

### Introduction

The investigation, conservation, and restoration of cultural heritage objects require non-invasive diagnostic tools capable of revealing internal structures without compromising the physical integrity of artworks. Many historical artefacts are inherently complex, composed of heterogeneous and multilayered assemblies that combine organic and inorganic materials. The interfaces between these layers may evolve over time due to ageing, environmental conditions, or previous restoration interventions.

Millimetric imaging technologies operating in the 60–300 GHz frequency range provide a relevant and physically safe approach to address these challenges. Based on low-energy, non-ionizing electromagnetic waves, millimetric measurements enable fully contactless investigations while remaining sensitive to dielectric contrasts between materials. This sensitivity allows access to internal interfaces, layer discontinuities, detachments, and material heterogeneities that are not accessible through visual inspection alone. In this context, millimetric imaging constitutes a complementary diagnostic technique alongside established conservation tools such as infrared reflectography, X-ray radiography, and optical multispectral imaging.

Optikan develops laboratory imaging platforms based on high frequency millimetric radar technology, initially designed for advanced material characterization and non-destructive testing. When applied to cultural heritage studies, these platforms offer controlled and repeatable measurements with adaptable configurations in terms of operating frequency, focusing conditions, and scanning geometry. This flexibility allows the technique to be tailored to the specific constraints of museum environments and conservation laboratories, where non-contact operation and interpretative caution are essential.

### uSense



uSense is an all-in-one raster-scan millimeter 3D imaging system designed specifically for scientific applications. It offers unique features and remarkable performance, enabling volumetric control of the structural integrity of any dielectric object.

Highly versatile, uSense can be adapted to numerous studies: detection of cracks, delamination, metallic or wet foreign bodies, extraction of permittivity, optical indices, and even provide density information.

### Case study #1 - Renaissance Parade Shield

The artefact investigated is a Renaissance parade shield (rondache d'apparat), a type of ceremonial defensive object produced in Europe during the 16th century. The piece is round and is most likely of Italian manufacture—possibly Venetian—or German, dated to approximately 1550–1570. Parade shields of this kind were not intended for combat use but rather for display, courtly representation, or ceremonial contexts, which allowed for particularly elaborate decorative treatments.

The object is composed of a wooden support forming the structural core of the shield. This support is covered with an organic layer made of “cuir bouilli” (hardened leather) or animal skin (vellum-type), onto which a black lacquered surface decoration was applied. The decoration is enriched with gold-leaf ornamental motifs, including a heraldic escutcheon framed by lambrequins, now partially erased. This



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combination of materials results in a highly stratified structure, typical of Renaissance parade arms, where mechanical support, organic interfaces, and decorative layers coexist.

From an art-historical standpoint, the studied shield can be closely related to several comparable examples preserved in major European museum collections. A particularly similar shield, decorated on both its interior and exterior surfaces, is held in the collections of the Ashmolean Museum (University of Oxford, inventory AN1685.B.13). Additional comparable parade shields are preserved at the State Hermitage Museum and at the Wallace Collection. These objects share analogous construction principles, material compositions, and decorative vocabularies, situating the present rondache within a well-defined corpus of Renaissance ceremonial shields.

From a conservation and diagnostic perspective, such artefacts present several challenges: assessing the integrity of the wooden core, evaluating the adhesion between wood and leather layers, and identifying potential internal detachments, voids, or material heterogeneities beneath the decorated surface. These aspects are difficult to access using surface-based inspection alone. The following sections describe how millimetric imaging was applied to this rondache to investigate its internal structure while fully respecting the non-destructive and non-contact requirements of cultural heritage conservation.



Figure - Parade Shield in the uSense station

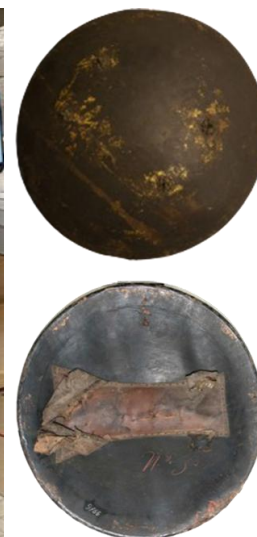


Figure - Top and Bottom View

### Frequency-Dependent Observations

The following sections present a selection of representative millimetric images acquired at the different operating frequencies, illustrating how the interaction between electromagnetic waves and the material of the shield varies across the millimetric spectrum.

In the present case, 120 GHz was found to provide the most suitable operating frequency, offering the best compromise between spatial resolution and penetration depth within the artefact. Measurements performed at 60 GHz produced images closely comparable to those obtained at 120 GHz, while exhibiting a naturally reduced spatial resolution, approximately two times lower, as expected from the longer wavelength.

Measurements at 240 GHz revealed features that are not directly associated with the internal wooden structure. These features are likely related to remnants of gold ornaments concealed beneath the black lacquer layer, or to geometric imprints left by these decorative elements within the surface layers. This



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frequency thus appears particularly sensitive to near-surface decorative structures rather than to the deeper wooden assembly.

By contrast, measurements conducted at 300 GHz did not reveal any specific or exploitable features. At this frequency, the electromagnetic waves were strongly absorbed by the surface layers of the artefact, preventing sufficient penetration to generate usable internal contrast.

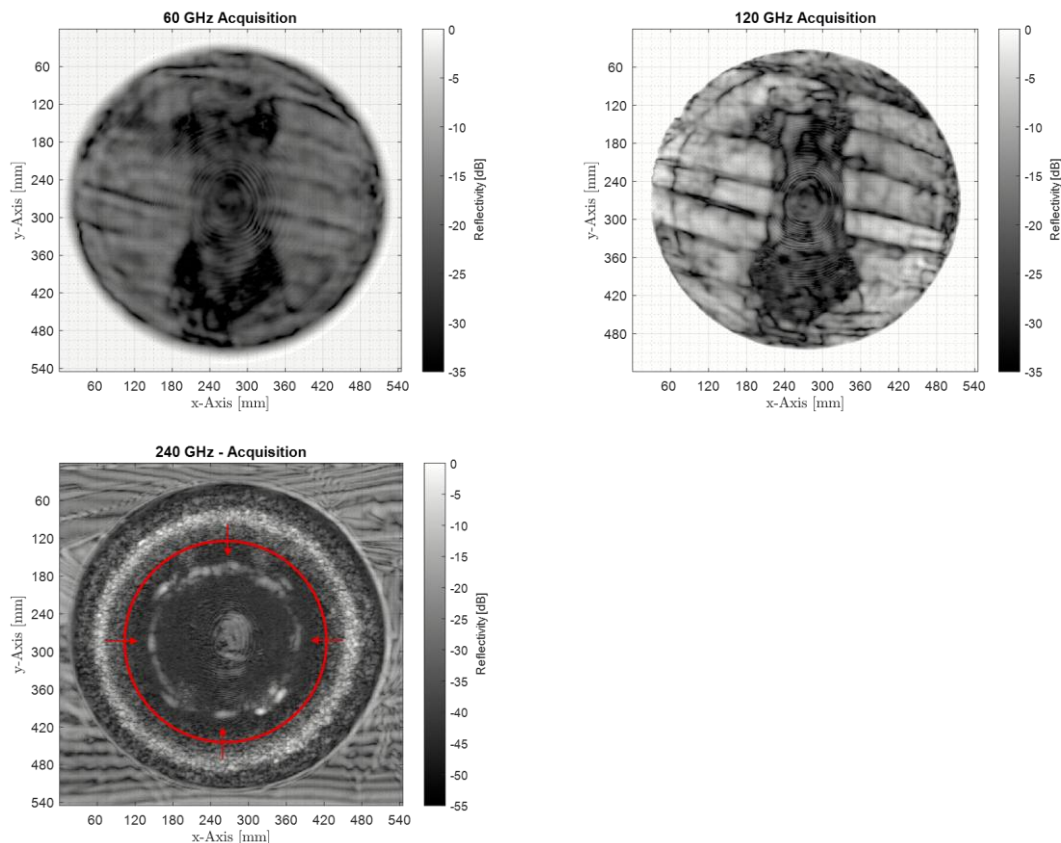


Figure - 60, 120 and 240 GHz Images

## Case study #2 - Painting on Canvas

The second case study focuses on a painting on canvas, a class of artworks that frequently undergo complex conservation histories involving structural interventions. In this case, historical and conservation evidence suggests that the original canvas may have been detached from its initial wooden support and subsequently adhered to a new backing structure, a process commonly referred to as relining or re-adhering.

Such interventions, while often necessary for long-term preservation, can significantly alter the internal structure of the artwork. Adhesive layers, interface discontinuities, or residual features from the original support may remain embedded within the canvas assembly, yet remain difficult to detect using surface-based inspection techniques alone. Identifying these features is essential for understanding the conservation history of the painting and for informing future restoration decisions.



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Millimetric imaging offers a complementary approach for the investigation of paintings on canvas by providing access to internal contrasts related to material interfaces and structural heterogeneities. By probing the artwork with a different form of non-ionizing electromagnetic energy than those typically used in optical or infrared diagnostics, this technique enables the exploration of internal features that may not have been observed previously.

In this case study, millimetric measurements were performed with the objective of identifying indications of a potential relining operation, as well as exploring the painting's internal structure using alternative probing energy. The following sections present the measurement configuration and the main observations obtained from this investigation.

### Frequency-Dependent Observations

The frequency-dependent analysis underlines the interest of exploiting multiple millimetric frequencies to access complementary information within the artwork, even though not all available bands were required in this specific case.

For this painting, the 60 GHz configuration was not used, as the limited thickness and planar geometry of the canvas did not justify the use of lower frequencies with reduced spatial resolution. The analysis therefore focused on higher millimetric frequencies, which are better suited for resolving fine stratigraphic features within thin layered structures.

From acquisitions performed on limited regions of interest, the system demonstrated its ability to discriminate successive internal layers in depth that are not visible in conventional optical images restricted to surface information. These internal strata appear as distinct interfaces within the canvas assembly, revealing a layered structure that cannot be inferred from visual inspection alone.



Figure - Painting



Figure - 240 GHz Image on ROI

The presence of such stratification constitutes a potential indicator of a relining or re-adhering operation, as additional adhesive or interface layers are typically introduced during such conservation treatments. While millimetric imaging alone does not allow definitive material identification, the observed layered structure provides structural evidence that may support conservation hypotheses when interpreted alongside historical documentation and complementary diagnostic techniques.



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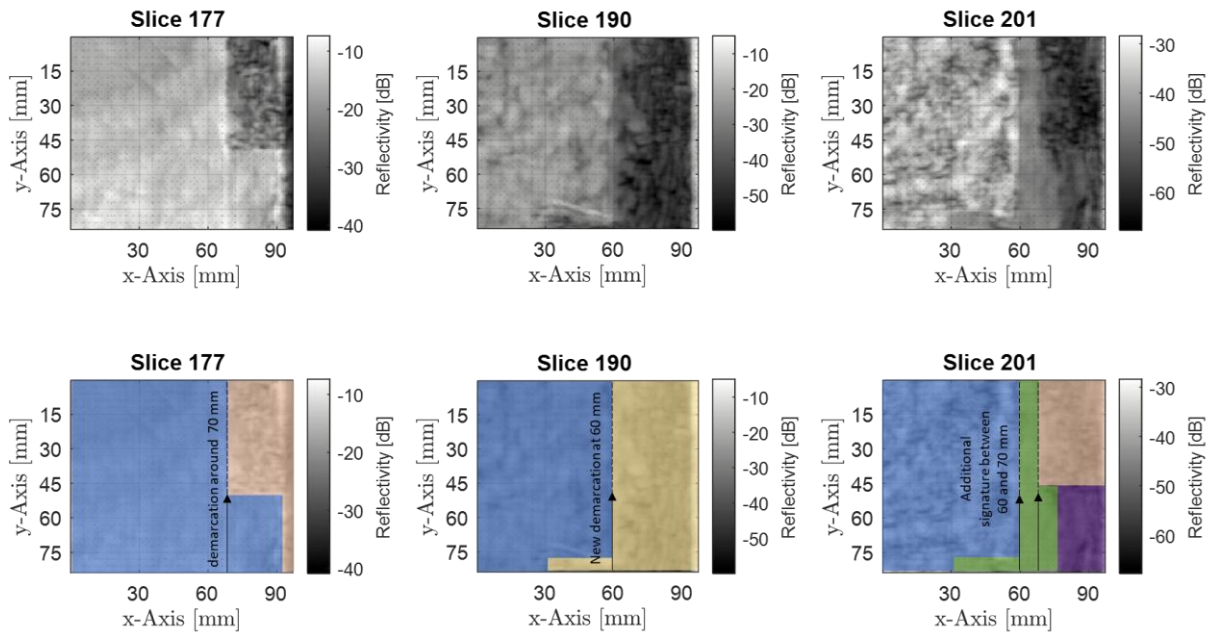


Figure – Stratification Highlights

Extended acquisitions performed over the entire canvas revealed localized demarcations with increased absorption, particularly in areas where the original wooden frame is no longer present but remains in close proximity to former contact zones. These features indicate localized material or structural heterogeneities within the canvas assembly. While their exact nature cannot be unambiguously identified based on millimetric imaging alone, such demarcations may be consistent with residual adhesive layers or interface modifications associated with past conservation interventions.

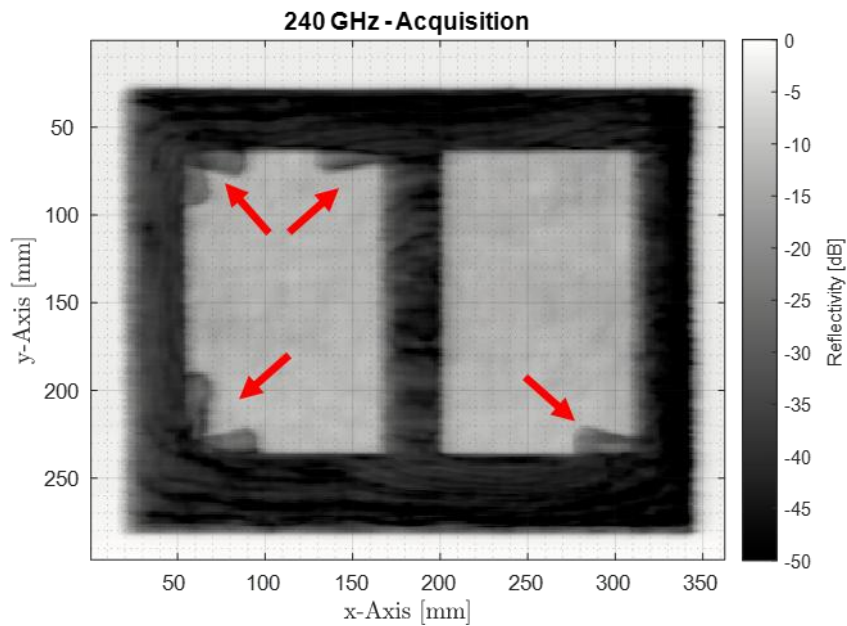


Figure - Area with Increased Absorption



## Case study #3 - Lacquered Wooden Marquetry with Painted Design

The third case study concerns a lacquered wooden marquetry object with a painted decorative design. Such artefacts are typically characterized by complex surface treatments and layered decorative finishes, which can significantly limit the penetration of electromagnetic waves and complicate internal inspection.

In this case, the primary objective was to assess whether millimetric imaging could provide insight into the internal construction of the wooden support, despite the presence of lacquer and painted surface layers.



Figure - Wooden Marquetry

Measurements were performed using several millimetric frequencies. Due to the strong attenuation introduced by the surface layers, no exploitable signal was obtained at the higher frequencies. Only the 60 GHz configuration provided sufficient penetration to probe the internal structure of the object. A focusing lens with a 50 mm focal length was used in order to maximize lateral resolution under these conditions.

The 60 GHz acquisitions revealed that the artefact was not manufactured from a single wooden block, but rather assembled from multiple wooden elements joined together. These internal boundaries were not visible through surface inspection and could only be identified through millimetric imaging.

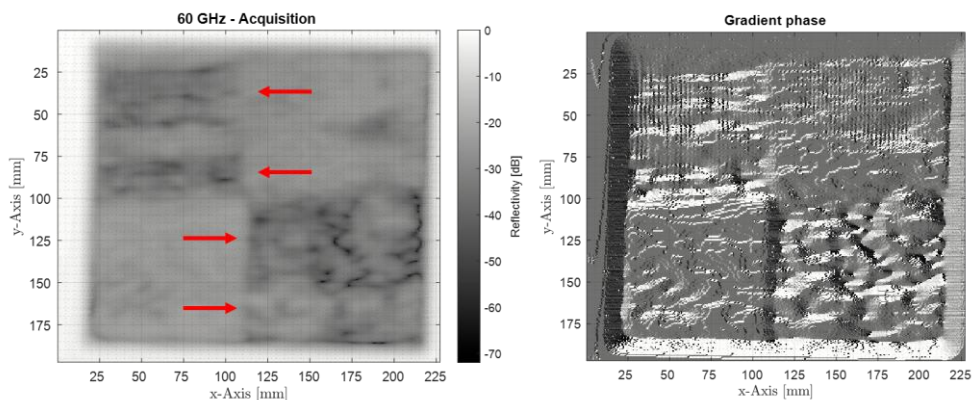


Figure - Identification of Different Wood Blocks



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Although this investigation was intentionally limited in scope, it demonstrates the ability of Optikan's imaging to access internal structural information in highly attenuating, decorated wooden objects. This case further illustrates the interest of adapting both frequency and optical configuration to the specific material composition and thickness of cultural heritage artefacts.

For more information, please contact Optikan at: [contact@optikan.com](mailto:contact@optikan.com).

