

Introduction

Composite materials and bonded assemblies are widely used in industrial applications, where structural integrity strongly depends on the quality of internal interfaces and adhesive bonds. Detecting bonding defects, adhesive thickness variations, voids, or low-density foreign objects remains challenging for conventional non-destructive testing techniques, particularly in heterogeneous or multilayer composite structures.

Millimetric imaging, operating in the 60–300 GHz frequency range, provides a contactless and non-ionizing approach that is sensitive to dielectric contrasts within composite stacks. This makes it well suited for the investigation of adhesive interfaces, internal heterogeneities, and bonding-related defects. Adaptable in terms of frequency and focusing configuration, millimetric imaging can be applied as a complementary diagnostic tool during feasibility studies, process validation, and pre-industrial inspection of composite and bonded structures.

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 – Aramid-based Composite with Foreign Objects

This first use case focuses on an aramid-based composite component, representative of high-performance fibrous composites commonly used in industrial applications. Aramid fibers are organic polymer fibers known for their high tensile strength, low density, and impact resistance. In composite structures, these fibers are embedded in a polymer matrix, resulting in a heterogeneous and anisotropic material.

The investigated part has a total thickness slightly below 1 cm and contains several foreign objects of different natures intentionally embedded within the composite. The objective of this study was to detect these foreign objects, determine their relative depth, and assess their material nature based on their interaction with millimetric radiation.

Measurements were performed using millimetric radar heads operating at 120 GHz and 300 GHz.

At both 120 GHz and 300 GHz, the presence of two foreign objects located on the left-hand side of the imaged area was clearly detected. These objects exhibit a strong reflective response and were identified as metallic inclusions, reflecting the incident electromagnetic radiation.



Applicative Note – Composites and Bonded Structures

At 300 GHz, the acquisitions additionally reveal the fibrous structure of the composite, which is not resolved at 120 GHz. This behavior is attributed to the shorter wavelength at 300 GHz, providing higher spatial resolution and increased sensitivity to fine structural features.

Conversely, at 120 GHz, additional foreign objects were detected that do not appear in the 300 GHz images. These three inclusions are of polymeric nature and are located beneath the metallic objects within the composite thickness. Their absence at 300 GHz is explained by the reduced penetration depth at higher frequency, which limits access to deeper layers when strong reflectors are present upstream.

The distinction between metallic and polymeric foreign objects can be achieved by analyzing the signal intensity originating from regions located beyond the inclusion. Metallic objects reflect nearly all of the incident radiation, resulting in no detectable signal from deeper regions. In contrast, polymeric inclusions partially transmit the incident radiation, allowing a fraction of the signal to propagate through the object and return to the sensor. This difference in signal behavior provides a practical criterion for foreign object discrimination using millimetric imaging.

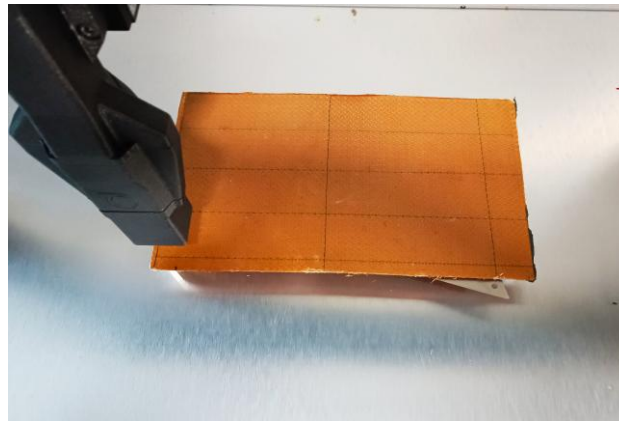


Figure – Aramid-based Composite Sensed with the uSense

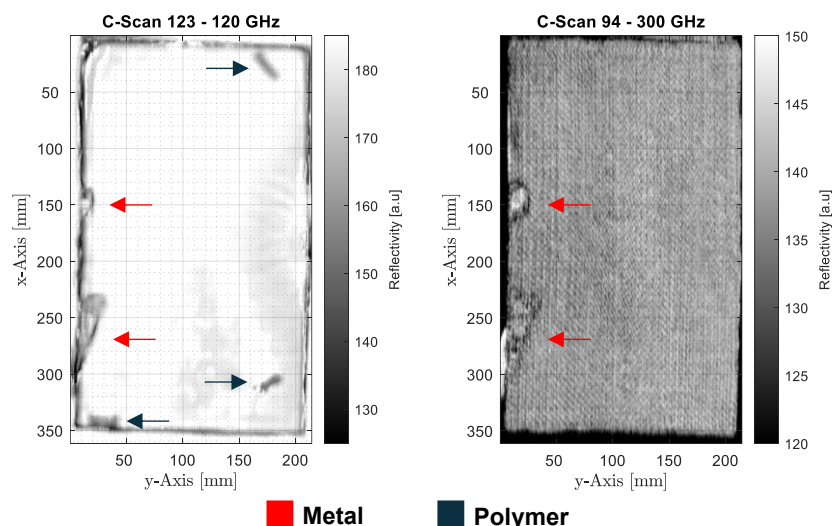


Figure – 120 GHz Acquisition (left); 300 GHz Acquisition (right)



Case study #2 – Glass Fiber / Epoxy Composite with Cracks and Air Voids

This second use case focuses on a glass fiber–reinforced epoxy composite, representative of structural composite materials commonly used in industrial applications. Such materials are susceptible to internal defects introduced during manufacturing or service, including cracks and air voids, which can significantly affect mechanical performance and durability.

In this study, the composite sample contains both crack-like defects and air voids. The air voids were intentionally introduced through the insertion of PTFE (Teflon®) discs, providing controlled low-density inclusions used as reference defects.

Measurement Configuration

Measurements were performed using Optikan’s technology with radar heads operating at 60 GHz, 120 GHz, 240 GHz and 300 GHz. Given the limited thickness of the composite sample and the need to resolve fine internal features, a 25 mm focal-length lens was used for both frequency configurations.

The scanning was carried out using a motorized increment step of 1 mm, providing an adequate compromise between spatial resolution and acquisition time for the detection of internal cracks and air voids.

Frequency-Dependent Observations

Images acquired at both frequencies using Optikan’s technology reveal a series of internal defects within the composite structure. The presence of cracks and air voids is highlighted through dielectric discontinuities within the epoxy matrix and at the fiber–matrix interfaces.

The frequency-dependent acquisitions emphasize the complementary nature of the measurements. Differences in contrast and defect visibility across frequencies illustrate the sensitivity of Optikan’s technology to both volumetric defects, such as air voids, and localized discontinuities, such as cracks. These results demonstrate the ability of Optikan’s technology to reveal multiple defect types in glass fiber–epoxy composites using a fully contactless and non-ionizing inspection approach.



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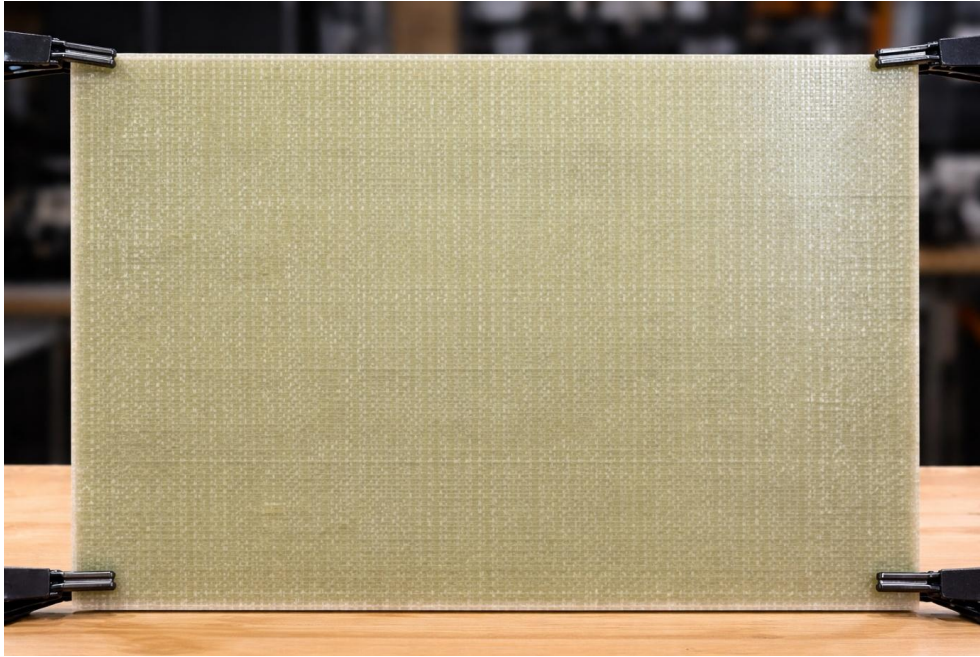


Figure – Glass Fiber / Epoxy Composite Photograph

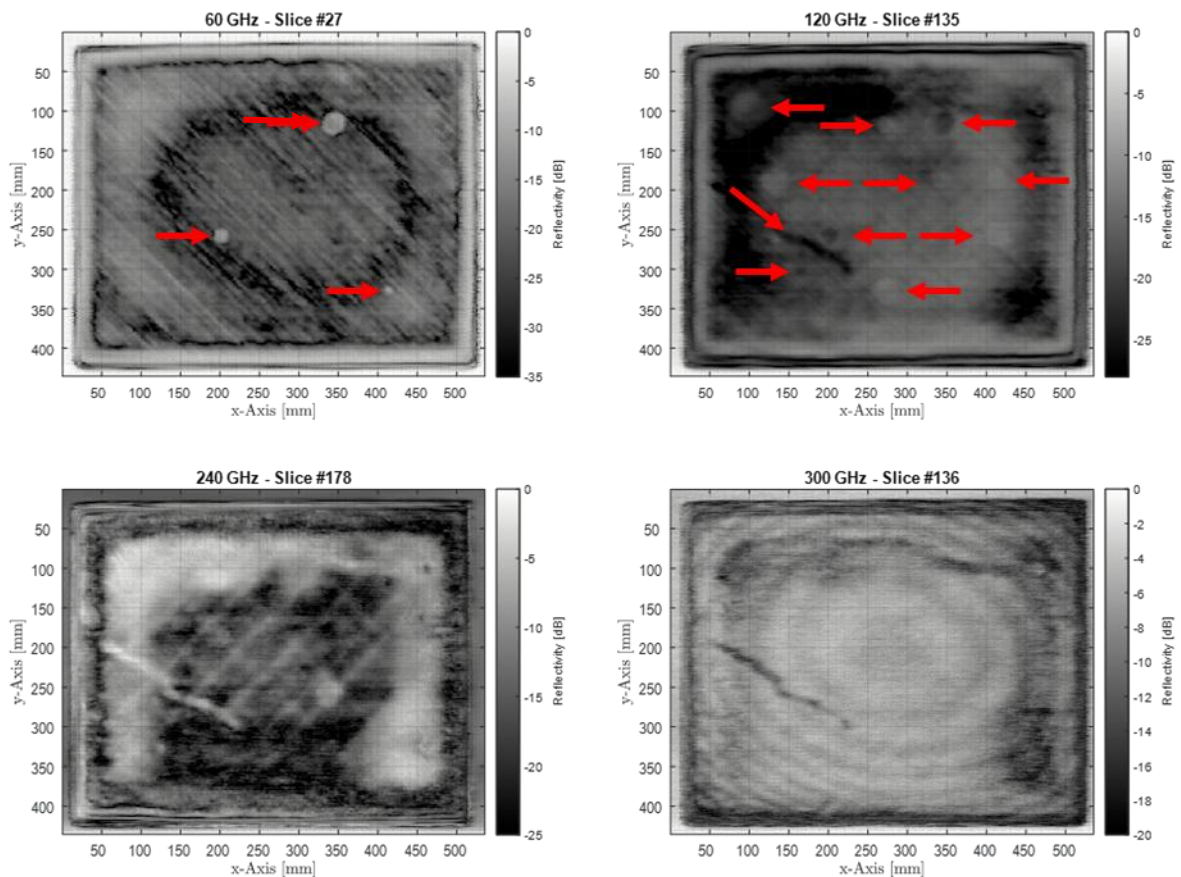


Figure – 60 GHz, 120 GHz, 240 GHz and 300 GHz Acquisition of the Fiber Glass / Epoxy Composite, Highlighting Various Defects (Voids and Cracks). Red Arrows Point to Detected Defects. Defects are only Highlighted on the 60 and 120 GHz Images.



Case study #3 – Sealant Joint Thickness Estimation in Composite and Metallic Structures

The reliability and long-term durability of sealant joints between windshields and structural frames (metallic or composite) are critical to ensuring the structural integrity, safety, and environmental sealing of modern transportation vehicles. In this context, the presence of air gaps between the sealant and the frame can lead to mechanical weakness, loss of sealing performance, or premature ageing of the assembly.

The objective of this use case is to estimate the air gap at the sealant–structure interface, which is inferred indirectly through the effective thickness of the sealant joint. Variations in joint thickness are assumed to be correlated with the degree of intimate contact between the sealant and the underlying structure.

In the investigated, the used radar head, given its current bandwidth and hardware architecture, does not provide sufficient longitudinal resolution to directly extract sealant thickness using classical Time-of-Flight (ToF) methods. This limitation follows from the fundamental relationship governing longitudinal resolution, $\delta z = c / (2\Delta f)$, where Δf is the signal bandwidth.

To address this constraint, an alternative approach was explored based on the frequency-dependent interaction between the electromagnetic field and the sealant material. Rather than relying on time-domain ranging, the reflected signal was analyzed in the frequency domain. The frequency-dependent reflection coefficient was squared to compute the reflected power, which was then integrated over several sub-bands of the chirp.

Among these sub-bands, a specific frequency interval was identified as being particularly sensitive to variations in sealant thickness, exhibiting consistent and monotonic trends in reflected power. This behavior is attributed to a combination of thickness-dependent absorption effects, consistent with Beer–Lambert-type attenuation, and frequency-dependent interference phenomena.

This use case demonstrates how Optikan’s technology can be leveraged to extract interface-related information in bonded assemblies by exploiting spectral signatures, even in configurations where direct ToF-based thickness measurements are not feasible. The following sections detail the experimental configuration and the results obtained from the sub-band analysis.

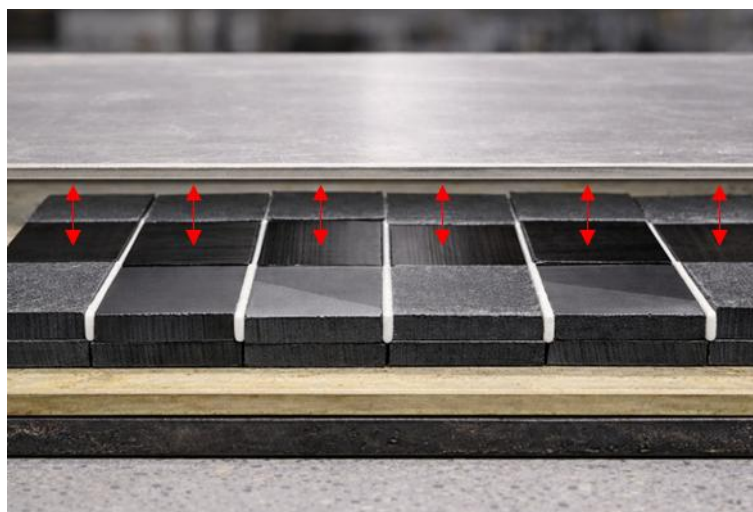


Figure – Composite Structure with Metal, Sealant and Fiber Glass.



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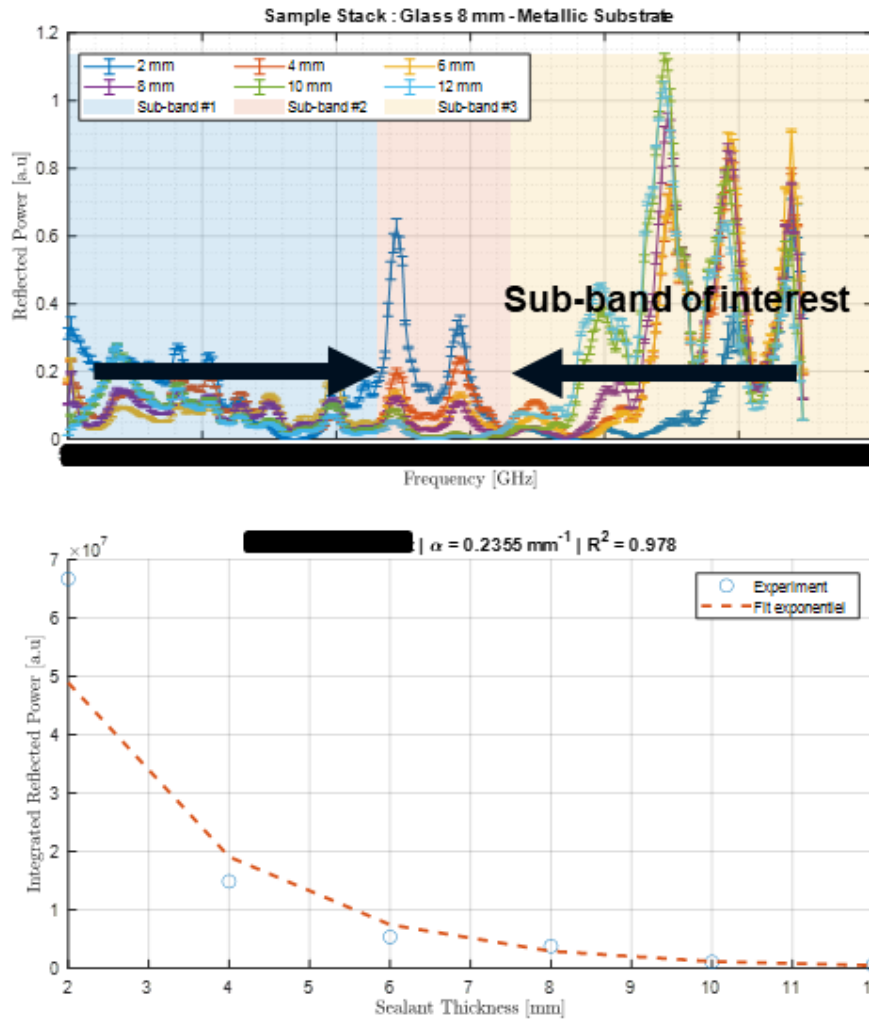


Figure – Reflected Power in a Specific Radar Sub-band as a Function of the Sealant Thickness (top); Experimental-fit curve (bottom)



Case study #4 – Adhesive Bead Monitoring in Automotive Spoiler Assemblies

This use case addresses the inspection of **adhesive bonding between polymer components** in an automotive spoiler assembly. The spoiler consists of two polymer-based parts bonded together:

- an upper outer shell, primarily aesthetic, painted and weakly loaded with fillers,
- a lower structural component, designed to integrate electronic elements and ensure mechanical robustness.

Ensuring proper bonding between these two parts is critical not only for mechanical integrity, but also to prevent water ingress, which could compromise embedded electronics and long-term durability.

The bonding process involves a polyurethane adhesive bead applied between two reinforced polyethylene-based composite structures. From a non-destructive testing perspective, this configuration requires the ability to detect very small density contrasts between the adhesive, the surrounding polymers, and potential air gaps.

Measurement Principle and Observations

Millimetric images acquired make it possible to visualize the adhesive bead at different depths, owing to the time-resolved capability of Optikan’s imaging system. This enables the identification of the spatial continuity of the adhesive layer within the bonded assembly.

The acquired images reveal that the adhesive bead is not continuous in the lower-left portion of the inspected area. In this region, the bead application is incomplete: the adhesive dispensing gun does not terminate its path at the same location where it initiated it. As a result, an air gap is present where the beginning and end of the bead face each other, forming a characteristic geometry often described as “duck-bill”-shaped terminations.

In industrial practice, such issues are partially mitigated through the use of robotic dispensing systems equipped with flow meters, which allow control of the total adhesive volume deposited. However, volumetric control alone does not provide information on the spatial distribution of the adhesive, nor does it indicate where material may be locally missing.

By contrast, Optikan’s technology enables direct spatial imaging of the adhesive bead, allowing the precise localization of missing or insufficiently deposited adhesive. This capability not only supports quality control but also enables targeted repair or rework, rather than rejecting entire parts or relying solely on indirect process metrics.



Applicative Note – Composites and Bonded Structures

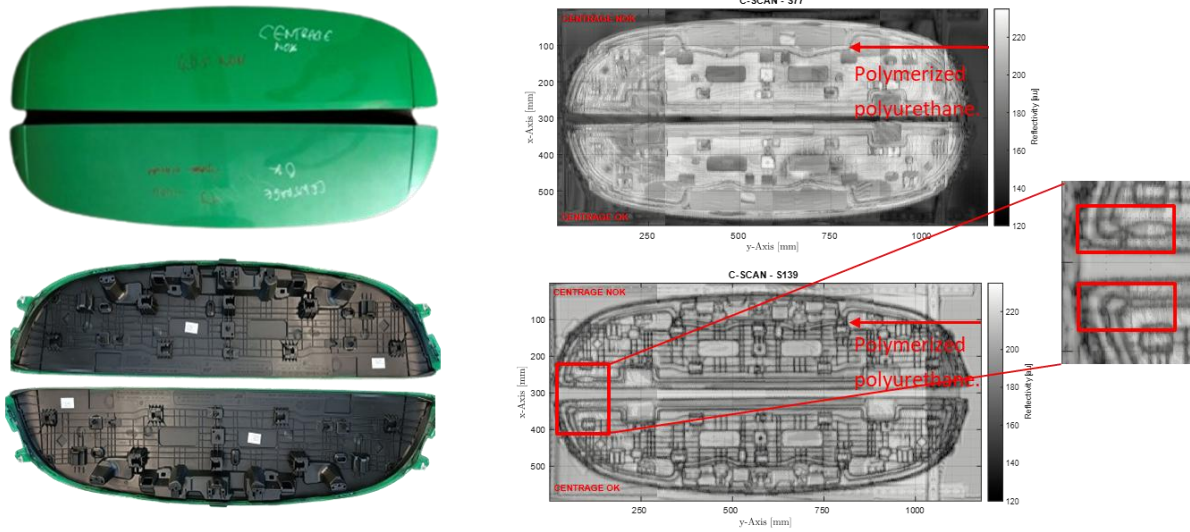


Figure – Photograph of the Spoiler (left); Optikan's view (right)

For more information, please contact Optikan at: contact@optikan.com.

