



**Feasibility Study for ARL Inspection of Ceramic Plates
Final Report - Revision: B**

by Jinchi Zhang, Simon Labbe, and William Green

ARL-TR-4482

June 2008

prepared by

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Canada**

under contract

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14. ABSTRACT This report is on the inspection of SiC-N ceramic tiles with engineered internal flaws using different ultrasonic testing methods. These methods included high-frequency, both focused and unfocused (flat), and phased-array techniques. The detectability of three main flaw types that can be present in manufactured SiC-N tiles was investigated. The tiles were produced and provided by the U.S. Army Research Laboratory.					
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1. Introduction

The aim of this project is to examine ceramic plates using ultrasonic inspection. The detection of very small fabrication or engineered flaws put into the plates is requested for this study as well as inspection speed. Both conventional and phased-array ultrasonic techniques are used.

Three ceramic plate samples were inspected. These samples contain defects of known nature, with approximate size and at known depth. However, the x-y positions of the defects are unknown. The purpose of this study is to find an adequate UT inspection method providing enhanced detection and speed.¹

2. Sample and Tools

2.1 Description of the Samples

Table 1 describes the three samples provided by the U.S. Army Research Laboratory at Aberdeen Proving Ground, MD.

Table 1. Information about the samples.

Name	Sample P	Sample V	Sample A
Code	8-0284-2/41261	8-0284-7/41265	8-0284-4/41264
Material	SiC-N	SiC-N	SiC-N
Defects	Lower density material sized ~20–30 μm introduced ~3 mm from the top surface	Higher density material (inclusions) sized 1–3 mm at ~3 mm from the top surface	Larger sized grains (~35–40 μm) ~3 mm from the top surface

The three samples have the same geometry: $\sim 100 \times 100 \times 20$ mm. The measured longitudinal wave speed is 12,211 m/s and the shear wave speed is 7960 m/s. The introduced defects are at ~3 mm from the top surface, but their x-y positions are unknown.

It is noted from table 1 that sample V has known defects of the order of mm, whereas samples P and A are supposed to have defects of the order of tens of microns. Accordingly, different UT frequency ranges were chosen for the inspection of these two types of defects. The sample V will be inspected at relatively low frequency of ~10 MHz, at which phased-arrays can be efficiently supported by R/D Tech's instrumentation. The other two samples are inspected at relatively high frequencies (20–50 MHz) using conventional probes.

¹Latouche, F.; Roque, V. *Test on ARL Ceramic Samples Using Ultrasonic Techniques*; R/D Tech: Waltham, MA, 22 June 2004.

2.2 Equipment

2.2.1 Phased-Array Technology

Phased-array technology is used for sample V, which has defects of the order of mm. The frequency range of R/D Tech's instruments for phased-array probes is 17 MHz and below, and is therefore adequate for the application.

- **Phased-array probe.** The phased-array probe selected is a 10L64E32-5, i.e., the frequency is 10 MHz, the element number is 64, the pitch is 0.5 mm, and the element height is 5 mm. It should be mentioned that linear phased-array probes of 13 and 17 MHz were compared to the 10-MHz probe. Probably because of their small element pitches (0.2 mm and 0.25 mm, respectively), their respective performance was not as good as that of the 10-MHz probe.
- **Electronics.** The acquisition unit is a Focus, but OmniScan Phased Array MX can achieve the same results.
- **Software.** Tomoview 2.2 R9
- **Setup.** The beam incidence is normal to the sample top surface. To take advantage of the speed scanning offered by phased-array technology, a bi-directional linear scan is utilized, i.e., the electronic scan is perpendicular to the mechanical bi-directional scan, as shown in figure 1. Each mechanical scan pass covers a band of 24.5 mm in width. To cover the entire sample surface, only five passes are required. In the results presented in section 3, six passes will be used for additional coverage. If a conventional probe was used for the same inspection, the scan pass number and therefore the scanning time would be much greater. This is shown in section 5.

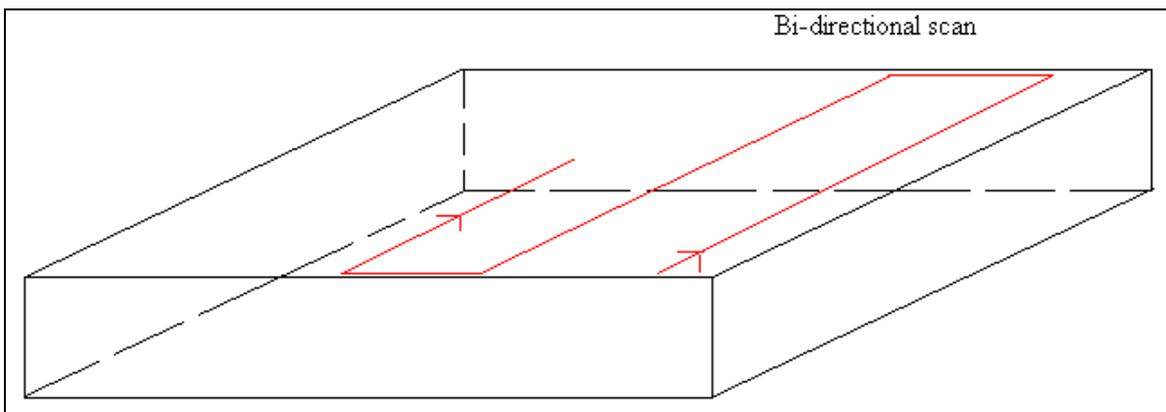


Figure 1. Bi-directional scan plan.

2.2.2 High-Frequency Conventional UT Technology

To detect the smallest defects in samples P and A, high-frequency UT technology has to be used. This test was done in the laboratory of Panametrics-NDT, where the technology has been fully studied for ~20 years.

- **Probes.** Three conventional high-frequency probes were used for the tests as shown in table 2.

Table 2. High-frequency conventional UT probes used for samples P and A.

Panametrics Part Nos.	PI50-2-R1.00 (in)	V316-SU	V3282
Frequency, MHz	50	20	50
Radius of curvature, in	1	Unfocused	Unfocused
Probe diameter, in	0.25 in	0.125 in	0.25 in
Notes	Polymer transducer. For inspection at 3 mm below top surface, spot size at focus is ~125 μ m.	To attempt bulk measurement.	The delay line is not long enough to inspect full depth in samples.

- **Electronics.** The instrument used was a Pulser-Receiver 5900 PR with a Remote Pulser Preamplifier, number 5627 RPP. The system frequency band is from 10 to 125 MHz. The system uses a 1GS/s PC digitizer card. Scans were done with either 500 MS/s or 250 MS/s digitization rates.
- **Software.** Panametrics' software: ScanView Plus.

3. Results

3.1 Phased-Array Technology: Sample V

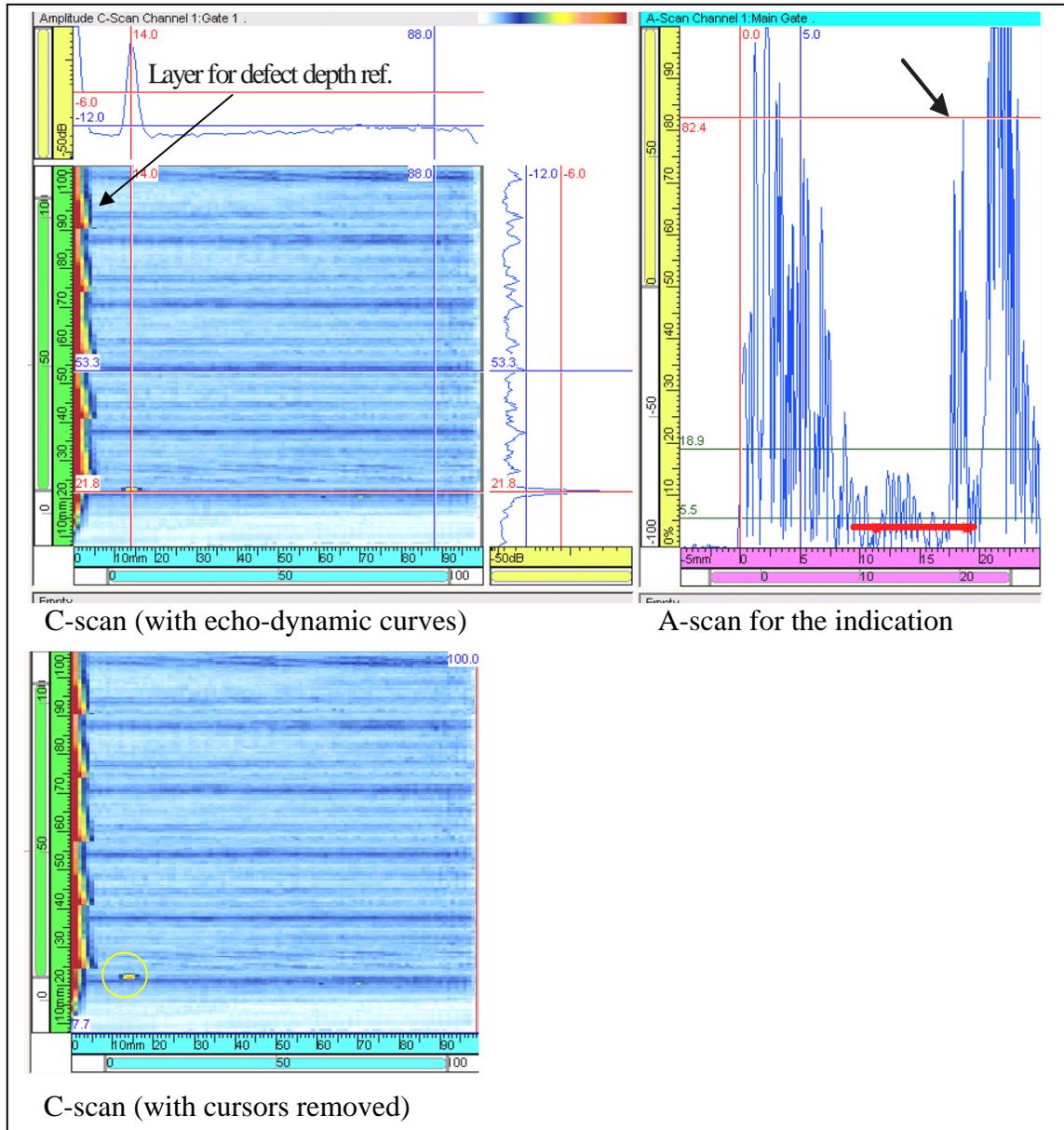
The inspection results obtained at 10 MHz are shown in figure 2. During this inspection, the sample was inspected from the face that is the furthest away from the defect. The purpose of doing this is to avoid the dead zone due to the ring-down of the echo after transmission at the interface. The dead zone is estimated to be about 9 mm.

The inspection in figure 2 took less than 10 s. The inspection can be done manually with a water box in contact with the samples.

3.2 High-Frequency Conventional UT Technology: Samples P and A

3.2.1 The 50-MHz Focused Polymer Transducer

This high-frequency conventional probe was used for both samples. Because of the high velocity in the material, a probe of long-distance focus or large radius of curvature was used to



Note: The layer depth reference statement refers to an artifact that is present in each plate. It appears like a delamination that is located at the depth of the defect. This indication is assumed to be a reference purposely placed in the plates to mark the defect depth.

Figure 2. Phased-array inspection of sample V. The defect is indicated in the C-scan and in the A-scan. The layer for the defect depth reference in the sample is also indicated in the upper-left C-scan.

avoid surface-wave generation. Minimum water column was used to achieve 3-mm focal depth. Figures 3 and 4 show the global and zoomed views for sample P and A, respectively. In figure 3 (sample P), defects with sizes much $> 30 \mu\text{m}$ are observed, while the known target defect size is $\sim 20\text{--}30 \mu\text{m}$ with lower density in nature. It is difficult to say which indications are related to

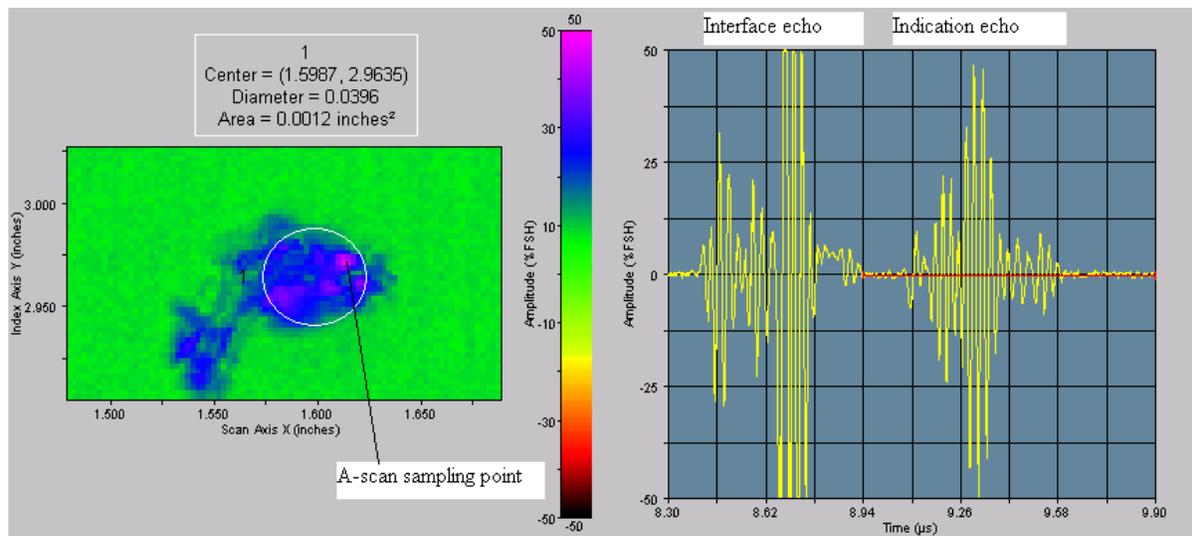
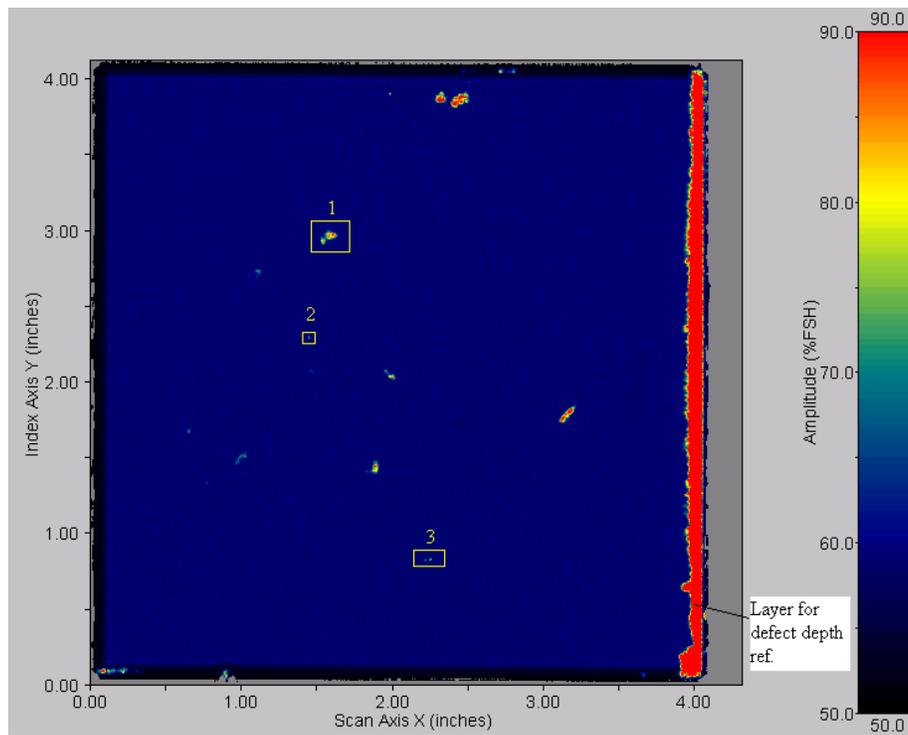
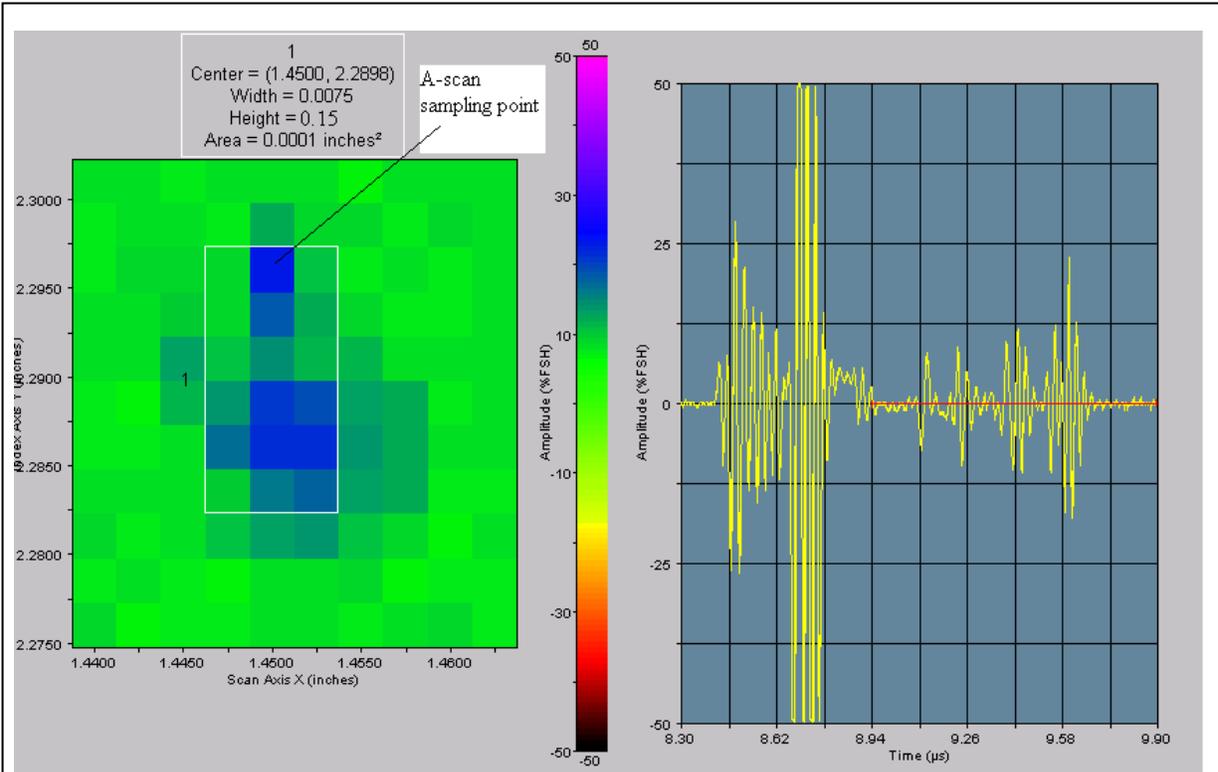
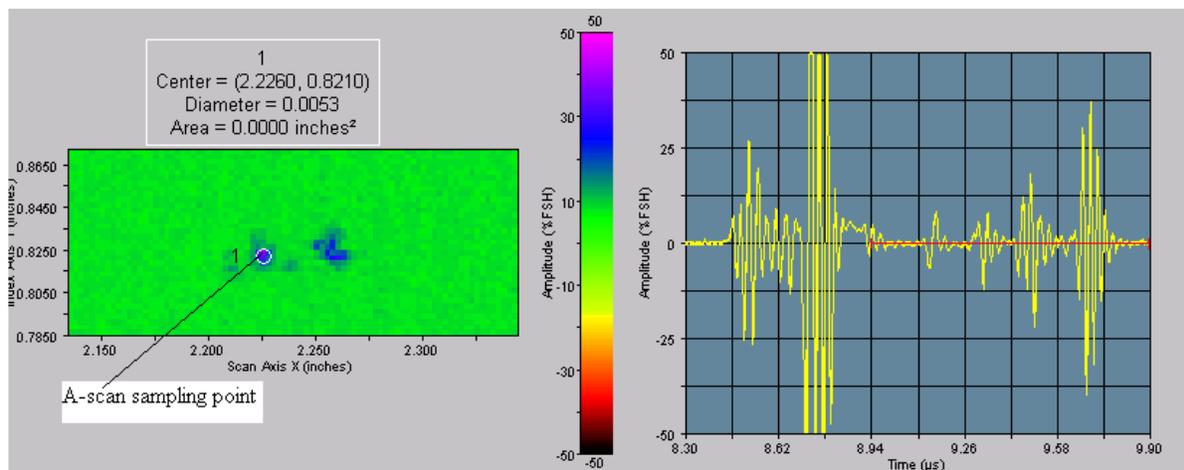


Figure 3. Sample P. Global view, C-scan resolutions 0.002 in (0.0508 mm), and zooms of three typical indications, C-scan resolutions 0.0025 in (0.0635 mm). The y-axis identification of each left-hand side color (green and blue shades) scan area (Zoom [1], Zoom [2], Zoom [3]) is Index Axis y (in).



Zoom [2]



Zoom [3]

Figure 3. Sample P. Global view, C-scan resolutions 0.002 in (0.0508 mm), and zooms of three typical indications, C-scan resolutions 0.0025 in (0.0635 mm). The y-axis identification of each left-hand side color (green and blue shades) scan area (Zoom [1], Zoom [2], Zoom [3]) is Index Axis y (in) (continued).

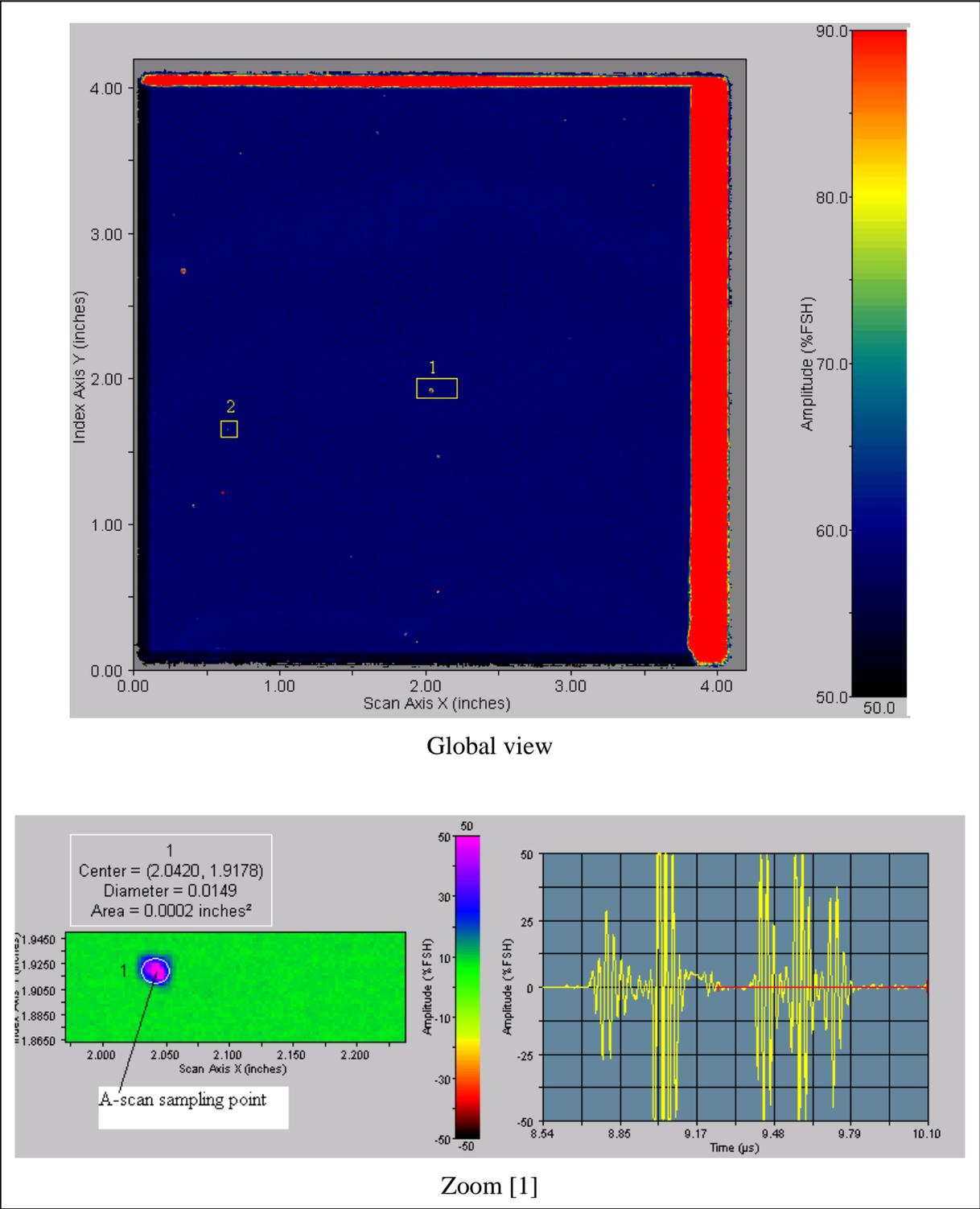


Figure 4. Sample A. Global view, C-scan resolutions 0.004 in (0.1016 mm), and zooms of two typical indications, C-scan resolutions 0.0025 in (0.0635 mm). The y-axis identification of each left-hand side color (green and blue shades) scan area (Zoom [1] and Zoom [2]) is Index Axis y (in).

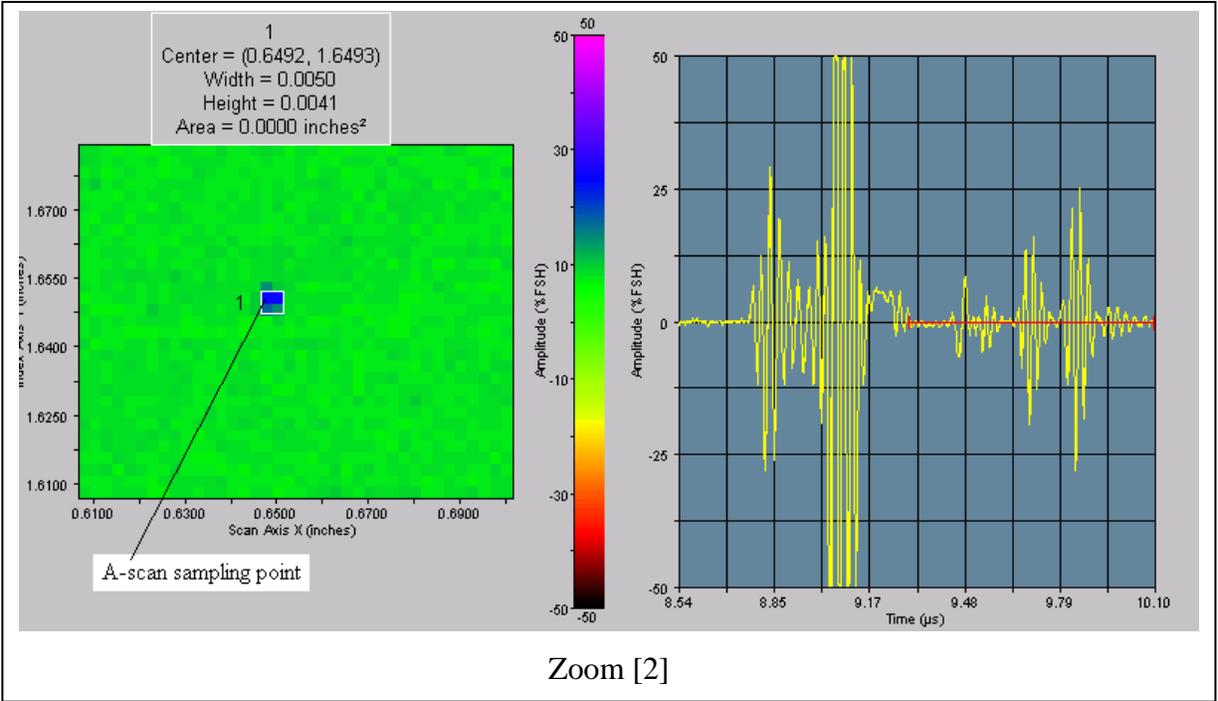


Figure 4. Sample A. Global view, C-scan resolutions 0.004 in (0.1016 mm), and zooms of two typical indications, C-scan resolutions 0.0025 in (0.0635 mm). The y-axis identification of each left-hand side color (green and blue shades) scan area (Zoom [1] and Zoom [2]) is Index Axis y (in) (continued).

these defects. All the indications are located at ~3 mm from the surface where the reference layer for defect depth is detected as well. The A-scans related to the zoomed indications show different waveforms, which may contain information on the nature of the defects that could be further exploited. The indications in figure 4 (sample A) generally seem much smaller and point-shaped.

While this probe can strongly focalize the energy at a depth of 3 mm from the top surface, other portions of the depth remain quiet. To inspect the bulk material, an unfocused probe should be used, but the price is the sacrifice of the focalization. The focalization efficiency and depth coverage are always contradictory for conventional probes.

The time needed to obtain the complete C-scan image in figure 3 is ~1.5 hr and that of figure 4 is ~1 hr.

3.2.2 The 20-MHz Unfocused Probe for Bulk Material Inspection

Since some of the defects in sample P seem of the order of mm, these indications may be detected by a relatively lower frequency probe. Also, the possibility for bulk material inspection may be tried using an unfocused probe. A 20-MHz unfocused probe was used for this test. Figure 5 shows the C-scan inspection results. In this test, the sample is horizontally flipped in the test and then the C-scan image is also horizontally flipped to make easy the comparison with

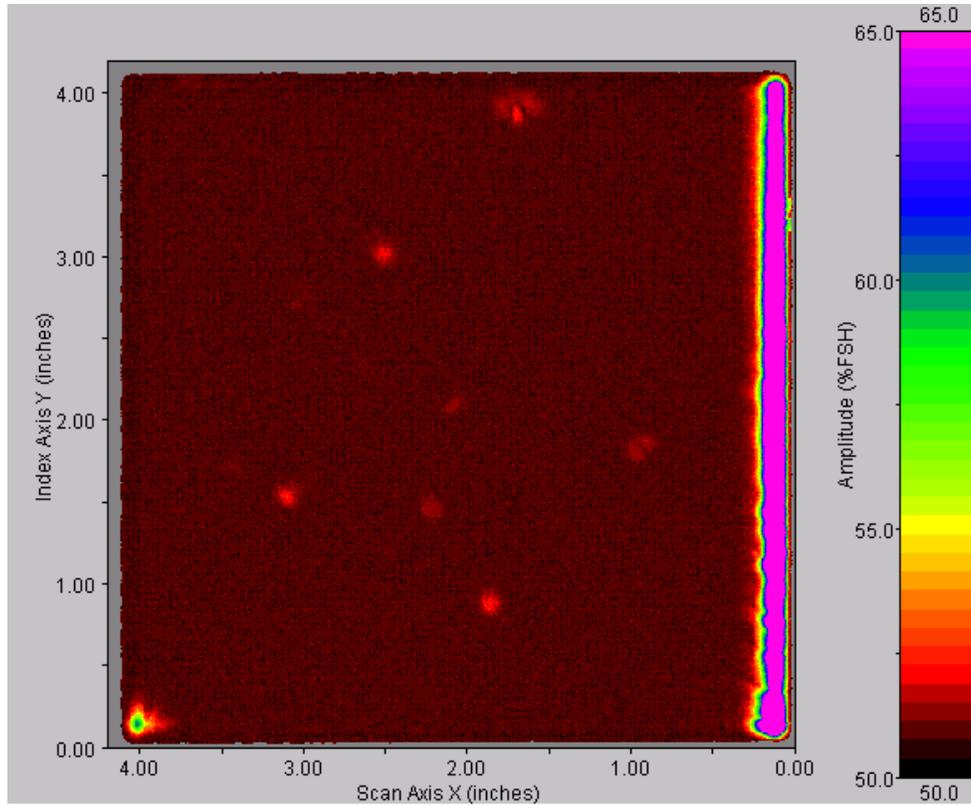


Figure 5. Sample P. Both the plate and the C-scan are horizontally flipped in order to facilitate the comparison with figure 3. The C-scan resolutions are 0.008 in (0.2032 mm).

the normal case in figure 3. The detecting gate covers the depth zone of defects. By comparing figure 5 with figure 3 (result previously obtained with the 50-MHz focused probe), we can see that the major targets are detected with enlarged target sizes.

3.2.3 The 50-MHz Unfocused Probe

The probe that was available for the 50-MHz unfocused test at the time of the study has a short delay line, so the full depth of the samples cannot be covered, i.e., the defects cannot be detected if the plate is flipped. A test of this probe can however help to understand its detection ability to small defects. A typical defect in sample A was zoom-scanned from the top surface of the sample (see figure 6a). The obtained image is much better than that obtained with the 20-MHz unfocused probe (see figure 6b). By reasoning from the observation in section 3.2.2, we may presume that the same target will be detected if the sample is flipped.

Note that for the high-frequency conventional work, unfocused 20- and 50-MHz probes were used. Unfocused probes are better for this application as they allow a better volume inspection. Because the 50-MHz probe had a short delay line by mechanical design, it could not be used for an in-depth inspection. It was therefore used for a near-surface inspection, thus, not in an optimal condition.

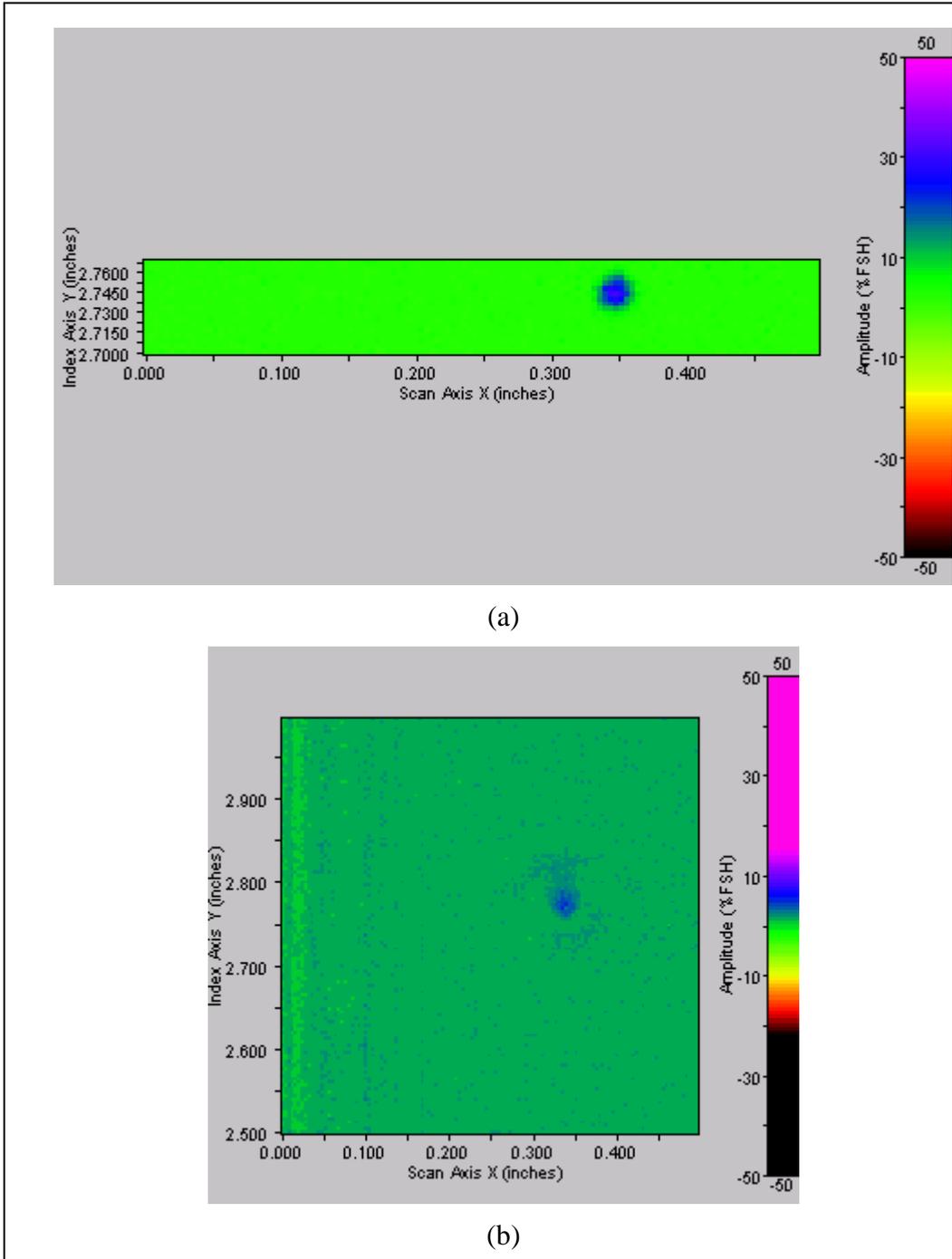


Figure 6. Sample A. A comparison between 50-MHz unfocused probe (a) and 20-MHz unfocused probe (b) by detecting the same target from the top of the plate. The indication in (a) has a better signal-to-noise ratio.

Both probes yield good results but it is felt that the 50-MHz probe should do better than the 20-MHz probe if it is built with a long delay line. Note that the probes are custom built so that a longer delay is available.

4. Conclusions

Phased-array technology is adequate for defects of the order of mm. The inspection is fast and can be done manually. The depth coverage can be achieved by flipping the sample. For this type of inspection, the proposed phased-array probe is 10L64E32-5 with a water box.

High-frequency conventional UT technology is adequate for defects of the order of <0.5 mm, such as those in samples P and A. A focused high-frequency conventional probe can detect defects as small as $20\ \mu\text{m}$ at a fixed depth (focused probes with frequency as high as 125 MHz are available). An unfocused high-frequency probe can cover nearly full depth with less sensitivity to the smallest defects. The time needed for the inspections is on the order of 1 hr and the inspection should be executed in a water tank. The recommended probe for the defects in samples P and A is 50 MHz unfocused conventional probe with appropriate delay line.

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