

Dynamic Gain Correction Map for Automated Ultrasonic Inspection of Composite Structures

Ahmad Chahbaz¹ CEO, Rene Sicard¹ R&D Manager

¹TecScan; St-Bruno-de-Montarville, Québec, Canada, Phone: +1-450-233-4973, e-mail: achahbaz@tecscan.ca

Abstract

Automated Ultrasonic Testing (UT) plays a vital role in the aerospace industry, especially for inspecting large, complex composite parts and structures. One of the main challenges in ultrasonic inspection arises from the geometric variations of these parts, which affect ultrasonic wave propagation and result in defect detection variations across different regions of an inspected part. In particular, significant changes in part curvature and, in the case of transmission C-scans, variations in thickness can cause notable differences in signal amplitude. This requires either localized interpretation of UT signals or multiple C-scans at varying receiver gains to ensure complete coverage.

To automatically address these sensitivity variations, a novel Gain Correction technique has been developed and patented by TecScan. This technique automates the defect interpretation process by using gain variation maps generated from calibrated reference parts. Instead of adjusting detection thresholds, the Gain Correction technique uses these maps to dynamically adjust the gain, ensuring consistent signal interpretation while reducing the need for manual adjustments.

This paper presents the benefits of implementing this Gain Correction method, particularly in terms of normalisation of the signal amplitude in the case of through-transmission scanning, and its impact on flaw detection and sizing within complex composite aerospace parts and structures.

Introduction

Ultrasonic Testing (UT) is the most widely used technique for detecting imperfections and defects in composite materials and structures, both during manufacturing and in-service inspections. While manual UT or phased array testing can effectively detect defects in simple, flat parts,

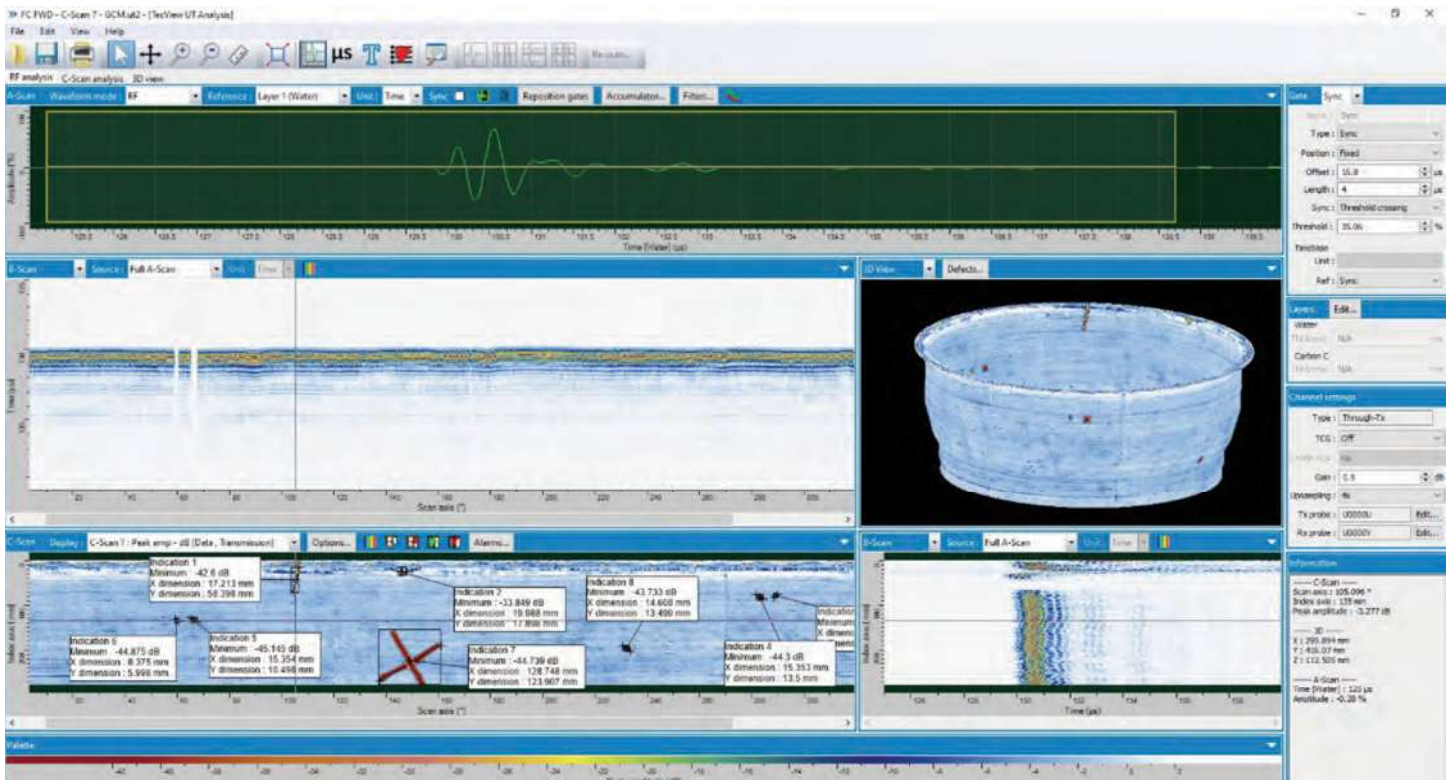
the use of automated mechanical scanners enhances the inspection of larger parts and complex structures by providing more consistent and repeatable probe or array coupling. Also, accurate UT measurements with high mechanical precision allow inspectors to clearly visualize the scanned parts and material imperfections, enabling faster and more informed inspection decisions.

The test results obtained from automated ultrasonic scans are usually presented in high resolution C or B-Scans to accurately characterize the detected material defects. These scans map the ultrasonic signal amplitudes or time-of-flight information collected within a selected time or material thickness interval to a predetermined color palette. However, when the inspected parts have varying thickness or significant curvature variations, the ultrasonic signal propagation properties change, leading to fluctuations in C-Scan sensitivity, which affects defect detectability and signal-to-noise ratio. This often requires local interpretation of the inspection data or the use of multiple scans at different receiver gains to ensure full coverage of the part.

Advanced Gain Correction Map Technique (GCM)

The ability to perform repeatable automated UT scans on large and complex parts is particularly beneficial in the aerospace industry, where even minor flaws can have significant safety implications. The ability to accurately produce C-Scan mapping and assess defects in critical parts ensures that only those parts meeting stringent quality standards are used in aerospace applications.

An advanced gain correction technique was developed and patented by TecScan in recent years to automatically account for C-Scan mapping and inspection result variations when performing automated ultrasonic



testing of parts having varying thicknesses or important variations in curvature. While such parts are typically divided into sections with different C-Scan mapping adjustments and/or adapted detection thresholds, the gain correction map tool automates this process. It generates a gain variation map of the part, created from the scan of one or more reference parts, to perform these mapping adjustments automatically during the scan.

For transmission scanning, this translates into a more uniform amplitude of the signal across the part surface. Analysis, such as dB drop sizing, becomes much easier since the reference amplitude is consistent across the entire part, eliminating the need for local analysis.

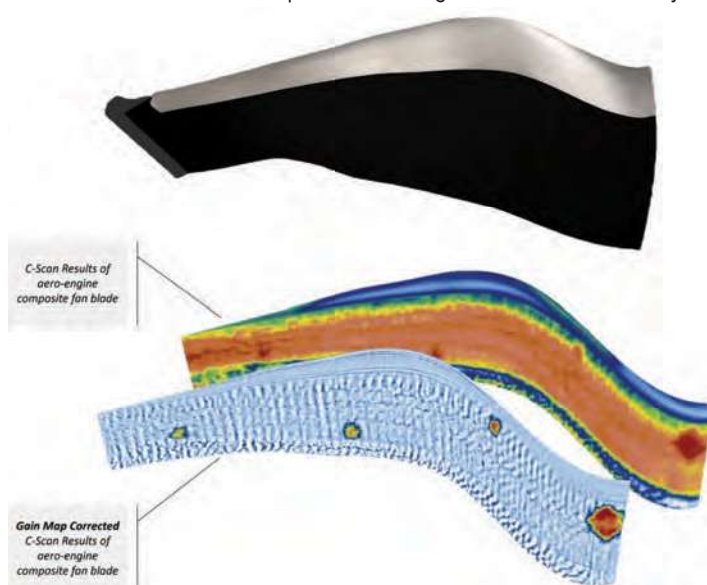


Figure 1: C-Scan results of composite engine fan blade with Gain Correction Map (GCM)

This also leads to a data set that is much easier to interpret, while providing optimal signal-to-noise ratio at any position on the part.

Experimental Setup: Automated Immersion Tank

To demonstrate the developed Dynamic Gain Correction Map technique, experimental automated UT tests were conducted on an aircraft flap section. A 10-axis Scan3D ultrasonic Immersion system was used to perform the automated through-transmission scans using a pair of 5MHz transducers. Two independently controlled X and Y carriages, two Z axes, and two fully automated high precision Gimbal/Gimbal manipulators were used.

TecView® 3D is used to manage and perform the inspection of this complex aircraft flat structure. In order to optimize the accuracy and



Figure 2: Scan3D 10-axis Ultrasonic Immersion System

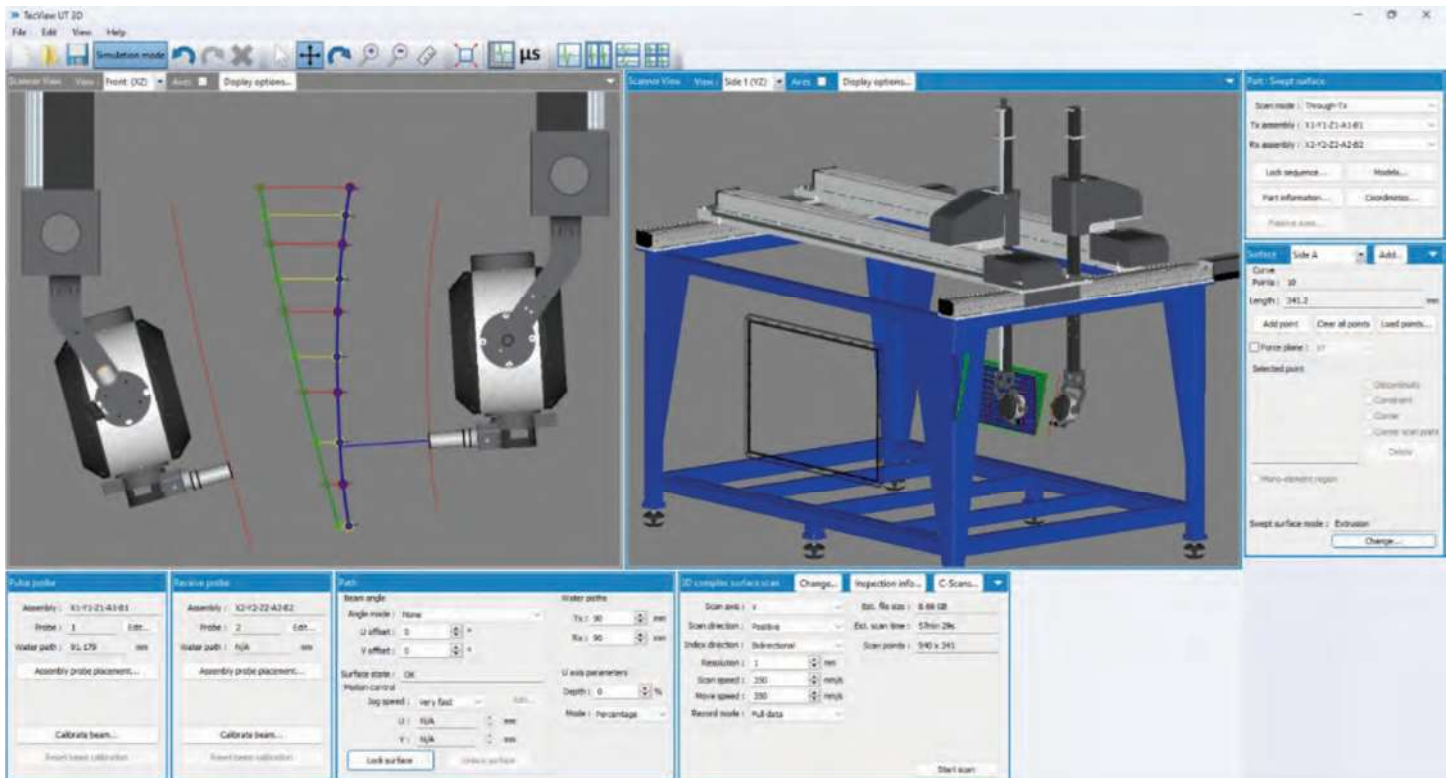


Figure 3: TecView® 3D Virtual representation of the aircraft flap within the scanner model

the overall ultrasonic testing solution, the 3D geometry of the inspected composite structure sample was converted from a CAD file and imported in the inspection software environment. The geometry of the immersion scanner along with the Gimbal manipulator were also modeled and imported in the software; accurately displaying the part within the scanner's environment allows the operator to visualize and validate the imported scanner displacement trajectories prior to scanning.

Experimental Results: Aircraft Flap Section

An aircraft flap section made of panels bonded to a honeycomb core structure with artificial disbands was inspected with the Scan3D



Figure 4: Aircraft flap section made of panels bonded too honeycomb structure

immersion system.

Results from **Figure 5** show the ultrasonic signal variation effect on the honeycomb structure due to the part's geometry. In such conditions, sizing defects becomes more difficult as the reference signal is not constant across the sample, which makes amplitude-based detection and sizing difficult, as well as potentially leading to saturation in some areas and low signal amplitude in others. As illustrated by the histogram of the C-S-Scan image, the amplitude is spread across a wide range of amplitude for the honeycomb area and at on a different amplitude distribution as the amplitudes representing the bonded panels area where no honeycomb structure is present.

Such honeycomb structure not only presents a gradient of thickness, but also local variations of signal amplitude resulting from the honeycomb geometry. Defining a proper Gain Map therefore requires taking these two variables into account. Since the honeycomb structure cells may not appear exactly at the same position from one part to another, it is the attenuation trend across the part that must be corrected rather than local attenuation. The solution therefore resides in acquiring a set of reference amplitude curves (Figure 6) along the indexing axis, at different scanning positions of a reference part, and define a function that best represents the attenuation trend at any position on the flap.

It is this function that is then used to generate a Gain Map Correction, which can then be applied as the scan is being recorded, or as a post-acquisition analysis.

This resulted in a C-Scan image with a normalized honeycomb signal, revealing indications with an optimal signal-to-noise ratio across the whole sample, as illustrated in Figure 7. The histogram distribution

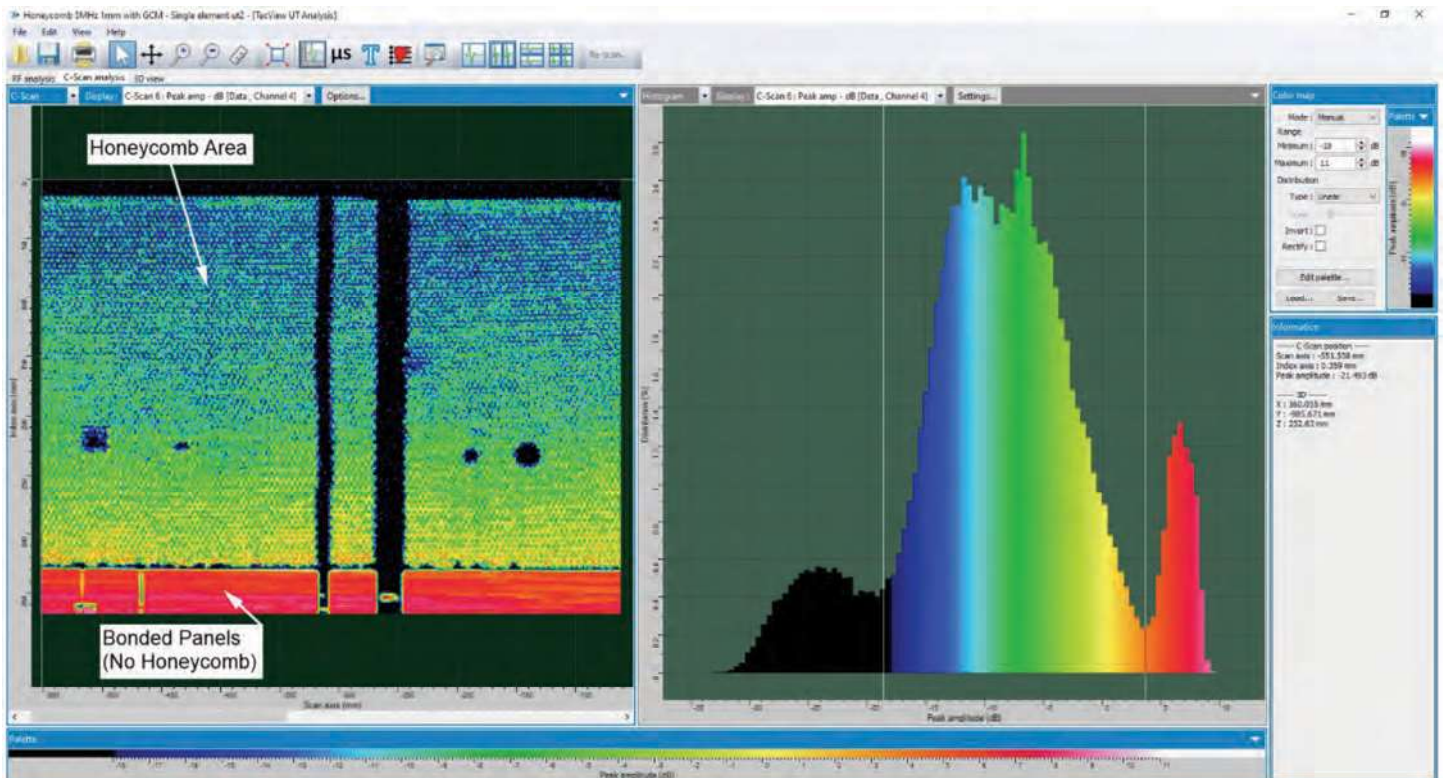


Figure 5: C-Scan results of a honeycomb core structure without Gain Correction Map (GCM) along with the histogram of the amplitude distribution of the C-Scan image

It is this function that is then used to generate a Gain Map Correction, which can then be applied as the scan is being recorded, or as a post-acquisition analysis.

also exhibits a single peak that includes the honeycomb and panel-to-panel bonded areas with a more compact amplitude distribution than in Figure 5.

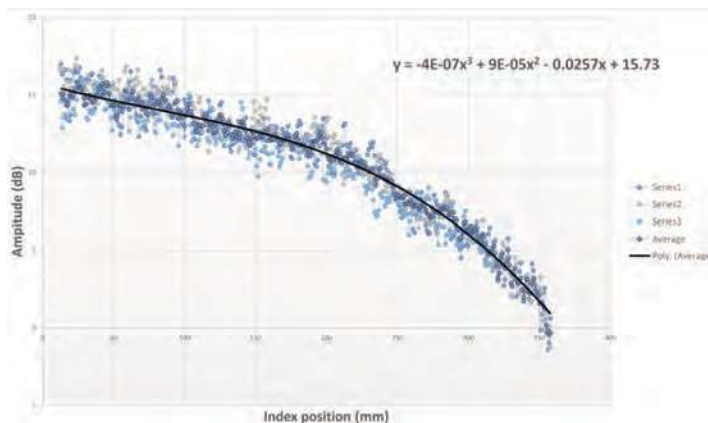


Figure 6: Example of GCM curve generated from a polynomial fit based on the average amplitude recorded as a function of index position and taken at different scanning positions of a reference sample

A side-by-side comparison of the C-Scans obtained without and using the Gain Correction Map technique allows us to appreciate the impact of the GCM. Annotation boxes measuring the average C-Scan amplitude within a 25.4 mm circle were placed at identical positions on both C-Scans in the thin, thick, and average thickness areas of the sample. While the average amplitude monitored on the C-Scan without GCM displays variations of approximately 10dB among the measured points, it is reduced to a maximum variation of 0.42dB on the C-Scan acquired with the GCM. This sought after stability of the average response facilitates the analysis by enabling the use a single detection and/or sizing threshold across the entire part surface.

Conclusion

Automated ultrasonic testing with Gain Correction capabilities provides a highly valuable tool to enhance the accuracy and thoroughness of flaw detection in large and complex composite parts and structures. The technique automates the defect interpretation process by using gain variation maps generated from calibrated reference parts. Instead of adjusting detection thresholds, the Gain Correction technique uses

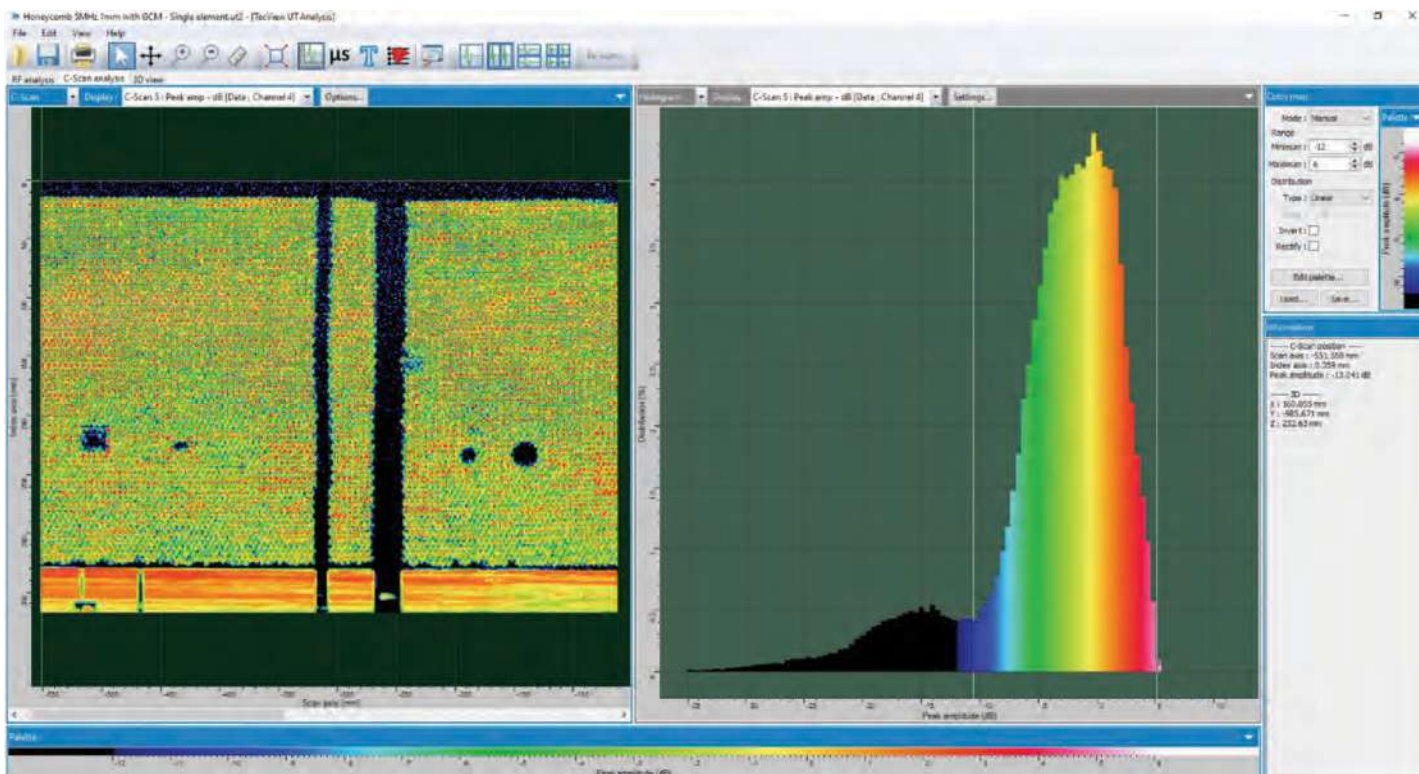


Figure 7: C-Scan results of a honeycomb core structure with Gain Correction Map Technique (GCM)

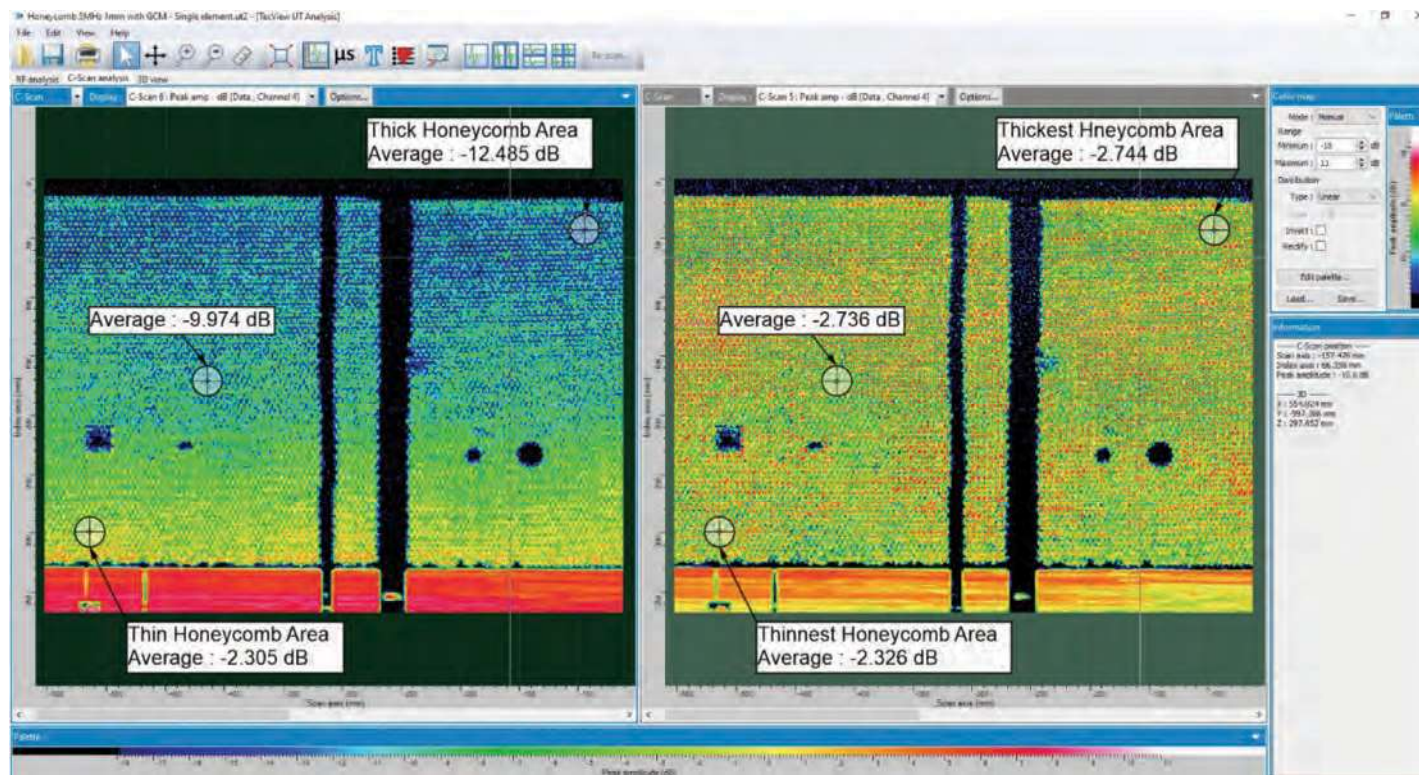


Figure 8: C-Scan images comparison obtained without (left) and using Gain Correction Map (GCM - right)

these maps to dynamically adjust the gain, ensuring consistent signal interpretation while reducing the need for manual adjustments. The benefits of this method lie in the capability to scan a sample with optimal signal-to-noise ratio in a single pass rather than having to run scans at

different sensitivities but also allows to use a common detection threshold across the entire sample since the reference amplitude baseline has been normalized for all honeycomb sections.