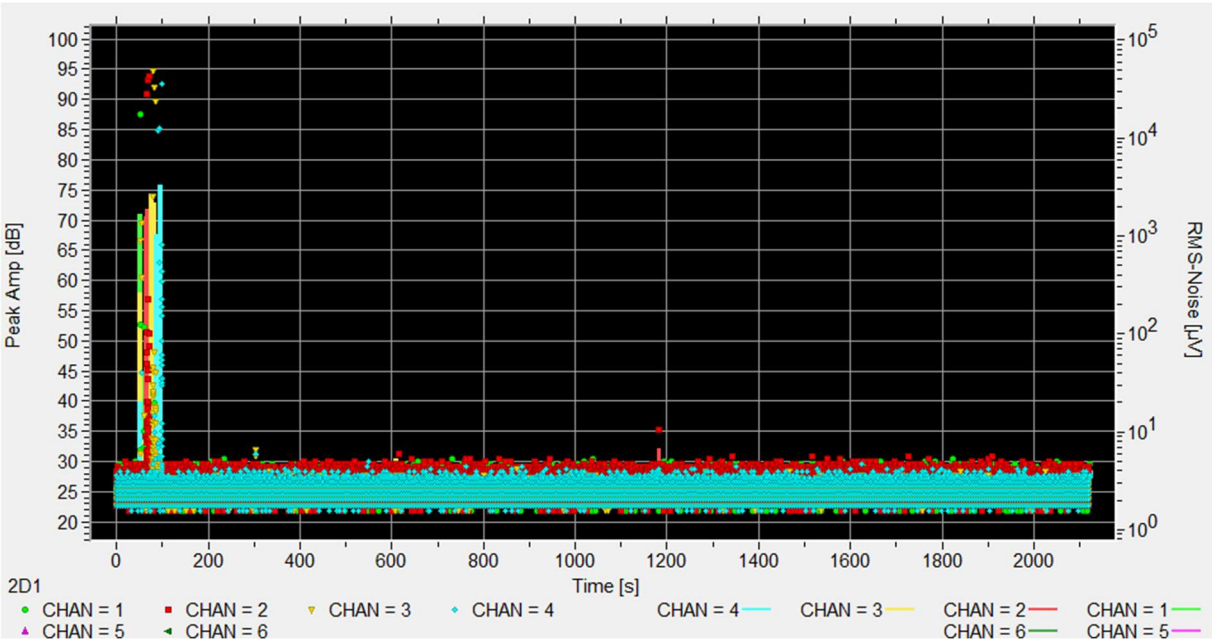


Fig. 22 Finished test on healthy wood. Background noise at PLB at ~100 seconds

To ensure good knowledge of your possible background noise,

Do the test for as long as needed to meet your objective. If your test is taking place during nighttime or longer than 24h, repeat PLB at the end of the test or once every 24h to ensure that sensors are still working correctly. For long tests, verify (especially if testing on the ground) if footsteps are detected. If yes, change location if possible. If not, warn the staff and put paper and pencils near the test zone for people to write their time of passage to know which hits you can associate with footsteps.

After the test is done, stop the measurement in the Vallen Acquisition panel. Save your set up in VisualAE and close the windows. Clean your installation according to indications in "coupling method" chapter.

Analysis of the data

Visual analysis

Label determination (infested/clean) is currently being done by visual analysis of the object, the data and knowledge about the context of the test. Past experiences of infested and non-infested objects in different environments lead to the following observations on AE data:

Background noise can be easily identified by testing a healthy wood sample. It forms a regular straight band of hits, most of the time being close to 30 dB max. It can be slightly lower or higher depending on the environment. (fig. 1;17;21)

24h tests helps to determine if the detected signals are due to activity during work hours or constant background noise.
The graph next page shows a 24h test. Starting at 8am, it containing the usual background noise, three PLB (big peaks) done at 8am (0s), 5pm (6E4s) and 8am^{+1} (9E4s) and some activity, but exclusively during work hours. This means that the detected signals aren't due to activity coming from within the tested object, but from the external activity in the room.

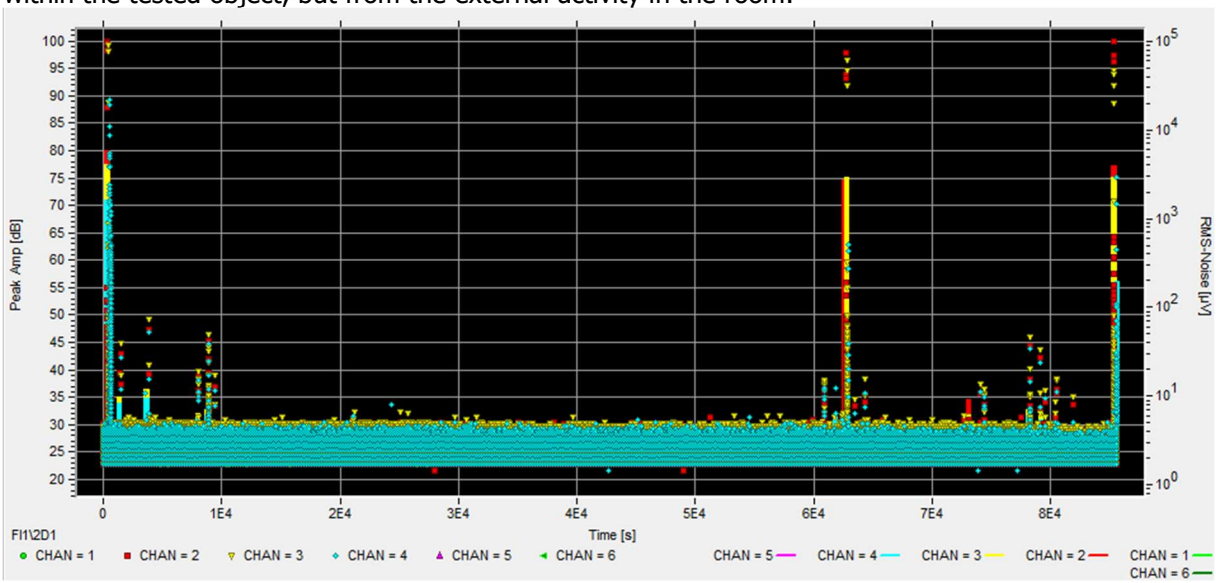


Fig. 23 24H test. Three PLB. Activity during working hours.

Infested data seems to present cloud-like hits during the whole duration of the test, with possible fluctuation in intensity in long tests. The cloud of hits is relatively dense and its values in dB may vary, without reaching the intensity of PLB.

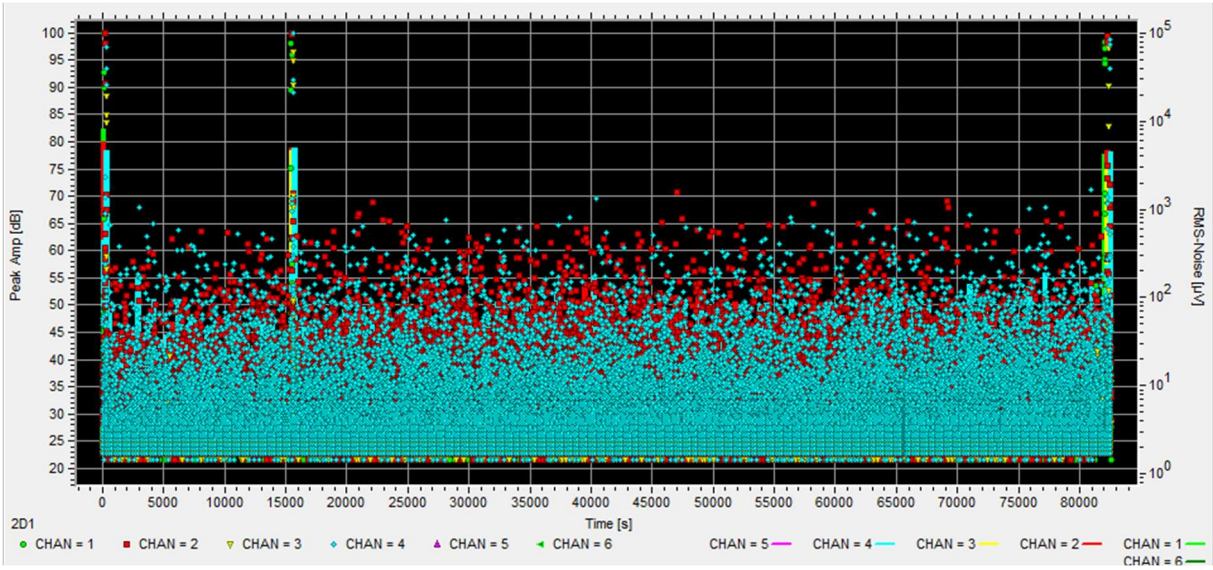


Fig. 24 Heavily infested wood. 24h test, three PLB.

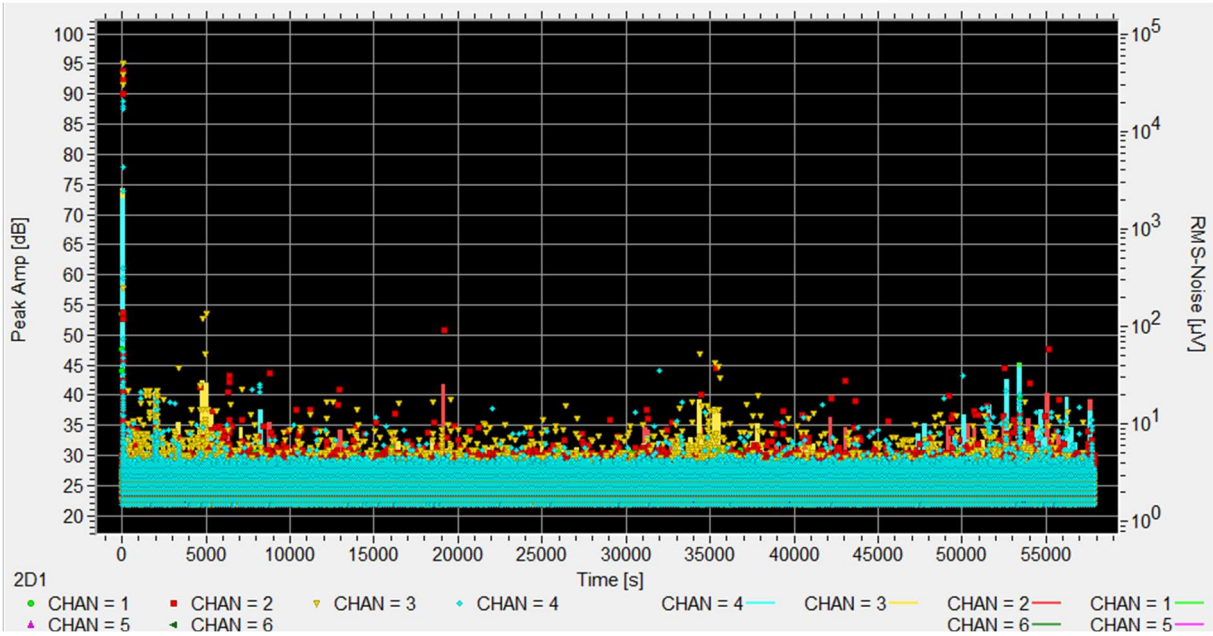


Fig. 25 Lightly infested wood. 24H test. One PLB

Non infested data can be observed in two main different form: no signals except for PLB and background noise or detection of AE signals emitted by other sources than insect activity. As the first category is easily noticeable, the second one needs further observation:

- Too little hits (fig.25) or isolated intense hits (fig. 26, yellow arrow) aren't considered as infestations signs, but as others AE signals such as cracking or interference due to the coupling method used.

- Hits that are detected by reference sensor and/or by all sensors when placed on different wood samples can be classified as external background noise (fig. 22)

- Small cluster of light or heavy intensity that doesn't repeat can be caused by something/someone touching the sensor or the detachment of the sensor. (fig.26, red circle)

- In some setups, footsteps might be heard. Signals will appear differently depending on the nature/quantity of the footsteps

- When wood sample are actively drying, some important clusters can appears and look similar to intense insects activity (fig. 26, white arrow). For this reason, it is recommended to not conduct AE testing on drying wood when trying to confirm or refute infestation

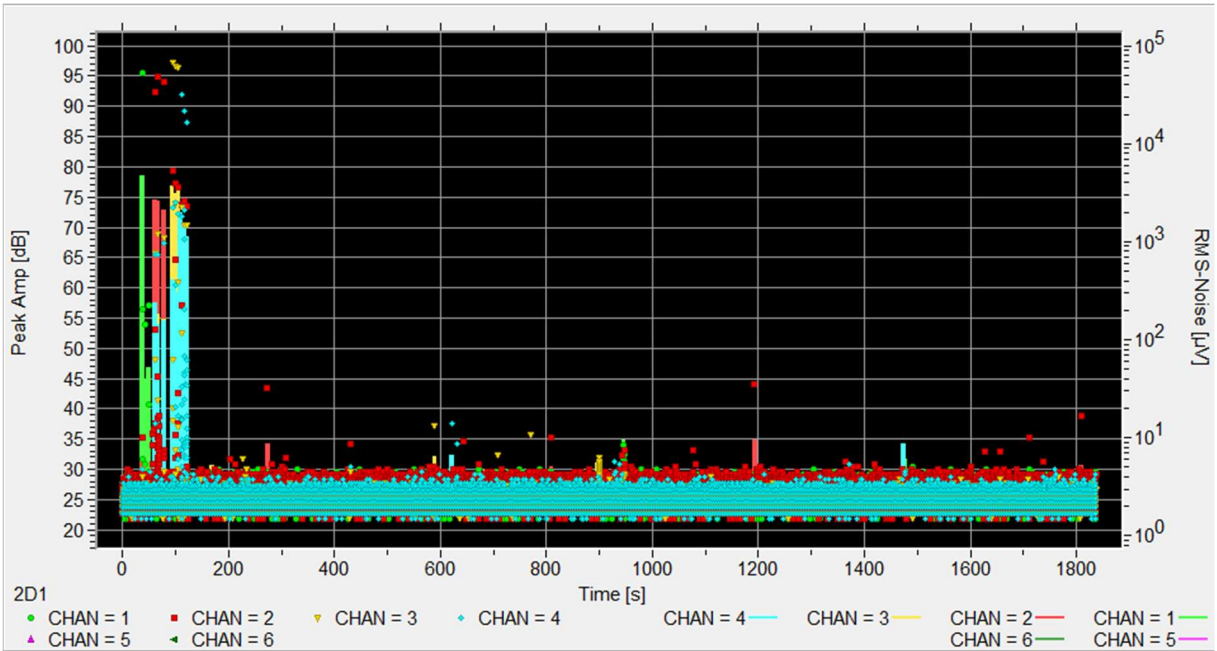


Fig. 26 Healthy wood. 30min test. One PLB

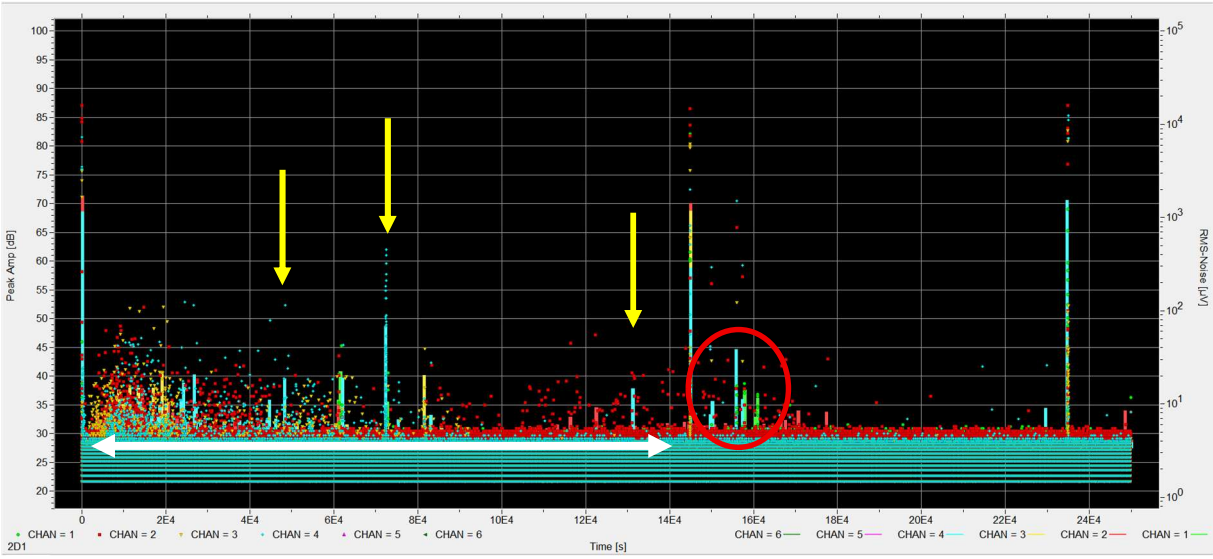


Fig. 27 Actively drying wood. 72h test. Three PLB.

Some environments aren't suitable for AE test. Outdoor testing during rainy and windy weather resulted in intense hits that could mask hits provoked by larvae activity.

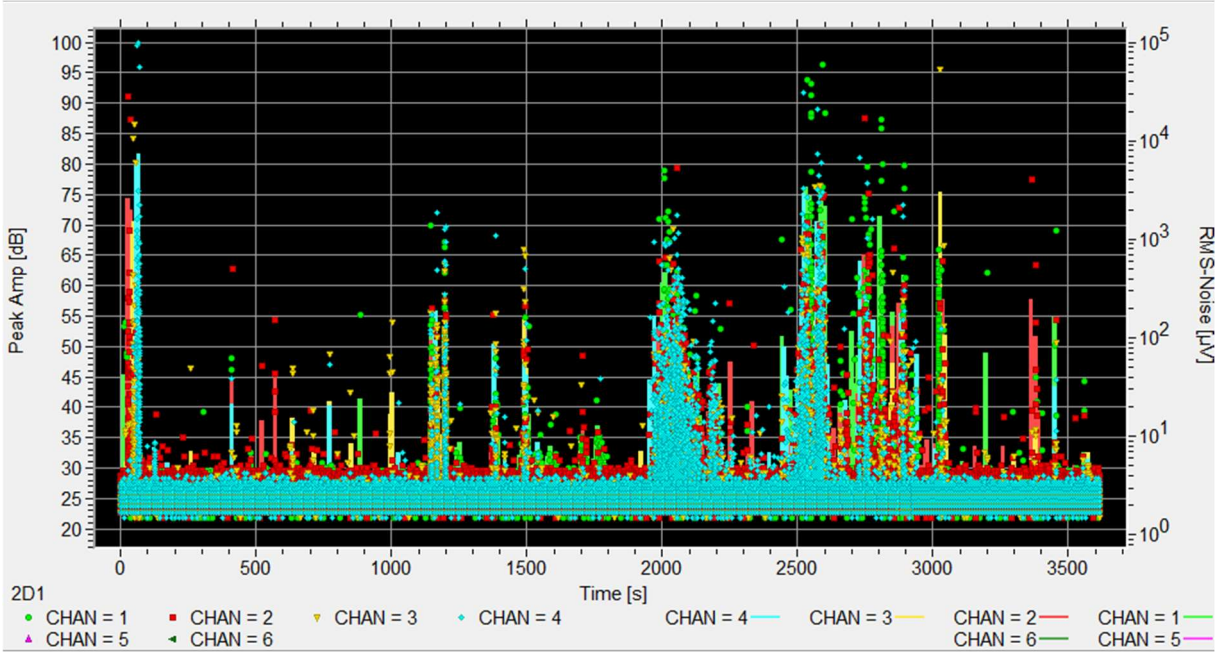


Fig. 28 Healthy wood. Outside measurement. Rain and wind.

To help confirm an on-going infestation, wood sample can be stored in a place or bag where their condition can be monitored. The apparition of new frass, new exit holes, living adults or larvae can attest the active infestation. Looking at temperature and humidity data is also a good indicator, knowing that most species of woodboring insects aren't active below 10°C and increase their activity when temperature exceeds 20°C (Creemers, 2024, p.4-7)

If confirmation can't be obtained by visual observation of the wood sample, it then follow a freezing treatment of one week. If the AE signals are still observed, it is froze again for one week, then one day out and one week in the freezer again. If after this treatment, AE signals is still being detected without much changes, it is safe to assume that those signals are emitted by another source than insects, as they must have been killed.

The major flaw of this determination system is the approximation of every parameter. There is no defined limit of what is considered "too little" or "too high". While it may work for heavily infested objects, it is not suitable for noisy environment, light infestation or very shorter tests.

<u>Care of the equipment</u>
When your testing is finished, carefully dissemble the equipment and tidy everything in their storage boxes.
Roll the cables according to their natural orientation and attach them with a string.
Clean the sensor with ethanol, or mineral spirit if there is remaining dry renaissance wax on them, before packing them.
Put the equipment back to its designated space.

4.3 AE protocol – infestation detection

Preparation

- Ensure having all the AE equipment (sensors, preamplifiers, cables, chassis, mechanical pencil and guide shoe, leads, computer, coupling material).
- Document the test: ID number, dimensions, conditions (dry/humid, cracks), temperature and relative humidity of the room, pictures (before, during, after).
- Set up (.pridb) file with the adequate name.
- If you don't have a pre-existing fil, create one (see Acquisition Setup).

Sensor placement

- Reference sensor: place it close to the tested object, ceramic plate facing up (for background noise).
- Test sensors: select ideally flat, stable areas.
- Dry clean (soft brush) the tested area.
- Coupling: choose a coupling method compatible with the tested object.
    - Renaissance wax: apply thin layer, wait approximately 5 minutes to harden, press and lightly twist into the surface to remove excess.
    - Cyclododecane (solvent-free): spray a thin layer, immediately press the sensor into the surface. Add a layer around the sensor.
      If the sensor is placed upside down and the test last more than 8 hours, secure with clamp or ribbon.
    - Non-chemical: cotton ribbons, weights (horizontal surface), clamp.

Acquisition Setup

- Connect sensor → preamplifiers (check connection labels: Sensor IN / Sig OUT) → chassis → computer.
- Place chassis and computer on a separate support (avoid interferences).
- Start Vallen Control Panel → Acquisition → select the (.pridb) file (or create) → verify the parameters → Record.
- Open VisualAE, select current test file and start real-time display (▸ button, top left).

System Check

- Use 0.5mm 2H mechanical pencil with guide shoe (Vallen®), 3mm lead extension.
- Perform 3 lead breaks, 1cm from each sensor. Use an interface (sticky-note pocket) to protect the object and avoid flying leads.
- Results should show high dB hits. The higher the more efficient the wave transmission (max value is 100).

Test duration

- Run test for required time. (24h for background noise assessment, at least 30min for pest detection in adequate climatic conditions.
- Repeat PLB every 24h or at test end to ensure sensor performance.

After the test

- Stop acquisition in Vallen Control Panel. Save your setup.
- Clean sensors and objects:
    - Renaissance wax: wipe with cotton swab. Use mineral spirit if dry.
    - Cyclododecane: allow sublimation or brush it off dry.
- Store AE equipment adequately in its boxes.
- Analyze your results.

4.4 Use and update of the heatmap

<u>How to use the current heatmap</u>
When opening the Tableau® file, you will find at the bottom left the different sheets, named after the floors. By clicking on them, you will obtain the heatmap visual of the floor concerned:

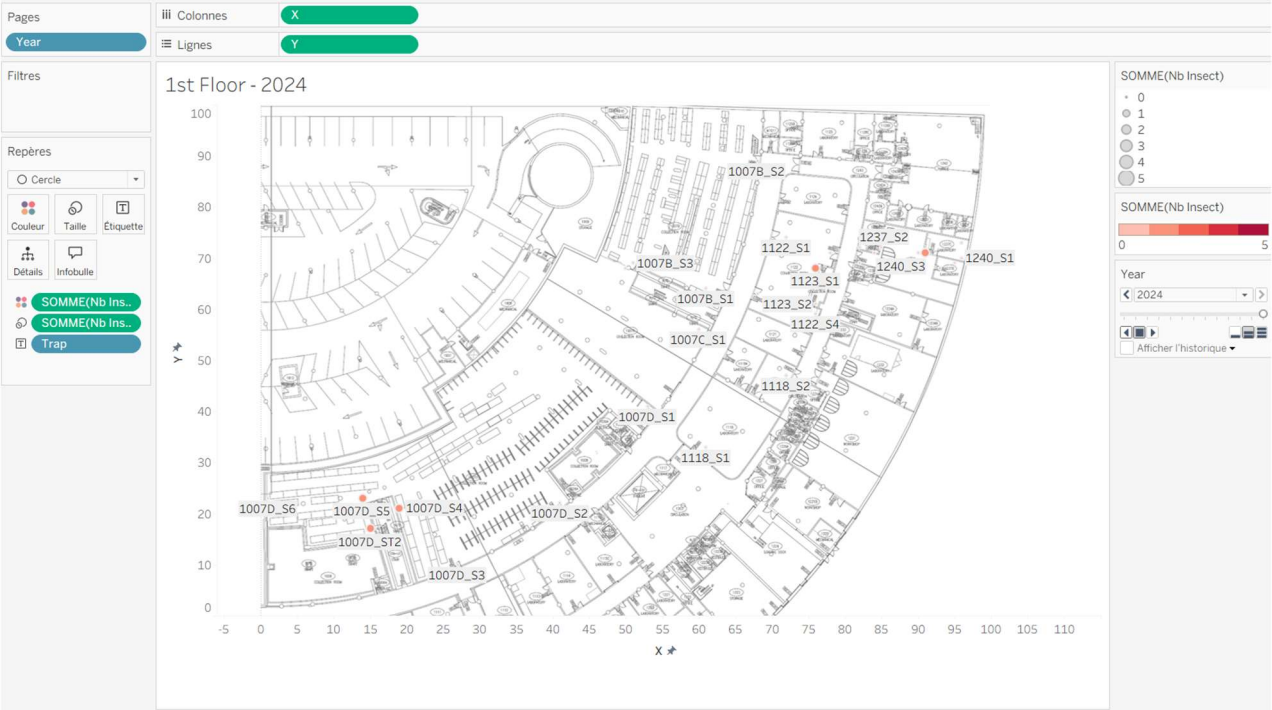


Fig. 29 Heatmap 1st floor 2024

On the left, in "Marks", you can modify the visual aspect (color, size, shape) of the marks that indicates the number of beetles found.
At the moment, the mark are presented by a size and color ratio to the number of insects. The max amount is 5, but that number can be adjusted by clicking the two window on the right "SOMME(Nb Insect)"
The window "Year" allow you to travel through the data of the different years.
By placing your mouse on a trap, you can see more detailed information about the coordinate of the trap and the number of insects.

<u>Data connexion</u>
It is important to note that Tableau Public® don't copy the data from your files in its own data base but get them from your files. This allow you to easily update the heatmap, but it also requires you to be very careful about **keeping all the documents** (Excel sheet, jpeg of the floor plans, Tableau® file**) in the same folder** and not moving them nor the folder. By moving them, you will break the connection.

However, if this happens, you can easily fix it by modifying the data source. Place yourself in the "data source" sheet. In the menu, select "data", "name_of_your_file" and "modify the connection". then select the same file as before.

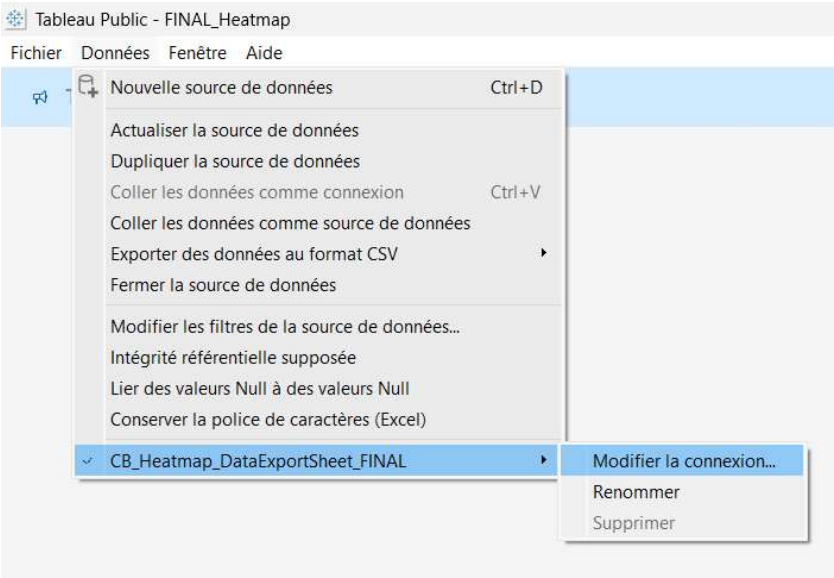


Fig. 30 Tableau Public®. Modifying data source

If the issue occurs with the maps used as a background, go in each sheet (1st floor, 2nd floor, etc), select "map", "background picture" and "name_of_the_sheet". A new text box will open

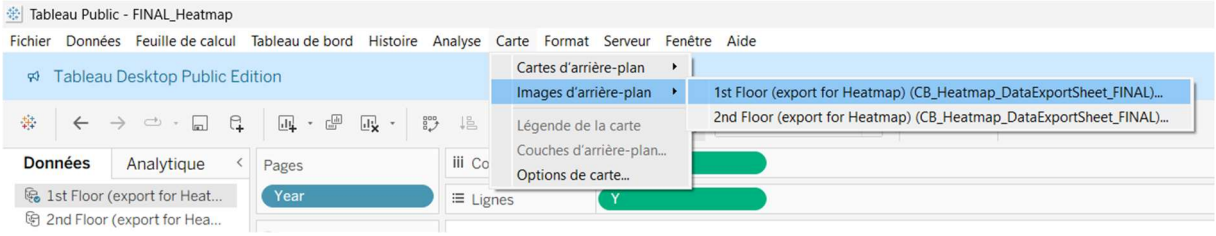


Fig. 31 Modifying map, 1st step

Select "add a picture" and select the corresponding one. **Always use the pictures delivered with the heatmap**, as the coordinates of traps are calculated based on them. Then enter the correct values as in fig.32. You can choose the transparency of the map according to your preference.

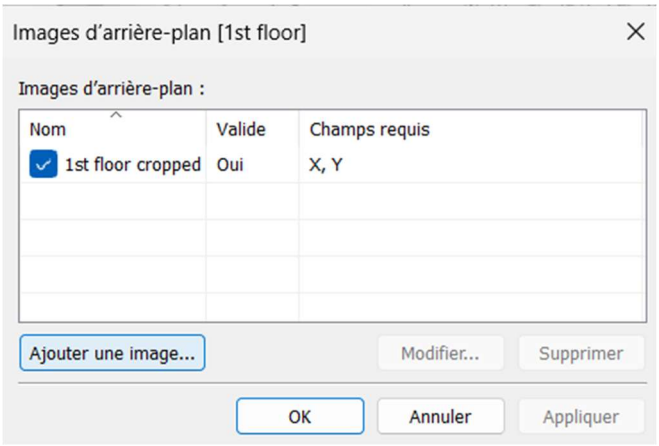


Fig. 32 Modifying map, 2nd step

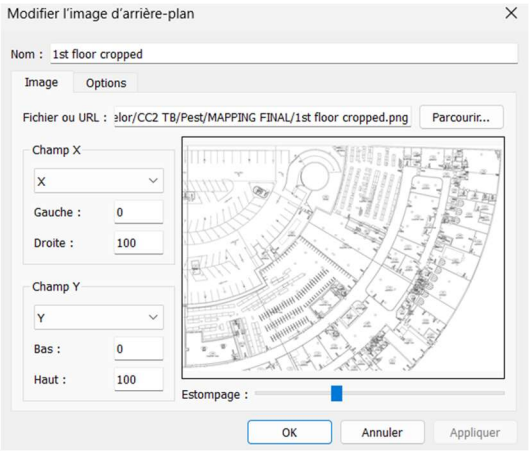


Fig. 33 Modifying map, 3rd step

How to update the heatmap

The first step is to open the Excel file. The first sheet "Trimestral General" has been constructed to respect the way the data of pest tracking was taken until now. It can be filled regulary with the newest data.
All the cells in the table is formatted to change colors depending on the value of the number. This give some information at first glance.
The total by room, floor and year is automatically calculated at the end of each part of the table
The entered data are then automatically transferred to the second sheet "Yearly General". This sheet, who also have formatted cells that changes colors allow a better view on the evolution of pest through longer time period, but it is mainly useful to proceed with the next step.

Room n°	1007D							1007C		1007B			1118		1122	
Trap n°	S1	S2	S3	S4	S5	S6	ST2	S1	S2	S1	S2	S3	S1	S2	S1	S2
2012	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2024	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
2025																

Fig. 34 Extract of the "Yearly General" sheet of Excel file for heatmap

The next sheets are named after their corresponding floor number, followed by "(export for heatmap)". They are constructed to allow smooth and easy export into Tableau®. The year, trap number, their coordinates (X,Y) and the number of insect found is listed.
To add data, simply copy-paste the column "year", "trap", "X" and "Y" of the previous year to keep the exact same traps number and emplacement. Then copy-paste the data of insect from "Yearly General" to the last column. Repeat for each floor.
If through the year some traps were moved, added or suppressed, their coordinates and name can simply be modified in the corresponding cell. To establish the new coordinate, you have to refer to the heatmap in Tableau Public®.

When the data are successfully entered, go in Tableau Public® and open your file. In "data source" sheet, select "data" and "update data". Data are now automatically updated for all your sheets.

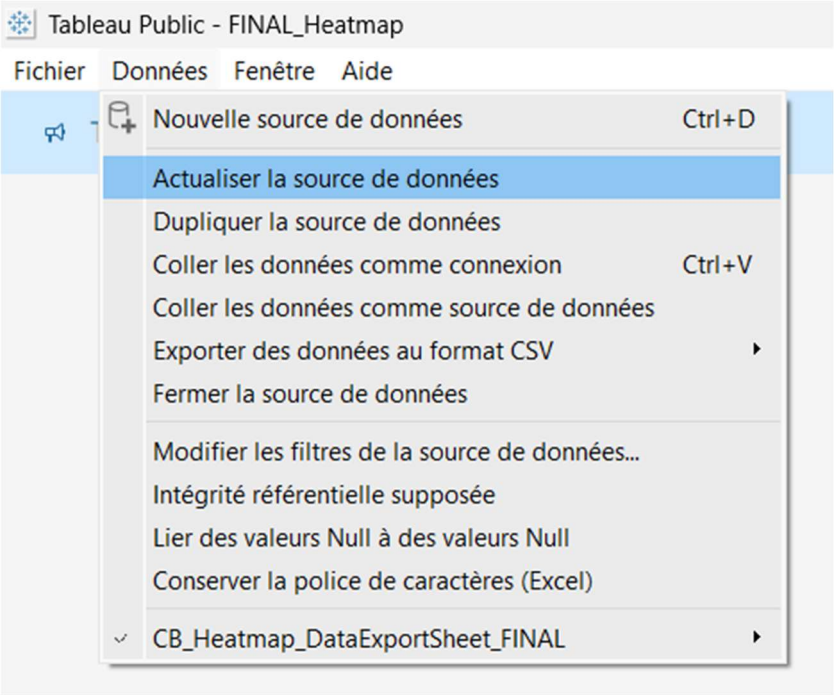


Fig. 35 Update heatmap

<u>How to modify the displayed data</u>
As Tableau Public® can easily synchronize data when the Excel file keeps the same format, adding a new column will break the current heatmap. It is however normal and easy to fix. Start by modifying the excel file according to your needs.

Go back to Tableau Public® and update the data as viewed previously. Then, for each sheet, double click on your file source on the left side menu.

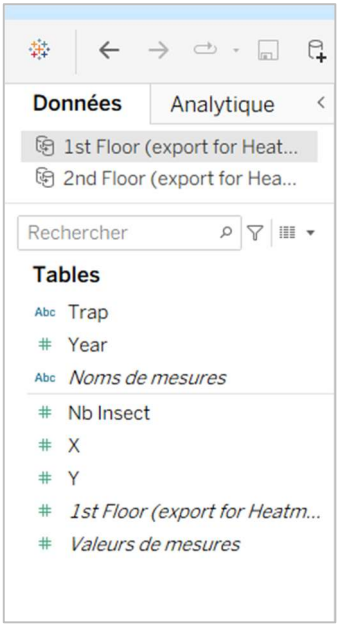


Fig. 36 Modify data step 1

This will open your data in "data source":

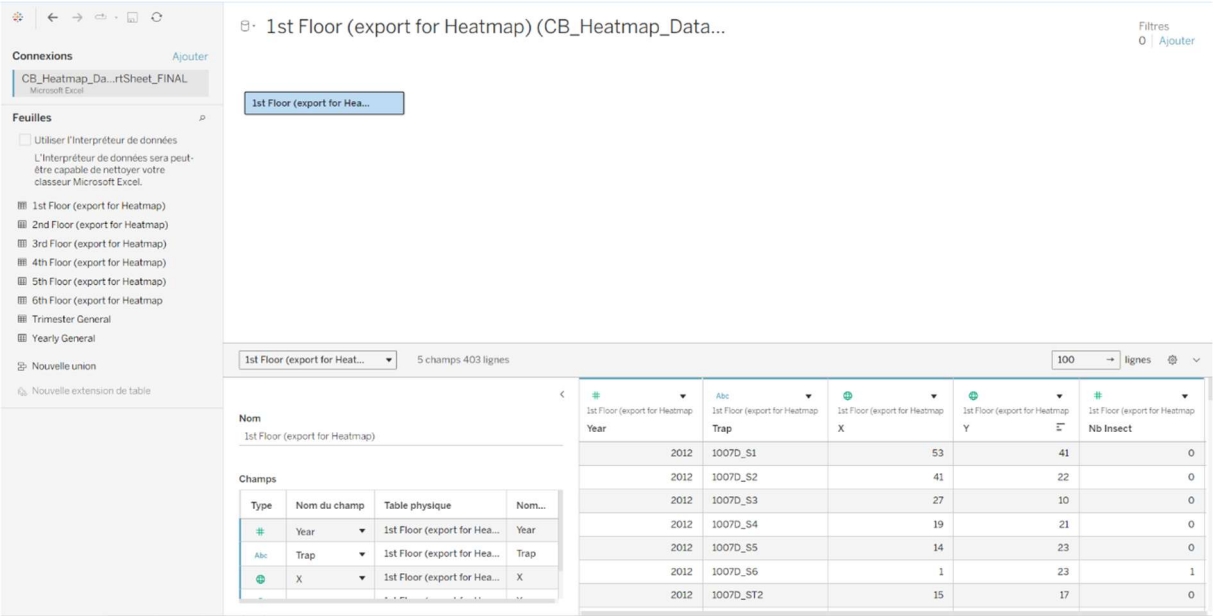


Fig. 37 Modify data, step 2

The data displayed now is the one currently used. "Nb insect" referring to carpet beetle. Ensure that each of the columns are indicated as the right type. Click on the icon on the top of each column (or in "field") and select the corresponding description. "Year" and "Nb insect" must be "number" (# symbol). "Trap" has to be "chain" (abc symbol). "X" and "Y" have to be respectively latitude and longitude (icon). Choose the corresponding type for your new data.

Go back to the floor sheet and place your new data by clicking and dragging it into the "mark" section, then choose a visual according to your needs.

<u>Important notice</u>
In case you encounter some difficulties with the heatmap, here is a reminder of the keys parameters for it to work correctly :

- Files shouldn't be moved, unless you move a temporary copy of it (no modification possible afterward)
- One data source per sheet (do not link excel sheets in the "data source" sheet)
- In "data source" sheet, X and Y must be in latitude/longitude.
- In each floor sheet, X and Y are in dimension and not in average (right click on the pannel)
- The data source is uptdated
- If new data format has been entered, it has been modified for each sheet in data source
- The background map is using the correct parameters (fig.31)

5 Technical Sheets

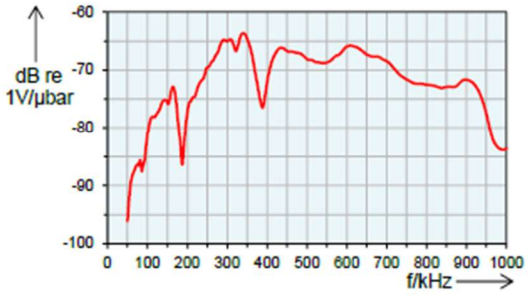
The Acoustic Emission Company

vallen systeme

AE–Sensor Data Sheet

VS900-M

The VS900-M is a passive piezoelectric AE-sensor that has a broad frequency response. Its response is characterized by two peaks at 190 kHz and 350 kHz with accompanying anti-resonances at 200 kHz and 400 kHz. Benefits of the VS900-M are a high sensitivity over a broad frequency range with compromises regarding the flatness of response. It combines a good response in the standard frequency - and high frequency range.



Technical Specification			
Frequency Range (f_{Peak}) [kHz]	100 to 900 (350)	**Size (D x H) [mm]**	20.3 x 14.3
Capacity [pF]	540	**Weight [g]**	22
Integrated Preamplifier	No	**Case Material**	Stainl. Steel (1.4571/ 1.4404)
Operating Temperature [°C]	-50 to +100	**Wear Plate**	Ceramics
Vibration – Sinus sweep	2 Oct/Min, 5 to 180 Hz, 40 g	**Connector**	Microdot
Ingress Protection Rating	IP40	**Shield Cross-Talk [dB]**	< -80

Standards and Directives		Certifications
EMC Directive	2014/30/EU	CE UK CA
EMC Standards	EN61326-1, EN61326-2-3	
Shock and Vibration Stand.	EN60068-2-6	
AE Standard	EN13477-1, EN13477-2	

Accessories			
Preamplifier	AEP5H, AEP5, AEP3N	**Sensor Cable**	CBL-1-1M2-V5
Mounting Holder	MAG4M		

Think AE - Think Vallen!

Important instructions for your safety

The sensor was produced according to the state of technology and tested against highest quality standards and technical safety requirements. A risk of malfunction remains which can lead to danger to life of operator, uninvolved third parties as well as damage of object under test or objects in its vicinity. Read the safety instructions carefully before using the AE-sensor.

Supplemental safety directives

1. Read the Acoustic Emission Sensors document (https://www.vallen.de/quote-ref)
2. Make sure that you comply to regulations at the AE-sensor installation site
3. Store these instructions

⚠ CAUTION	*CAUTION indicates a hazardous situation which, if not avoided, may result in minor or moderate injury.*

Damaging of AE-sensor

An AE-sensor can get damaged when it is not operated within specified limits or handled carelessly. The function of the AE-sensor may be compromised or it may even be inoperable although its appearance e.g. housing, connector or wear plate do not indicate any damage.

Risk:

A damaged- or defective AE-sensor may not be able to detect potentially dangerous situations if it is used in a safety relevant inspection of e.g. pressure vessels or engineering structures such as bridges or dams.

How to avoid the risk of damaging an AE-sensor:

- Do not store, transport or operate the sensor outside its specified environmental conditions
- Do not drop the AE-sensor and handle it with care
- Transport AE-sensors only in the boxes provided by Vallen Systeme

How to avoid using a non-functional AE-sensor:

- Do not use an AE-sensor that is visibly damaged.
- Check the function and response of an AE-sensor prior to an inspection or AE-test by the use of controlled artificial sources
- Check the function and response of an AE-sensor in regular intervals or when suspected to be damaged or to have undergone severe environmental conditions

Redemption and Disposal Information of used Vallen Equipment.

- Equipment labelled with the symbol shown on the left must be disposed separately from unsorted municipal waste within the European Union.
- Owners of old instruments request our agreement to return old electronic equipment. The goods to be returned must be described unambiguously and identified by serial and/or identification number. You can fill in our contact form (*www.vallen.de/contact/*) or send us an email to sales@vallen.de.
- Upon our approval owners may ship the goods free of costs to us.
- We will dispose the goods according to the relevant laws and regulations on our costs.
- Goods returned without our approval will not be accepted and returned to the owner on his account.
- We explicitly point out that according to § 19a ElektroG3 you are responsible to delete any personal data on the appliances considered for disposal.

Disclaimer
The material contained in this document is provided "as is" and is subject to being changed, without notice, in future editions. Further, to the maximum extent permitted by applicable law, we, Vallen Systeme GmbH, disclaim all warranties, either expressed or implied with regard to this specification and any information contained herein, including but not limited to the implied warranties of merchantability and fitness for a particular purpose. We, Vallen Systeme GmbH, shall not be liable for errors or for incidental or consequential damages in connection with the furnishing, use, or performance of this document or any information contained herein. We shall not be liable for any direct, indirect, consequential or incidental damage arising out of the use or inability to use of the equipment delivered. We reserve the right to charge for any efforts taken to remedy any problems for which we are not responsible.

Vallen Systeme GmbH, Buergermeister-Seidl-Str. 8, 82515 Wolfratshausen, Germany
Email: info@vallen.de – www.vallen.de – Phone: +49 8171 38391-0

Technical sheet 1, Vallen® AE sensor VS900-M

The Acoustic Emission Company

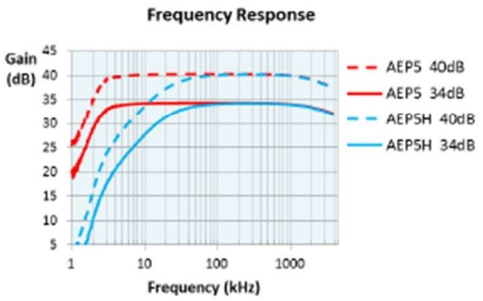
vallen systeme

AE–Preamplifier Data Sheet

AEP5 / AEP5H

AEP5 / AEP5H are general purpose wide-band preamplifiers supporting single ended AE sensors. The only difference between AEP5 and AEP5-H are different frequency bandwidths. Gain can be set to 34 dB or 40 dB by a switch located inside the preamplifier. Changing the gain requires opening of the housing as described in the specification of preamplifiers. Thereby accidental change of gain is excluded.

As every preamplifier of Vallen Systeme GmbH the AEP5 / AEP5-H can put a voltage pulse (up to 450 V_{PP}) through the preamplifier to the connected AE-sensor (sensor coupling test) while the supply voltage for the preamplifier is interrupted.



Technical Specification (typical)			
Preamplifier Gain @ 50 Ω [dB]	34, 40 switch selectable		
Bandwidth 34 dB Gain (-3 dB) [kHz]	2.5 to 2400 @ AEP5	20 to 2400 @ AEP5-H	
Bandwidth 40 dB Gain (-3 dB) [kHz]	2.5 to 2400 @ AEP5	20 to 2400 @ AEP5-H	
Input Impedance [MΩ] | [pF]	50 | 22		
Power Supply [V_{DC}]	28 (fed in via signal cable)		
Typ. Power Cons. [W]	1.8		
Input Range [mV_{Peak}]	100 @ Gain 34 dB	50 @ Gain 40 dB	
Output Range into 50 Ω [V_{PP}]	10		
Max. Puls Through [V_{PP}]	450 (suited for AMSY series)		
Noise (max. 1/s for dB_{AE} values)	Input 50 Ω	Input 330 pF	Input VS150-M
Filter 95 to 300 kHz [dB_{AE}] | [μV_{RMS}]	12.5 | 0.8	10.9 | 0.7	24.7 | 4.3
Filter 95 to 850 kHz [dB_{AE}] | [μV_{RMS}]	18.5 | 1.6	16.9 | 1.3	25.8 | 4.9

Mechanical and Environmental Specification			
Input Connectors	BNC	Case Material	Aluminium
Output Connector	BNC	Op. Temp. [°C]	-20 to +85
Vibration – Sinus sweep	2 Oct/Min, 5 to 50 Hz, 20 g	IP	40
Size (H x W x L) [mm]	30 x 55 x 90	Weight [g]	160

Think AE - Think Vallen!

Standards and Directives		Certifications
EMC Directive	2014/30/EU	CE UK CA
EMC Standards	EN61326-1, EN61326-2-3, EN61000-6-2, EN61000-6-4	
AE Standards	EN13477-1, EN13477-2	

Accessories	
Mounting Holder	MAG4AEP5-V1, MAG4AEP5-V2
Cable	CBL-1-xM-V1 (BNC cable)
Filters	To be located in subsequent measurement chain (e.g. ASIP-2 with AMSY-6 series)

Supplemental directives

Read the "Acoustic Emission Sensors and Preamplifiers" description and specification (https://www.vallen.de/quote-ref). Make sure that you comply with regulations at the installation site. Store these instructions for a later usage.

NOTICE *NOTICE indicates a property damage message.*

Improper handling damages an AE-Preamplifier

- Do not store, transport or operate the AE-Preamplifier outside its specified environmental conditions
- Do not drop the AE-Preamplifier and handle it with care

How to avoid using a non-functional AE-Preamplifier

- Check function of AE-Preamplifier in regular intervals or when suspected to be damaged or have undergone severe environmental conditions

Redemption and Disposal Information of used Vallen Equipment.

- Equipment labelled with the symbol shown on the left must be disposed separately from unsorted municipal waste within the European Union.
- Owners of old instruments request our agreement to return old electronic equipment. The goods to be returned must be described unambiguously and identified by serial and/or identification number. You can fill in our contact form (www.vallen.de/contact/) or send us an email to sales@vallen.de.
- Upon our approval owners may ship the goods free of costs to us.
- We will dispose the goods according to the relevant laws and regulations on our costs.
- Goods returned without our approval will not be accepted and returned to the owner on his account.
- We explicitly point out that according to § 19a ElektroG3 you are responsible to delete any personal data on the appliances considered for disposal.

Disclaimer
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Email: info@vallen.de – www.vallen.de – Phone: +49 8171 38391-0

Technical sheet 2 Vallen® Preamplifier AEP5

ONSET

HOBO® MX1101 Data Logger

Temperature/Relative Humidity

Onset's HOBO MX1101 data logger measures and transmits temperature and relative humidity data wirelessly to mobile devices or Windows computers via Bluetooth Low Energy (BLE) technology.

The self-contained wireless data logger works with your mobile device or Windows computer and Onset's free HOBOconnect app so you can configure the logger and read out data over a 100-foot range, with no other dedicated equipment required. Using Onset's free app, you can also view data in graphs, check the operational status of loggers, configure alarm notifications, and share data files.

Add the MX Gateway for remote access to your data in Onset's cloud-based HOBOlink software.

Key Advantages:

- Wireless communication via Bluetooth Low Energy (BLE) technology
- Easy to deploy and offload using the free HOBOconnect app
- Visual and audible high & low alarm thresholds
- Stores 84,000 measurements
- Accuracy: +/- 0.2C and +/- 2%RH
- Find me/pager feature
- Patented connectivity technology

1.800.561.8187 www.itm.com information@itm.com

HOBO MX1101 Data Logger Specifications

Temperature Sensor	
Range	-20° to 70°C (-4° to 158°F)
Accuracy	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)
Resolution	0.024°C at 25°C (0.04°F at 77°F)
Drift	<0.1°C (0.18°F) per year
RH Sensor*	
Range	1% to 90%, non-condensing
Accuracy	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C (77°F); below 20% RH and above 80% RH ±6% typical
Resolution	0.01%
Drift	<1% per year typical
Response Time	
Temperature	7:30 minutes in air moving 1 m/s (2.2 mph)
RH	20 seconds to 90% in airflow of 1 m/s (2.2 mph)
Logger	
Radio Power	1 mW (0 dBm)
Transmission Range	Approximately 30.5 m (100 ft) line-of-sight
Wireless Data Standard	Bluetooth Smart (Bluetooth Low Energy, Bluetooth 4.0)
Logger Operating Range	-20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)
Logging Rate	1 second to 18 hours
Logging Modes	Fixed interval (normal, statistics) or burst
Memory Modes	Wrap when full or stop when full
Start Modes	Immediate, push button, date & time, or next interval
Stop Modes	When memory full, push button, date & time, or after a set logging period
Restart Mode	Push button
Time Accuracy	±1 minute per month at 25°C (77°F)
Battery Life	1 year, typical with logging interval of 1 minute. Faster logging and/or statistics sampling intervals, entering burst logging mode, and remaining connected with the app will impact battery life. Excessive readouts, audible alarms, and paging all impact battery life. Visual alarms and other events can have a marginal impact on battery life.
Battery Type	Two AAA 1.5 V alkaline batteries, user replaceable
Memory	128 KB (84,650 measurements, maximum)
Full Memory Download Time	Approximately 60 seconds; may take longer the further the device is from the logger
LCD	LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range
Size	3.66 x 8.48 x 2.29 cm (1.44 x 3.34 x 0.9 in.)
Weight	56 g (1.98 oz)
Environmental Rating	IP50
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).
FC	

*Per RH sensor manufacturer data sheet

1.800.561.8187 www.itm.com information@itm.com

Technical sheet 3 HOBO MX1101 datalogger

FICHE TECHNIQUE

ARTECH PRO
Fournitures pour l'Art
www.artechpro.fr
contact@artechpro.fr
04 90 80 07 83

CIRE RENAISSANCE Cire Monocristalline	Date de mise à jour : 20/10/2021

Description : La cire microcristalline Renaissance est une cire d'une grande finesse offrant une excellente protection pour un grand nombre de supports (bois, métal, marbre, cuir, ivoire…). D'une grande polyvalence, elle ne tache pas, ravive les couleurs, et protège les œuvres de l'oxydation, de l'humidité et de la poussière.

Composition : De pH neutre, la cire Renaissance ne contient aucun acide à l'inverse des cires d'abeilles ou de carnauba qui à terme sont susceptibles de nuire aux surfaces sensibles. Elle ne coule pas, ne se décolore pas et ne fonce pas. Transparente après séchage, elle laisse sur l'objet un fini mat qu'il est possible de rendre plus brillant simplement en frottant avec un chiffon doux après application. Utilisable en conservation préventive, la cire microcristalline Renaissance est réversible avec de l'essence de térébenthine.

Caractéristiques : La cire Renaissance offre des avantages indéniables par rapport à nombre d'autres produits de traitement de surface, cires, huiles ou vernis. La cire d'abeille reste collante et grasse, et favorise donc la formation d'un dépôt de poussière et de saletés, dommageable pour l'œuvre. Le vernis se révèle souvent être trop brillant et a un aspect non naturel, il a de plus tendance à manquer d'homogénéité sur les surfaces irrégulières et à se condenser dans les reliefs profonds. Les surfaces huileuses se dessèchent et finissent par ne plus protéger des influences extérieures. La cire Renaissance offre au contraire une protection cristalline, égale et sèche en durcissant tout en restant non grasse. Elle permet de créer sur les objets une couche de protection contre les agressions atmosphériques ou de diminuer les effets de la friction dus à la manipulation. Avant application sur cuir, il est possible de consolider d'abord le matériau avec de la Klucel G.

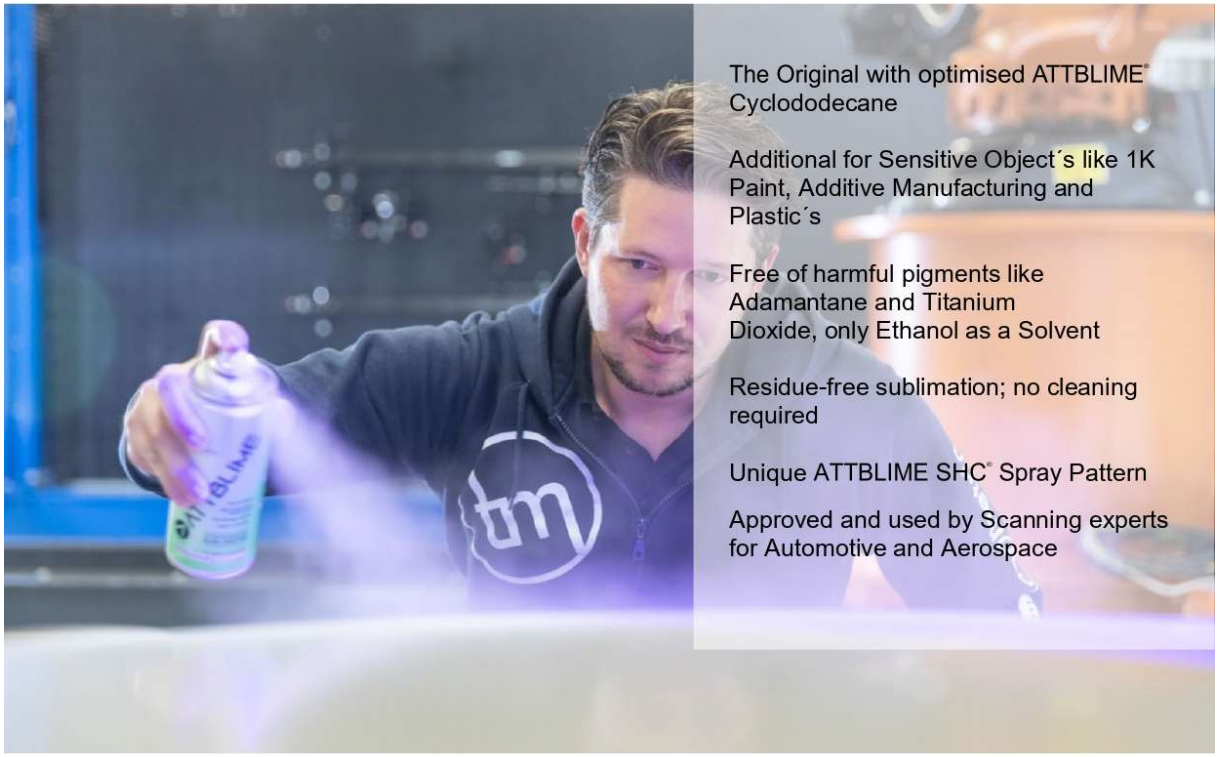
Applications : Bois, métal, marbre, cuir, ivoire…

Technical sheet 4 Renaissance wax

ATTBLIME® AB ZERO

ATTBLIME®
HIGH PERFORMACE 3D SCANNING SPRAY
MADE IN GERMANY

Technical DataSheet



Reflective, dark or shiny surfaces are difficult or sometimes even impossible to capture with optical 3D scanners. To mattify the surfaces to be measured, ATTBLIME® Scanning sprays can be sprayed before scanning which gives an accurate dimensional accuracy. This can be sprayed very thinly and evenly onto the surfaces to be recorded, so that high contrast values are created and even the smallest surface details are recorded.

The sublimating ATTBLIME version ABZERO is based on an optimised version of the substance ATTBLIME® Cyclododecane, which has been tried and tested for many years, and is characterised by complete sublimation with a service life of up to 6 hours. The spray applied evaporates without leaving any residue on the component. Subsequent cleaning of the component is not necessary. The even spray pattern has a layer thickness of < 3.0 µm in ABZERO.

Why ATTBLIME® Cyclododecane ?

ATTBLIME® Cyclododecane is specially treated and modified to create a very thin, homogeneous and a uniform layer that is completely residue-free unlike the other conventional cyclododecane or adamantane based products. Owing to its unique properties, ATTBLIME® Cyclododecane sprays require significantly less "after-spraying" due to its longer service life and thus protecting the environment while also making it significantly cost-economical.

Our key ingredient - Cyclododecane is an organic compound and the most stable representative in its family. It does not bioaccumulate in aquatic organisms and is therefore completely harmless to humans and the environment. It is non-toxic, non-carcinogenic and label free according to GHS "Globally Harmonised System".

According to SGS Institut Fresenius, no residual Cyclododecane could be detected 24 hours after an application of ATTTBLIME ABZERO making the product 100% Residue-free.

ATTBLIME SHC®

The spray cans are equipped with the unique SHC® system (spray-head-change-system), which allows the user to choose between vertical and horizontal, as well as wide and narrow exit angles, to control the film thicknesses and thus sublimation times.

Round spray head

Round spray pattern for high definition details. Shorter sublimation time due to a fine application.

Variable spray head (rotatable)
For a vertical and horizontal spray pattern. Longer sublimation time due to large area application.

Extended Tube spray head (optional)
For hard to reach area and high resolution details

Areas of Application/ Industry

- Automotive
- Aerospace
- Engineering
- Art
- Conservation and Restoration
- Architecture
- Medical
- Digital Archiving
- Optical Metrology
- Research and Development
- Measurement Services

and many more

PRODUCT CHARACTERISTICS

Form	Transparent Liquid
Basis	Solvent
Propellent (aerosol)	Propane/Butane
Colour	Whitish Gray
Pigment	Pigment-free
Key Ingredient	ATTBLIME® Cyclododecane
Free Scan Time(FST)* hrs	1 hours
Sublimation Time	1 - 2 hours
Type	Sublimating/ Self-evaporating
Residue	NIL
Film formation	60 seconds
Coating thickness	< 3.0 µm
Application	3D Scanning
Replaces	Conventional Developer Paint Non-evaporating Sprays
Adherence of Reference points on film	Yes
Size of Component	Small to Medium
Surface Compatibility	all types of material**
Toxicology	Irritant
Area Coverage (m2)	2.5
Spray mechanism	ATTBLIME SHC®
Spray Distance	10-20 cm's
Storage Temperature	5-45 °C
Shelf Life	5 years
Form / Pack Size	400ml Aerosols
Case Size	6 or 12

* FST - Free Scan Time is the actual intact duration that the coated layer stays before sublimation begins.
** Check compatibility on a test patch before use. Not advisable for us on 1K lacquered paints.

Application of ATTBLIME® AB2

Hold the can upright and spray a single even layer from a distance of 10-20 cm's onto the object to be scanned. Scan the object in a usual manner. The layer will disappear with NIL residue.

Storage

Store in well-ventilated area away from heat sources. Do not expose to temperatures exceeding +45° C

Health and Safety

Review all relevant health and safety information before using the product. For complete heath and safety information, refer to Safety Data Sheet.

The information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Graichen Produktions-und Vertriebs GmbH assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information/ recommendations and reserves the right to make any changes to the information and/or recommendations at any time, without prior or subsequent notice.

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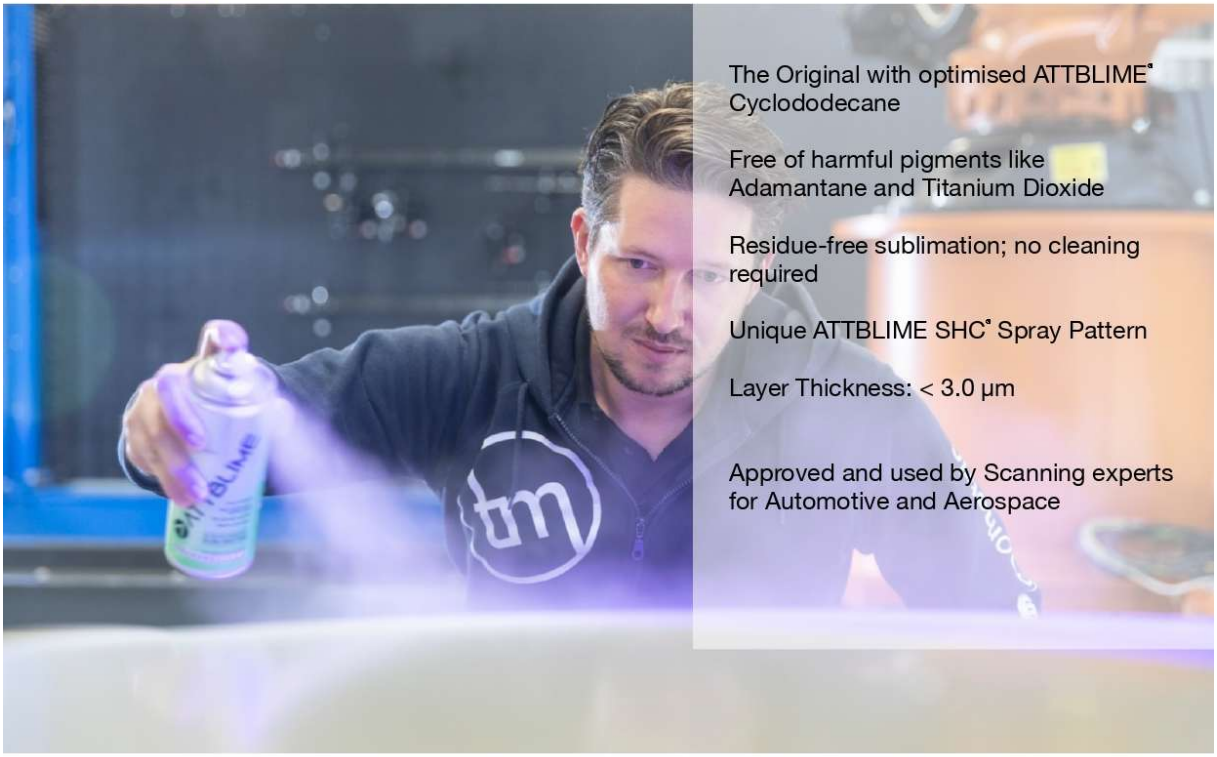
www.attblime.com

Technical sheet 5 Attblime® AB ZERO

ATTBLIME®
HIGH PERFORMACE 3D SCANNING SPRAY
MADE IN GERMANY

AB 2 **Technical DataSheet**



Reflective, dark or shiny surfaces are difficult or sometimes even impossible to capture with optical 3D scanners. To mattify the surfaces to be measured, ATTBLIME® Scanning sprays can be sprayed before scanning which gives an accurate dimensional accuracy. This can be sprayed very thinly and evenly onto the surfaces to be recorded, so that high contrast values are created and even the smallest surface details are recorded.

The sublimating ATTBLIME version AB2 is based on an optimised version of the substance ATTBLIME® Cyclododecane, which has been tried and tested for many years, and is characterised by complete sublimation with a service life of up to 6 hours. The spray applied evaporates without leaving any residue on the component. Subsequent cleaning of the component is not necessary. The even spray pattern has a layer thickness of < 3.0 µm in AB2.

Why ATTBLIME® Cyclododecane ?

ATTBLIME® Cyclododecane is specially treated and modified to create a very thin, homogeneous and a uniform layer that is completely residue-free unlike the other conventional cyclododecane or adamantane based products. Owing to its unique properties, ATTBLIME® Cyclododecane sprays require significantly less "after-spraying" due to its longer service life and thus protecting the environment while also making it significantly cost-economical.

Our key ingredient - Cyclododecane is an organic compound and the most stable representative in its family. It does not bioaccumulate in aquatic organisms and is therefore completely harmless to humans and the environment. It is non-toxic, non-carcinogenic and label free according to GHS "Globally Harmonised System".

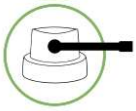
According to SGS Institut Fresenius, no residual Cyclododecane could be detected 24 hours after an application of ATTTBLIME AB2 making the product 100% Residue-free.

ATTBLIME SHC®

The spray cans are equipped with the unique SHC® system (spray-head-change-system), which allows the user to choose between vertical and horizontal, as well as wide and narrow exit angles, to control the film thicknesses and thus sublimation times.

Round spray head
Round spray pattern for high definition details. Shorter sublimation time due to a fine application.

Variable spray head (rotatable)
For a vertical and horizontal spray pattern. Longer sublimation time due to large area application.



Extended Tube spray head (optional)
For hard to reach area and high resolution details

Areas of Application/ Industry

- Automotive
- Aerospace
- Engineering
- Art
- Conservation and Restoration
- Architecture
- Medical
- Digital Archiving
- Optical Metrology
- Research and Development
- Measurement Services
  and many more

PRODUCT CHARACTERISTICS

Form	Transparent Liquid
Basis	Solvent
Propellent (aerosol)	Propane/Butane
Colour	Whitish Gray
Pigment	Pigment-free
Key Ingredient	ATTBLIME® Cyclododecane
Free Scan Time (FST)* hrs	1 - 2 hours
Sublimation Time	2 - 4 hours
Type	Sublimating/ Self-evaporating
Residue	NIL
Film formation	30 seconds
Coating thickness	< 3.0 µm
Application	3D Scanning
Replaces	Conventional Developer Paint Non-evaporating Sprays
Adherence of Reference points on film	Yes
Size of Component	Small to Medium
Surface Compatibility	all types of material**
Toxicology	Irritant
Area Coverage (m2)	2 - 2.5
Spray mechanism	ATTBLIME SHC®
Spray Distance	10-20 cm's
Storage Temperature	5-45 °C
Shelf Life	5 years
Form / Pack Size	400ml Aerosols
Case Size	6 or 12

* FST - Free Scan Time is the actual intact duration that the coated layer stays before sublimation begins.
** Check compatibility on a test patch before use. Not advisable for us on 1K lacquered paints.

Application of ATTBLIME® AB2

Hold the can upright and spray a single even layer from a distance of 10-20 cm's onto the object to be scanned. Scan the object in a usual manner. The layer will disappear with NIL residue.

Storage

Store in well-ventilated area away from heat sources. Do not expose to temperatures exceeding +45° C

Health and Safety

Review all relevant health and safety information before using the product. For complete heath and safety information, refer to Safety Data Sheet.

The information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Graichen Produktions-und Vertriebs GmbH assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information/ recommendations and reserves the right to make any changes to the information and/or recommendations at any time, without prior or subsequent notice.

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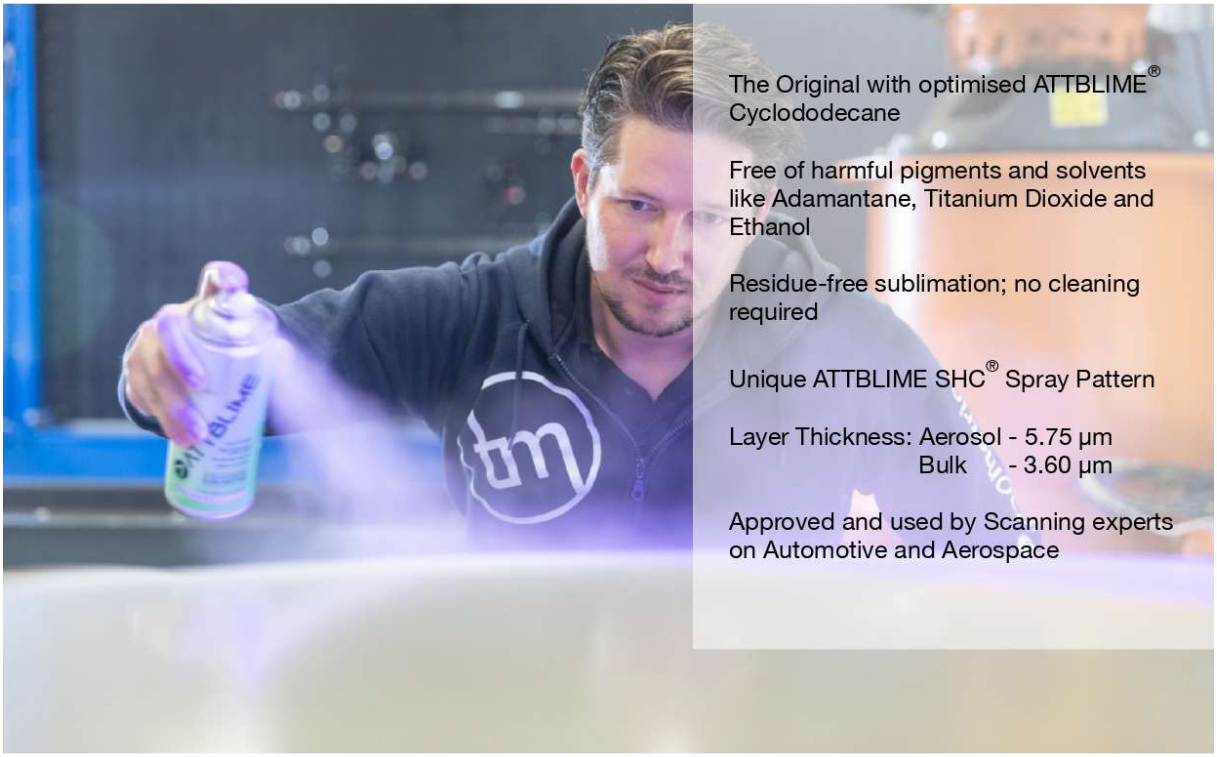
Technical sheet 6 Attblime® AB 2

ATTBLIME®
HIGH PERFORMACE 3D SCANNING SPRAY
MADE IN GERMANY

AB 6 **Technical DataSheet**



Reflective, dark or shiny surfaces are difficult or sometimes even impossible to capture with optical 3D scanners. To mattify the surfaces to be measured, ATTBLIME® AB6 can be sprayed before scanning which gives an accurate dimensional accuracy. This can be sprayed very thinly and evenly onto the surfaces to be recorded, so that high contrast values are created and even the smallest surface details are recorded.

The sublimating ATTBLIME version AB6 are based on an optimised version of the substance ATTBLIME® Cyclododecane, which has been tried and tested for many years, and is characterised by complete sublimation with a service life of up to 6 hours. The spray applied evaporates without leaving any residue on the component. Subsequent cleaning of the component is not necessary. The even spray pattern has a layer thickness of 5.75 µm in AB6 and 3.6 µm in AB6 G.

Why ATTBLIME® Cyclododecane

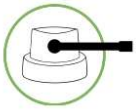
ATTBLIME® Cyclododecane is specially treated and modified to create a very thin, homogeneous and a uniform layer that is completely residue-free unlike the other conventional cyclododecane or adamantane based products. Owing to its unique properties, ATTBLIME® Cyclododecane sprays require significantly less "after-spraying" due to its longer service life and thus protecting the environment while also making it significantly cost-economical.

Our key ingredient - Cyclododecane is an organic compound and the most stable representative in its family. It does not bioaccumulate in aquatic organisms and is therefore completely harmless to humans and the environment. It is non-toxic, non-carcinogenic and label free according to GHS "Globally Harmonised System".

According to SGS Institut Fresenius, no residual Cyclododecane could be detected 24 hours after an application of ATTTBLIME AB6 making the product 100% Residue-free.

Round spray head
Round spray pattern for high definition details. Shorter sublimation time due to a fine application.

Variable spray head (rotatable)
For a vertical and horizontal spray pattern. Longer sublimation time due to large area application.



Extended Tube spray head (optional)
For hard to reach area and high resolution details

PRODUCT CHARACTERISTICS

Form	Transparent Liquid
Basis	Solvent
Propellent (aerosol)	Propane/Butane
Colour	White
Pigment	Pigment-free
Key Ingredient	ATTBLIME® Cyclododecane
Free Scan Time (FST)* hrs	2 - 4 hrs
Type	Sublimating/ Self-evaporating
Residue	NIL
Film formation	Instant
Coating thickness	5.75 microns
Application	3D Scanning
Replaces	Conventional Developer Paint Non-evaporating Sprays
Adherence of Reference points on film	Yes
Size of Component	All types
Surface Compatibility	all types of material**
Toxicology	Irritant
Area Coverage (m2)	3.5 - 4
Spray mechanism	ATTBLIME SHC®
Spray Distance	10-20 cm's
Storage Temperature	5-45 °C
Shelf Life	5 years
Form / Pack Size	400ml Aerosols
Case Size	6 or 12

* FST - Free Scan Time is the actual intact duration that the coated layer stays before sublimation begins.
** Check compatibility on a test patch before use. Not advisable for us on 1K lacquered paints.

Areas of Application/ Industry

- Automotive
- Aerospace
- Engineering
- Art
- Conservation and Restoration
- Architecture
- Medical
- Digital Archiving
- Optical Metrology
- Research and Development
- Measurement Services

Application of ATTBLIME® AB6

Hold the can upright and spray a single even layer from a distance of 10-20 cm's onto the object to be scanned. Scan the object in a usual manner. The layer will disappear with NIL residue.

Storage

Store in well-ventilated area away from heat sources. Do not expose to temperatures exceeding +45° C

Health and Safety

Review all relevant health and safety information before using the product. For complete heath and safety information, refer to Safety Data Sheet.

The information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Graichen Produktions-und Vertriebs GmbH assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information/ recommendations and reserves the right to make any changes to the information and/or recommendations at any time, without prior or subsequent notice.

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Technical sheet 7 Attblime® AB 6

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HIGH PERFORMACE 3D SCANNING SPRAY
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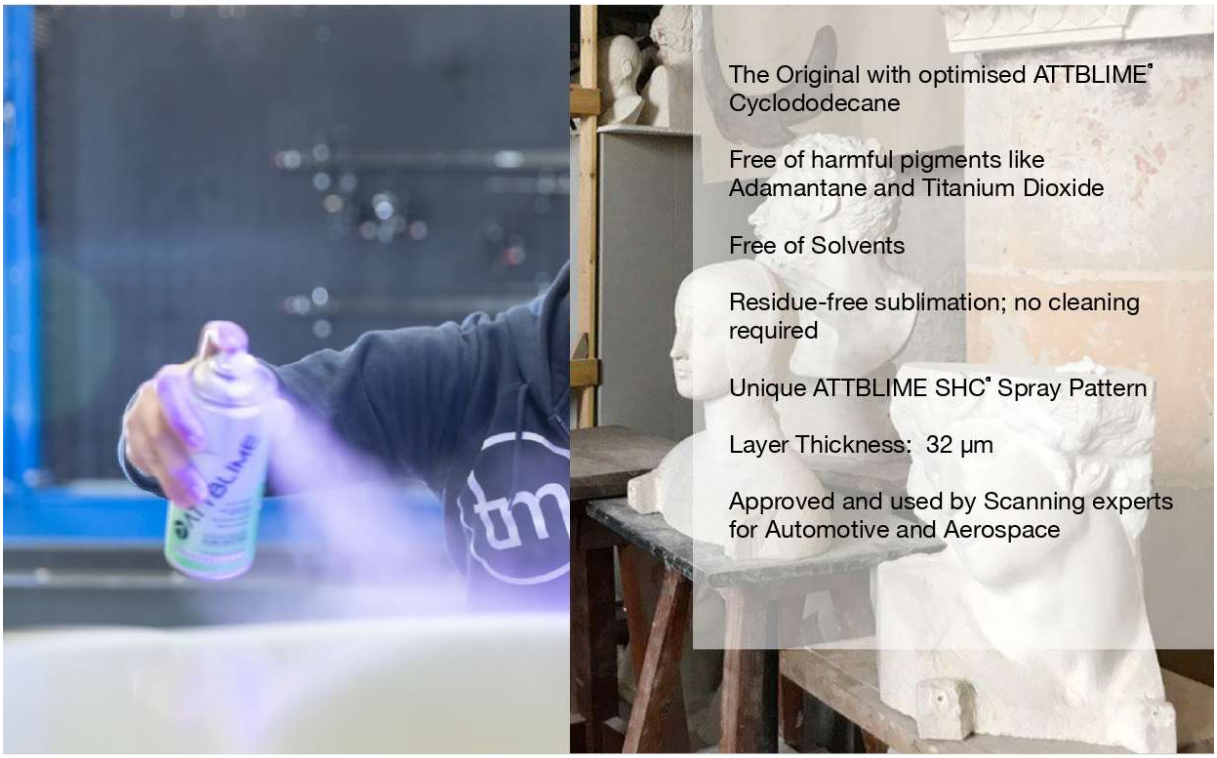
AB 24 **Technical DataSheet**



Reflective, dark or shiny surfaces are difficult or sometimes even impossible to capture with optical 3D scanners. To mattify the surfaces to be measured, ATTBLIME® Scanning sprays can be sprayed before scanning which gives an accurate dimensional accuracy. This can be sprayed very thinly and evenly onto the surfaces to be recorded, so that high contrast values are created and even the smallest surface details are recorded.

The sublimating ATTBLIME version AB24 is based on an optimised version of the substance ATTBLIME® Cyclododecane, which has been tried and tested for many years, and is characterised by complete sublimation with a service life of up to 6 hours. The spray applied evaporates without leaving any residue on the component. Subsequent cleaning of the component is not necessary. The even spray pattern has a layer thickness of < 32 µm in AB24.

Why ATTBLIME® Cyclododecane ?

ATTBLIME® Cyclododecane is specially treated and modified to create a very thin, homogeneous and a uniform layer that is completely residue-free unlike the other conventional cyclododecane or adamantane based products. Owing to its unique properties, ATTBLIME® Cyclododecane sprays require significantly less "after-spraying" due to its longer service life and thus protecting the environment while also making it significantly cost-economical.

Our key ingredient - Cyclododecane is an organic compound and the most stable representative in its family. It does not bioaccumulate in aquatic organisms and is therefore completely harmless to humans and the environment. It is non-toxic, non-carcinogenic and label free according to GHS "Globally Harmonised System".

According to SGS Institut Fresenius, no residual Cyclododecane could be detected 24 hours after an application of ATTTBLIME AB2 making the product 100% Residue-free.

ATTBLIME® AB24 is a preferred choice for experts in the field of Conservation and Restoration, Art and Architecture for applications in museums ans critical applications where artefacts, fossils, other valuable and priceless objects are to be preserved and protected. It acts as a temporary a temporary consolidant for treatment of artworks, including paintings, textiles and stone. Used for temporary consolidation, adhesion, cleaning and protection during transport.

To know more on how ATTBLIME® AB24 or ATTBLIME® Cyclododecane can be used in your application, please write to us.

ATTBLIME SHC®

The spray cans are equipped with the unique SHC® system (spray-head-change-system), which allows the user to choose between vertical and horizontal, as well as wide and narrow exit angles, to control the film thicknesses and thus sublimation times.

Round spray head
Round spray pattern for high definition details. Shorter sublimation time due to a fine application.

Variable spray head (rotatable)
For a vertical and horizontal spray pattern. Longer sublimation time due to large area application.

Areas of Application/ Industry

- Automotive
- Aerospace
- Engineering
- Art
- Conservation and Restoration
- Architecture
- Medical
- Digital Archiving
- Optical Metrology
- Research and Development
- Measurement Services
  and many more

PRODUCT CHARACTERISTICS

Form	Transparent Liquid
Basis	Solvent-free
Propellent (aerosol)	Propane/Butane
Colour	White
Pigment	Pigment-free
Key Ingredient	ATTBLIME® Cyclododecane
Free Scan Time (FST)* hrs	12 - 24 hours
Sublimation Time	24 - 48 hours
Type	Sublimating/ Self-evaporating
Residue	NIL
Film formation	Instant
Coating thickness	32 µm
Application	3D Scanning Art and Conservation
Replaces	Conventional Developer Paint Non-evaporating Sprays
Adherence of Reference points on film	Yes
Size of Component	Small to Large
Surface Compatibility	all types of material**
Toxicology	Non-Toxic
Area Coverage (m2)	3 - 3.5
Spray mechanism	ATTBLIME SHC®
Spray Distance	5 - 10 cm's
Storage Temperature	5-45 °C
Shelf Life	5 years
Form / Pack Size	400ml Aerosols
Case Size	6 or 12

* FST - Free Scan Time is the actual intact duration that the coated layer stays before sublimation begins.
** Check compatibility on a test patch before use. Not advisable for us on 1K lacquered paints.

Application of ATTBLIME® AB24

Hold the can upright and spray a single even layer from a distance of 5-10 cm's onto the object to be scanned. Scan the object in a usual manner. The layer will disappear with NIL residue.

Storage

Store in well-ventilated area away from heat sources. Do not expose to temperatures exceeding +45° C

Health and Safety

Review all relevant health and safety information before using the product. For complete heath and safety information, refer to Safety Data Sheet.

The information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Graichen Produktions-und Vertriebs GmbH assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information/ recommendations and reserves the right to make any changes to the information and/or recommendations at any time, without prior or subsequent notice.

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ATTBLIME
HIGH PERFORMACE 3D SCANNING SPRAY
MADE IN GERMANY

ABP **Technical DataSheet**

- ✓ Based on Renewable Raw Material
- ✓ Free of Harmful pigments like Adamantane, Titanium Di Oxide and Talc
- ✓ New Co-operative Gray Colour
- ✓ Easy to remove post Scanning
- ✓ Unique ATTBLIME SHC® spray system
- ✓ Available in container form for bulk application (ATTBLIME ABP G)
- ✓ Approved and used by scanning experts and customers

Reflective, dark or shiny surfaces are difficult or sometimes even impossible to capture with optical 3D scanners. To mattify the surfaces to be measured, ATTBLIME® ABP can be sprayed before scanning which gives an accurate dimensional accuracy. This can be sprayed very thinly and evenly onto the surfaces to be recorded, so that high contrast values are created and even the smallest surface details are recorded. The even spray pattern has a layer thickness of 7 µm in ABP and 3.95 µm in ABP G.

Compared to currently available products, ATTBLIME® comes with a newly developed colour called "New Co-operative Gray" and is equipped with our signature spray pattern.

ATTBLIME SHC®

The spray cans are equipped with the unique SHC® system (spray-head-change-system), which allows the user to choose between vertical and horizontal, as well as wide and narrow exit angles, to control the film thicknesses and thus sublimation times.

Round spray head
Round spray pattern for high definition details. Shorter sublimation time due to a fine application.

Variable spray head (rotatable)
For a vertical and horizontal spray pattern. Longer sublimation time due to large area application.

Application of ATTBLIME® ABP

Hold the can upright and spray a single even layer from a distance of 15-25 cm's onto the object to be scanned. Scan the object in a usual manner.

Storage

Store in well-ventilated area away from heat sources. Do not expose to temperatures exceeding +45° C

Health and Safety

Review all relevant health and safety information before using the product. For complete heath and safety information, refer to Safety Data Sheet.

PRODUCT CHARACTERISTICS

Form	Transparent Liquid
Propellent (aerosol)	Propane/Butane
Colour	New Co-operative Gray
Pigment	Food Grade Pigment
Type	Non Sublimating
Residue	Gray powder film
Film formation	15 seconds
Coating thickness	7 microns (ABP) 3.95 microns (ABP G)
Application	3D Scanning
Replaces	Conventional Developer Paint Non-evaporating Sprays
Adherence of Reference points on film	Yes
Size of Component	All types
Surface Compatibility	all types of material**
Toxicology	Irritant
Area Coverage (m2)	3 - 3.5 (ABP) 14 - 16/L (ABP G)
Spray mechanism	ATTBLIME SHC®
Spray Distance	15 - 25 cm's
Storage Temperature	5-45 °C
Shelf Life	5 years
Form / Pack Size	400ml (AB P) 1, 10, 200L (ABP G)
Case Size	6 or 12 (ABP)

The information and any recommendations, technical or otherwise, are presented in good faith and believed to be correct as of the date prepared. Recipients of this information and recommendations must make their own determination as to its suitability for their purposes. In no event shall Graichen Produktions-und Vertriebs GmbH assume liability for damages or losses of any kind or nature that result from the use of or reliance upon this information/ recommendations and reserves the right to make any changes to the information and/or recommendations at any time, without prior or subsequent notice.

* FST - Free Scan Time is the actual intact duration that the coated layer stays before sublimation begins.
** Check compatibility on a test patch before use. Not advisable for us on 1K lacquered paints.

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Technical sheet 9 Attblime® AB P

6 Documents

Permanent Exhibits:

- The first Monday of every month – CHH Dusting and Walkthrough (to check on artifact condition and placement misalignments)
- The first Thursday of every month – GH totem pole bases (dusting and checking for flakes and food/drink) – this is also done when I'm aware of an event passing no matter the time of month; except no dusting on Rebecca's requested areas.
  - Every 6 months I clean the House screen plinths and canoe area at the end of the houses.
  - When food/drink or fragments are found, they are documented – the food and drink are cleaned up, and fragments are kept and placed in a binder I have on my cart. For both of these, I also fill out the Incident report log found Here (**Incident Reporting Log – Template**)
- The second Monday of every month – FPH (this gets complicated, you will see in the schedule what areas I have assigned for each month – they are coloured/highlighted with a slightly deeper faint colour – it's a gallery that a schedule is still developing (you may notice as you look through the monthly tabs); except no dusting for Rebecca's requested area
- The second Thursday of every month – Salon areas (Nishga Girl, Four Seasons, and David Stewart Salon); except the IRS Monument and Rebecca's requested areas
  - For incidents I have document similarly to what I do with GH, except paintings – Amanda Gould has requested I report the incidents in KE under events (I'm still unfamiliar with this way, but I will be starting to determine what needs to be reported this way or not)
- For the IRL Monument in the Four Seasons Salon, I dust and wipe away handprints weekly on Wednesday – I have been asked to do this instead of facilities (because it is a hands allowed monument) in case someone left an offering; I recently made this day the day I visually monitor for dust for Rebecca as well (**WeeklyGalleryDustMonitoring** excel)

The areas that are done every 6 months will be coloured/highlighted a slightly deeper faint colour the months they need to be done (similar to what I do for FPH on the excel sheets)

Temporary Exhibits:

Depends on what is requested by our conservator team and the lending institution if an exhibit is travelling or we have loans within the exhibit. Right now, for music I dust the open display cases the first Tuesday of every month and the gallery walkthrough every Tuesday of the week.

Hope this helps. If you have any questions, let me know. I'll do my best to answer.

Meagan

Document 1 Communication 11.07.25, Meagan Barnhart (CMH, conservation technician) on maintenance work.

Chemical Category	C_7-C_9 Aliphatic Hydrocarbon Solvents Category	
Chemical Names and CAS Registry Numbers	**Substance Name**	**CAS Number**
	n-Paraffins Subcategory	
	n-Heptane	142-82-5
	n-Octane	111-65-9
	n-Nonane	111-84-2
	Iso-Paraffins Subcategory	
	Pentane, 2,2,4-trimethyl-	540-84-1
	Alkanes, C_{7-8}, iso-	70024-92-9
	Alkanes, C_{7-10}, iso-	90622-56-3
	Multi-Constituent Subcategory	
	Ligroine; petroleum ether	8032-32-4
	Naphtha, (petroleum), light catalytic reformed	64741-63-5
	Naphtha, (petroleum), solvent-refined light	64741-84-0
	Naphtha, (petroleum), hydrotreated heavy	64742-48-9
	Naphtha, (petroleum), hydrotreated light	64742-49-0
	Solvent naphtha, (petroleum), light aliphatic	64742-89-8
	Naphtha (petroleum), hydrodesulfurized light, dearomatized	92045-53-9

Document 2 C7-C9 solvents

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Health Canada Santé Canada

Health Canada
Regulatory Operations and Enforcement Branch
Pesticide Compliance Program
960 Carling Avenue
Building 22, Central Experimental Farm
Ottawa, ON, K1A 0C6

15 June 2023 Case ID: 22-QC-CV-4185

Jessica Lafrance Hwang, Manager of Conservation and Preservation
Canadian Museum of History
100 Laurier Street
Gatineau, QC, K1A 0M8

Sent via e-mail to: jessica.lafrance-hwang@museedelhistoire.ca

RE: Follow-up from Health Canada inspection, 13 Mar 2023

Dear Jessica Lafrance Hwang,

This letter is in follow-up to the inspection conducted by Inspectors Mark Hornsby and David Quesnel on 13 March 2023 of the Canadian Museum of History, 100 Laurier Street, Gatineau QC, K1A 0M8. Health Canada administers the *Pest Control Products Act* (PCPA) and its Regulations. The main objective of the PCPA and its Regulations is to protect human health and the environment, and to prevent unacceptable risks by regulating products used for the control of pests.

Health Canada's Pesticide Compliance Program conducted its inspection on 13 March 2023 as a follow-up to information received about the Canadian Museum of History's use of carbon dioxide (CO_2) as a pesticide; specifically, to fumigate various museum artifacts within a fumigation chamber. The inspection confirmed that the Canadian Museum of History was using CO_2 as a fumigant pesticide within a fumigation chamber, primarily as a preventative treatment rather than targeting specific insect pests. Subsequent follow-up with other regulated parties has confirmed that the Canadian Museum of History has been using and storing an unregistered source of CO_2.

This is a contravention of the PCPA: The use, and the storage, of unregistered pest control products are prohibited activities under PCPA 6(1):

> *No person shall manufacture, possess, handle, store, transport, import, distribute or use a pest control product that is not registered under this Act, except as otherwise authorized under subsection 21(5) or 41(1), section 48 or 51, any of sections 53 to 59 or the regulations*

As discussed during the 13 March 2023 inspection, please also note that the sole Canadian registered CO_2 fumigant pesticide in Canada, CARBON DIOXIDE FUMIGANT (Registration Number 20088), does not include several elements on its label as they relate to the Canadian Museum of History's use of CO_2. Specifically: the application method, the use site, the targeted pests, and the commodities to be fumigated are all inconsistent with the approved label for CARBON DIOXIDE FUMIGANT (Registration Number 20088) and would constitute a contravention under PCPA 6(5)(b):

> *No person shall handle, store, transport, use or dispose of a pest control product in a way that is*

Canada

Health Canada Santé Canada

inconsistent with… the directions on the label recorded in the Register, subject to the regulations

Furthermore, please also note that the approved label for CARBON DIOXIDE FUMIGANT (Registration Number 20088) requires that applicators be licensed and/or certified by the provincial/territorial pesticide agency where the application occurs. I will reiterate here the previous advice I had sent to the Canadian Museum of History on 09 March 2023: in Quebec, the appropriate agency to contact is Quebec's Ministère de l'Environnement et de la Lutte contre les changements climatiques, de la Faune, et des Parcs (QC-MELCCFP) – additional information may be found here.

Next Steps
Health Canada's Pesticide Compliance Program has discussed this issue with Health Canada's Pest Management Regulatory Agency (PMRA). The PMRA is responsible for the scientific review of all pest control products in Canada; the PMRA administers all registration and label amendment submissions as they relate to pest control products in Canada.

As you are aware, in Canada there is currently only a single registered pest control product for carbon dioxide: CARBON DIOXIDE FUMIGANT (Registration Number 20088). Health Canada's Pesticide Compliance Program encourages the Canadian Museum of History to work with the registrant of CARBON DIOIXDE FUMIGANT (Registration Number 20088), Linde Canada Inc., to expand its label to include the use of fumigating museum artifacts.

The Canadian Museum of History is also encouraged to contact the PMRA to discuss alternate regulatory pathways that may be available and which may allow CO_2 to be used to fumigate museum artifacts within a fumigation chamber prior to the completion of a formal label expansion submission.

Thank you for your attention to this matter. Please do not hesitate to contact me should you have any questions.

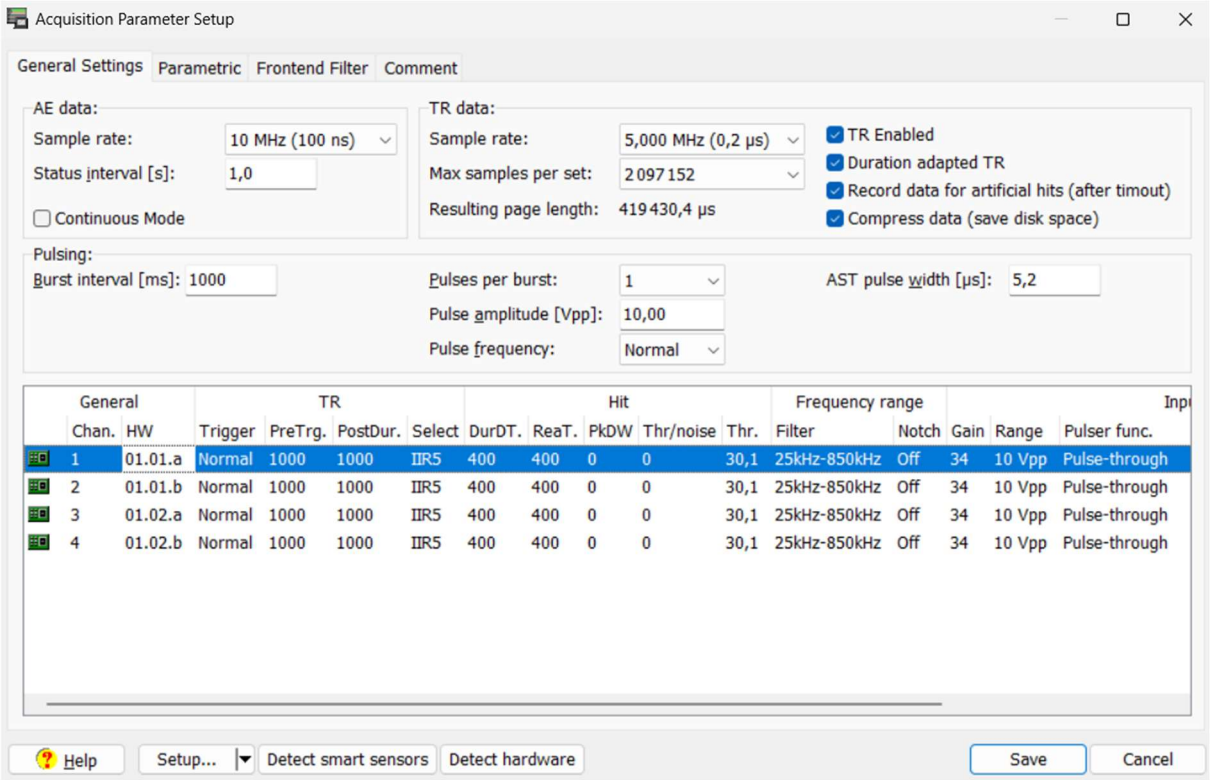
Sincerely,

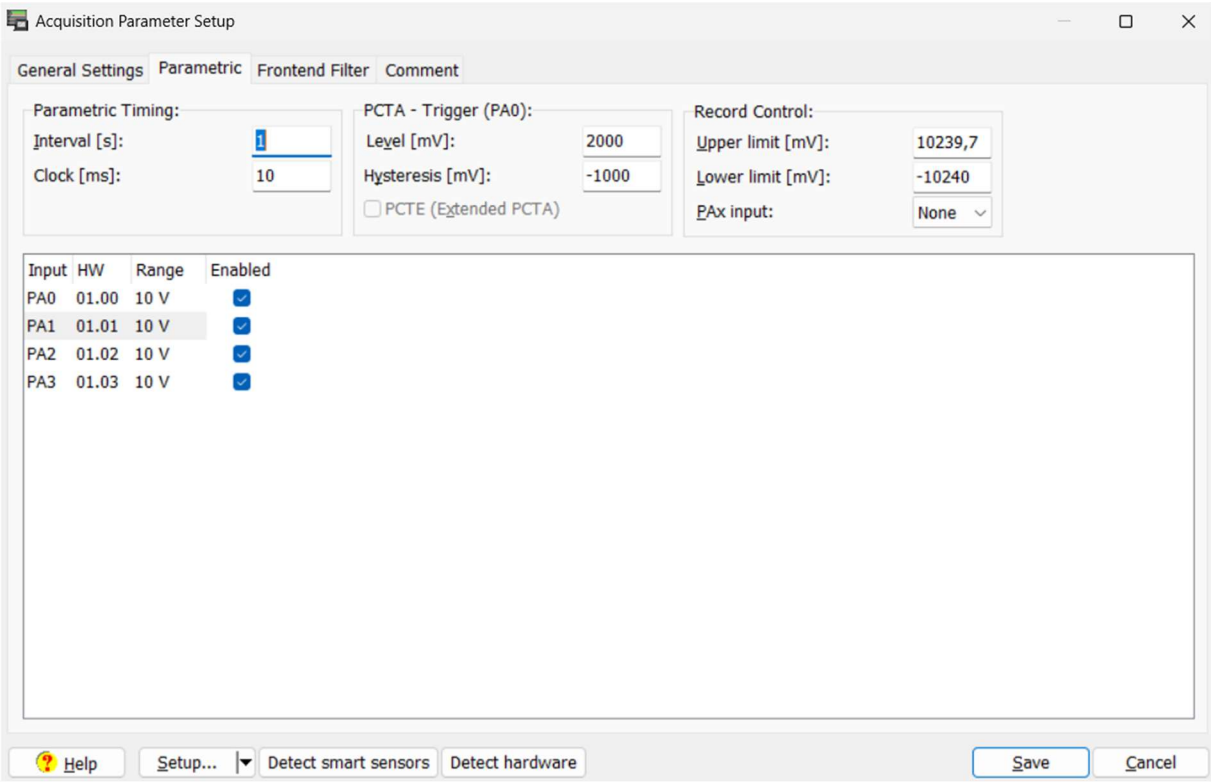
Hornsby, Mark
2023.06.15
13:25:00-04'00'

Mark Hornsby
Pesticide Compliance and Enforcement Officer, Pesticide Compliance Program
Regulatory Operations and Enforcement Branch
Health Canada / Government of Canada
Tel: 343-574-5027 / mark.hornsby@hc-sc.gc.ca

Canada

Document 3, Prohibition of CO2 treatment letter


Acquisition Parameter Setup
General Settings
Parametric
Frontend Filter
Comment
AE data:
Sample rate: 10 MHz (100 ns)
Status interval [s]: 1,0
Continuous Mode
TR data:
Sample rate: 5,000 MHz (0,2 µs)
Max samples per set: 2 097 152
Resulting page length: 419 430,4 µs
TR Enabled
Duration adapted TR
Record data for artificial hits (after timout)
Compress data (save disk space)
Pulsing:
Burst interval [ms]: 1000
Pulses per burst: 1
Pulse amplitude [Vpp]: 10,00
Pulse frequency: Normal
AST pulse width [µs]: 5,2
General
TR
Hit
Frequency range
Chan. HW Trigger PreTrg. PostDur. Select DurDT. ReaT. PkDW Thr/noise Thr. Filter Notch Gain Range Pulser func.
1 01.01.a Normal 1000 1000 IIR5 400 400 0 0 30,1 25kHz-850kHz Off 34 10 Vpp Pulse-through
2 01.01.b Normal 1000 1000 IIR5 400 400 0 0 30,1 25kHz-850kHz Off 34 10 Vpp Pulse-through
3 01.02.a Normal 1000 1000 IIR5 400 400 0 0 30,1 25kHz-850kHz Off 34 10 Vpp Pulse-through
4 01.02.b Normal 1000 1000 IIR5 400 400 0 0 30,1 25kHz-850kHz Off 34 10 Vpp Pulse-through
Help
Setup...
Detect smart sensors
Detect hardware
Save
Cancel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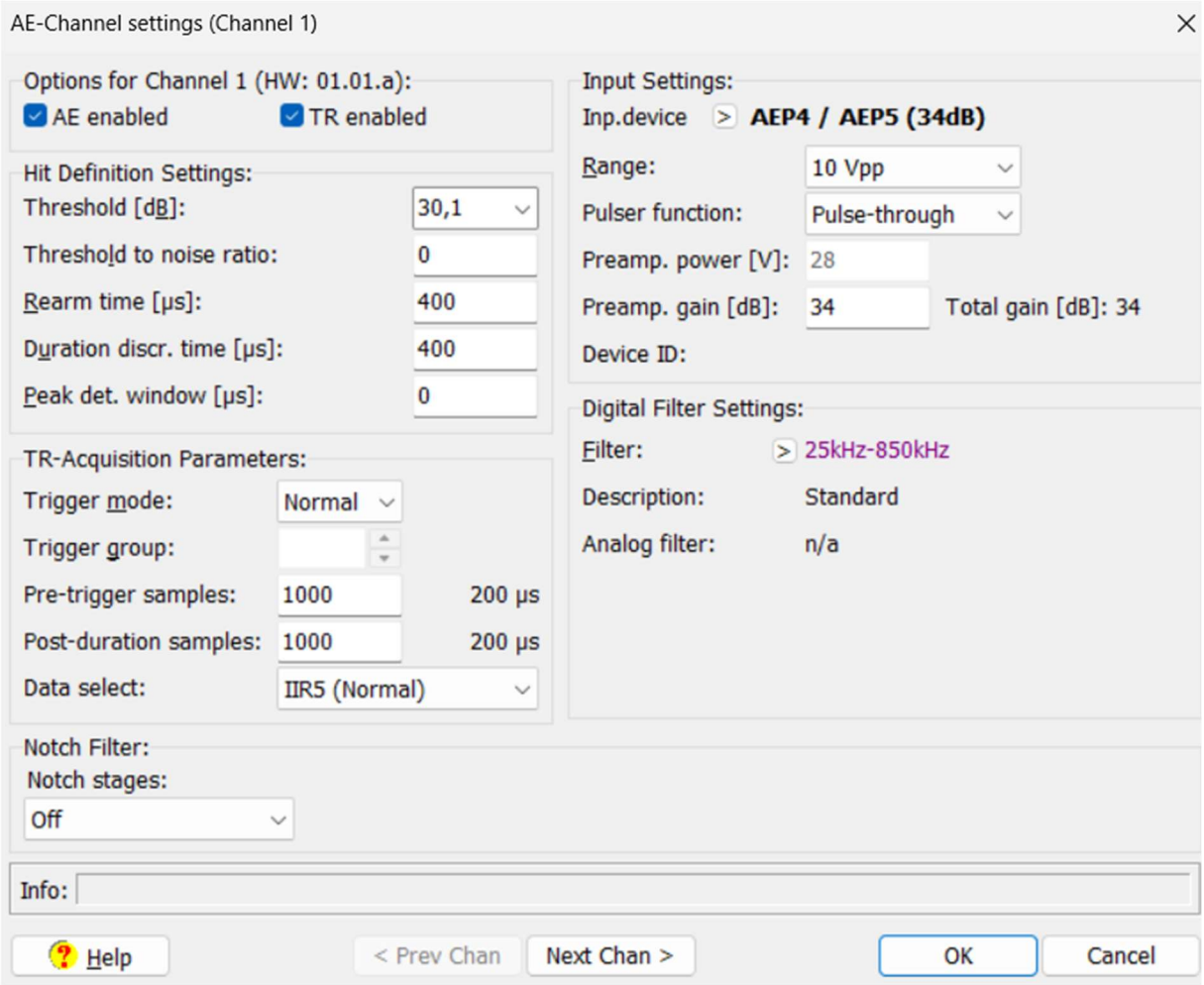
General Settings
Parametric
Frontend Filter
Comment
Parametric Timing:
Interval [s]: 1
Clock [ms]: 10
PCTA - Trigger (PA0):
Level [mV]: 2000
Hysteresis [mV]: -1000
PCTE (Extended PCTA)
Record Control:
Upper limit [mV]: 10239,7
Lower limit [mV]: -10240
PAx input: None
Input HW Range Enabled
PA0 01.00 10 V
PA1 01.01 10 V
PA2 01.02 10 V
PA3 01.03 10 V
Help
Setup...
Detect smart sensors
Detect hardware
Save
Cancel



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