# UTILITY OF SPLIT SPECTRUM PROCESSING TO IMPROVE THE DETECTION OF INCLUSIONS IN TITANIUM ALLOYS

Manohar Bashyam
GE Aircraft Engines
Cincinnati, OH 45215

## OBJECTIVES

The objective of this research is to enhance target signals in titanium (Ti 6Al-4V and Ti 17β, referred to as Ti64 and Ti17 respectively) super alloys using signal processing for improved detection of hard-alpha and other inclusions. The overall objective is to generate easy to interpret images such as amplitude B-scans & C-scans by minimizing the clutter due to material noise. During this research we will evaluate the performance of several signal and image processing algorithms, based on the following evaluation criteria - number of detections verses number of false calls, algorithm execution time and robustness of the algorithms. The results of the different digital signal processing (DSP) algorithms will be compared to those of the focused C-scan images to show the advantages.

## NEED FOR IMPROVED DETECTION

The graph in Figure 1 shows the performance of present NDE capability using conventional ultrasonic peak amplitude thresholding for detecting hard-alpha in noisy titanium billets [1]. The graph shows 45 data points out of which 14 are real defects and 31 are false calls. The reason for this poor performance is due to the low level signals that need to be detected from a highly noisy material in an industrial environment. Hence, the objective here is to minimize the number of false calls (shown within the boxed section), while all the defects are detected. One approach to this problem is by improving the signal-to-noise ratio through signal processing.

## DIGITAL SIGNAL PROCESSING

Split spectrum processing (SSP) has been used to solve several problems in the past that require noise suppression. Examples of these can be found in the literature [2,3]. SSP consists of spectrally decomposing the received signals and their time domain representations are compounded using minimization & polarity thresholding to enhance the signal-to-noise ratio. The assumption made is that the target signal is frequency independent (within the bandwidth of the filters), while the grain noise is frequency dependent.

We now demonstrate the performance of the SSP algorithm in improving the detection of #1 (1/64 in., 0.4 mm) flat bottom holes (FBH) in the Ti17 alloy. The SSP algorithm was applied to RF signals from a Ti17 block. The signals were obtained from a block with sixteen FBH, four each of #1 through #4 (4/64 in., 1.6 mm) at one inch depth. The ultrasonic data was obtained using a 15 MHz transducer focused at the surface while gating the signal between the front surface and past the FBH. The signal-to-noise (S/N) ratio is approximately one. This can be observed in the A-scan, B-scans and C-scan shown

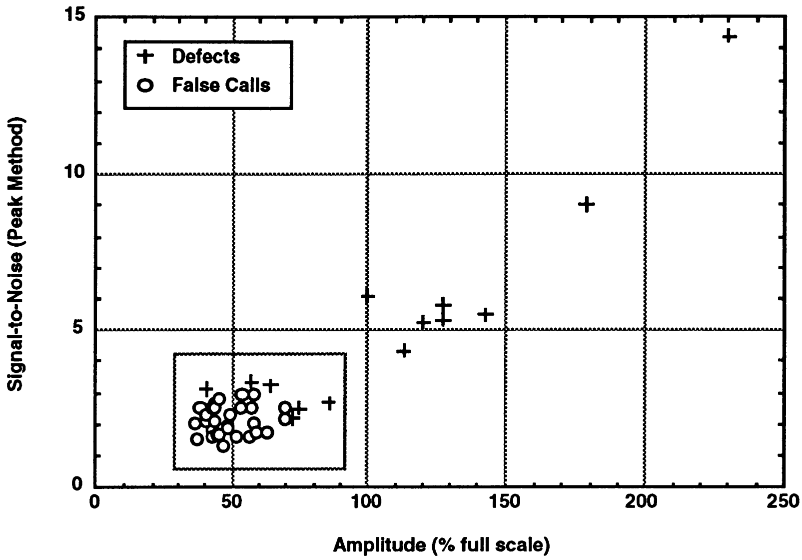


Figure 1. Shows the performance of present NDE capability using conventional ultrasonic amplitude thresholding for detecting hard-alpha in noisy titanium billets.

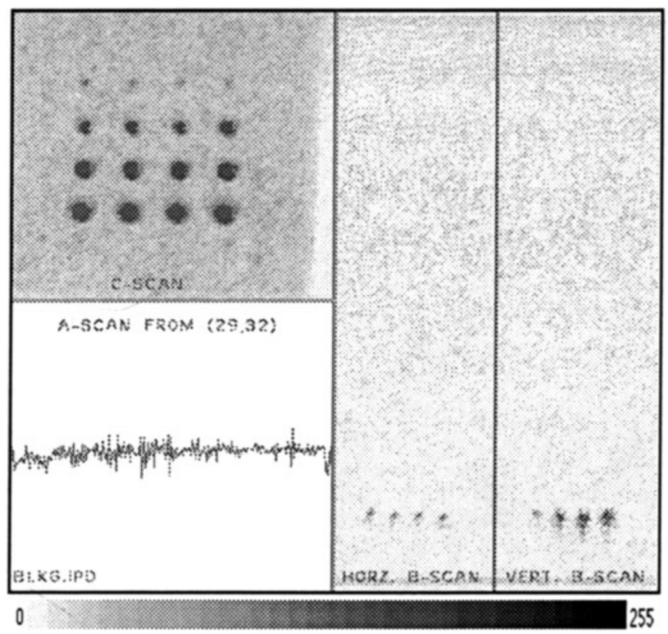


Figure 2. Shows the ultrasonic data obtained from a Ti17 block with #1 - #4 FBH, using a 15 MHz probe. Unprocessed C-scan (top left corner), unprocessed A-scan from #1 FBH (lower left corner), unprocessed horizontal B-scan across #1 FBH (center image) and unprocessed vertical B-scan along the #1 - #4 FBH (right most image).

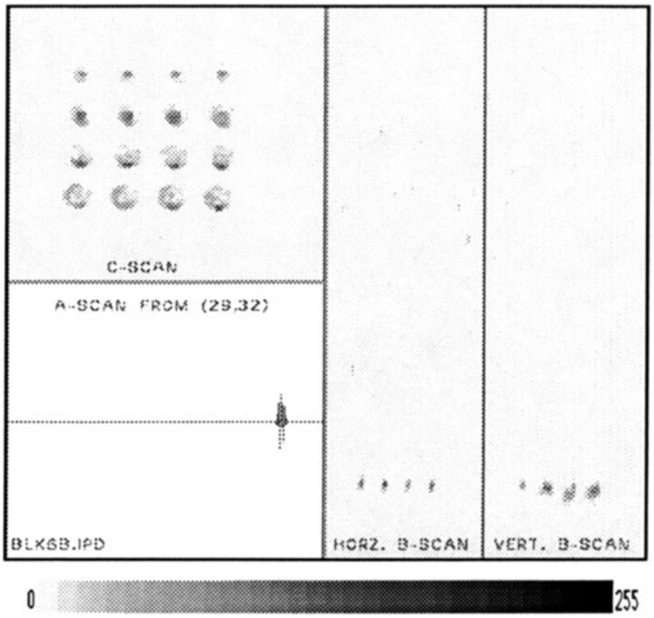


Figure 3. Shows the processed ultrasonic data obtained from a Ti17 block with #1 - #4 FBH, using a 15 MHz probe. Processed C-scan (top left corner), processed A-scan from #1 FBH (lower left corner), processed horizontal B-scan across #1 FBH (center image) and processed vertical B-scan along the #1 - #4 FBH (right most image).

in Figure 2. This data was processed utilizing the split spectrum minimization and polarity thresholding algorithm, with thirty-two filters placed between 15 and 18 MHz, each with 0.3 MHz bandwidth. This resulted in a significant improvement in detection, all the sixteen FBH are clearly visible with a significantly higher signal-to-noise ratio. The results of this processing is shown in Figure 3.

## SYNTHETIC HARD-ALPHA TEST BLOCKS

Since FBH are easier to detect than hard-alpha of the same size (due to the difference in acoustical properties), we decided to make several Ti64 blocks with synthetic hard-alpha inclusions of varying sizes #2 (2/64 in., 0.8 mm) through #5 (5/64 in., 2 mm)

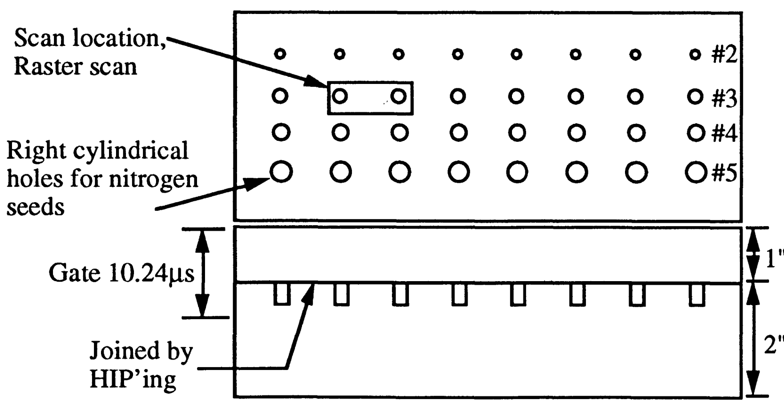


Figure 4. Shows the layout of the FBH before the nitrogen seeds were inserted and HIP'ed. The boxed region indicates the location where ultrasonic data was acquired for processing.

diameter cylindrical inclusions at one and two inches depth. The height of the cylindrical inclusions equals the diameter of inclusion, i.e. 2/64 - 5/64 inches. The synthetic hard-alpha was made by inserting 1.6% nitrogen seeds into cylindrical flat bottom holes and pressed hot isostatically (HIP) to make a test block. Similarly a block with 2.7% nitrogen seed was also made. Figure 4 shows the layout of the FBH before the seeds were inserted and HIP'ed.

## DATA ACQUISITION

Ultrasonic data from the 1.6% and 2.7% nitrogen blocks from the one inch face was acquired by scanning over two holes of equal diameter #3 size (3/64 in., 1.2 mm) with a scan resolution of 0.008 inches step x 0.008 inches index, using a 100 MHz A/D sampling rate. The transducer used was a 10 MHz, F11 transducer with a beam diameter of 0.067 inches which was focused on the front surface. The acquired data was gated from the front surface to 10.24 μs, well past the inclusions at ~8 μs. The boxed region in Figure 4 shows the location of the acquired data.

## RESULTS OF SPLIT SPECTRUM PROCESSING

Performance of the SSP algorithm on simulated hard-alpha using a 2.7% nitrogen seed is demonstrated here. Data from the 1.2 mm diameter or #3 inclusion (simulated hard-alpha) created using a 2.7% nitrogen seed, obtained using a 10 MHz, F11 transducer was processed using the split spectrum algorithm. The left column in Figure 5 shows sample raw unprocessed A-scans from 2 indications and a region with material noise. The right half shows processed A-scans from the same locations. This data was processed utilizing the split spectrum minimization and polarity thresholding algorithms, with fifty two filters placed between 10 and 15 MHz, each with 0.36 MHz bandwidth. The raw and processed data are shown in the form of a C-scan (created by gating the entire waveform) in Figure 6. On the left side are the raw C-scans from the 2 indications, with the corresponding image after thresholding at the bottom. The processed C-scans from the same locations are shown on the right, with the corresponding image after thresholding at the bottom. The result of this split spectrum processing shows the two inclusions clearly while the raw C-scan image shows the two indication along with a large region of noise (false call). By utilizing split spectrum processing we have eliminated this false call.

Having successfully demonstrated the improved detection of hard-alpha simulated by 2.7% nitrogen seeds, we now demonstrate the performance of SSP algorithm on detecting hard-alpha simulated by 1.6% nitrogen seeds. Ultrasonic data from #3 inclusions were collected in the same manner as the 2.7% nitrogen seeded data using the same transducer. The unprocessed A-scan data from the 1.6% nitrogen seeded block is shown on the left in Figure 7, with the corresponding processed A-scan on the right. This data was processed utilizing the split spectrum minimization and polarity thresholding algorithms, with forty six filters placed between 9.25 and 13.5 MHz, each with 0.36 MHz bandwidth. Figure 8 shows the C-scans made by gating the entire (10.24 μs) waveforms. From the unprocessed thresholded image of Figure 8 we observe three apparent indications and several regions of high noise (false calls). The results of the split spectrum processing shown on the right side of Figure 8 indicate that one of the indication is false and most of the noise in the data can be eliminated, revealing only the two programmed indications, clearly showing a significant performance improvement.

## SSP FILTER SELECTION CRITERIA

The filter selection criteria is based on the specular reflector criteria, that is, the ratio of wavelength to the size of the target to be detected must be greater than one (1:2 or 1:3). Longitudinal wave velocity ($V_L$) in Ti64 is 6.1 mm/μsec. Wavelengths ($\lambda$) contained in 10 to 15 MHz bandpass filters are 0.61 through 0.4 mm/cycle, while the minimum size of target to detect is 1.2 mm inclusion, hence, the selected filters performed reliably.

The processing time per A-scan with 1024, 8 bit samples points is 0.4 seconds, on a DEC VAX 4100 computer system. The processing time can be significantly reduced by coding the SSP algorithm on dedicated DSP hardware.

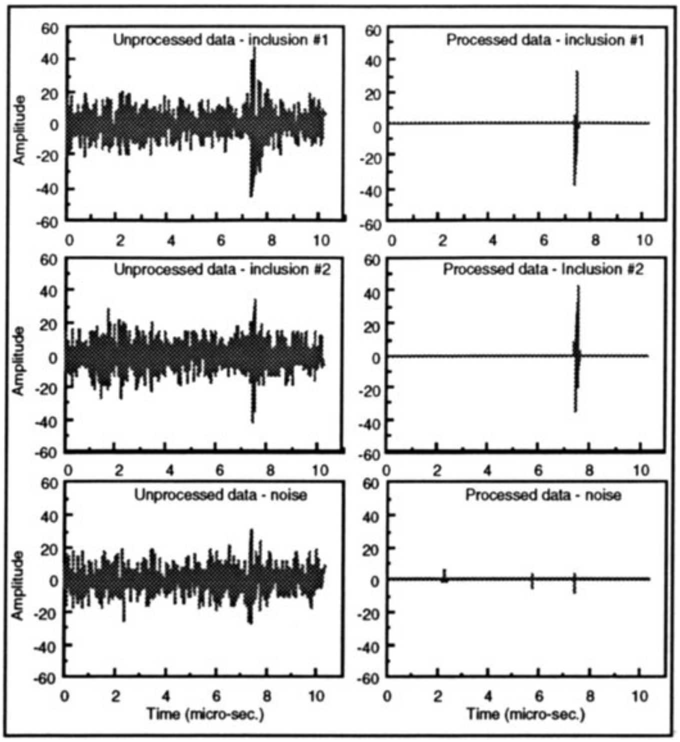


Figure 5. Shows sample raw unprocessed A-scans from #3 synthetic hard-alpha simulated using 2.7% nitrogen seeds, 2 indications and a region with material noise in the left column. The right half shows processed A-scans from the same locations.

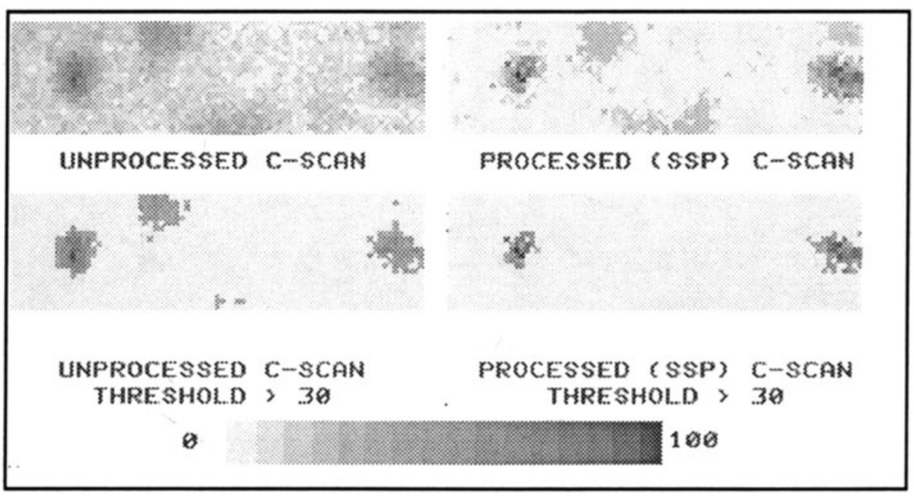


Figure 6. Shows the raw C-scans from the 2 indications (2.7% nitrogen seed) on the left, with the corresponding image after thresholding at the bottom. The processed C-scans from the same locations are shown on the right, with the corresponding image after thresholding at the bottom.

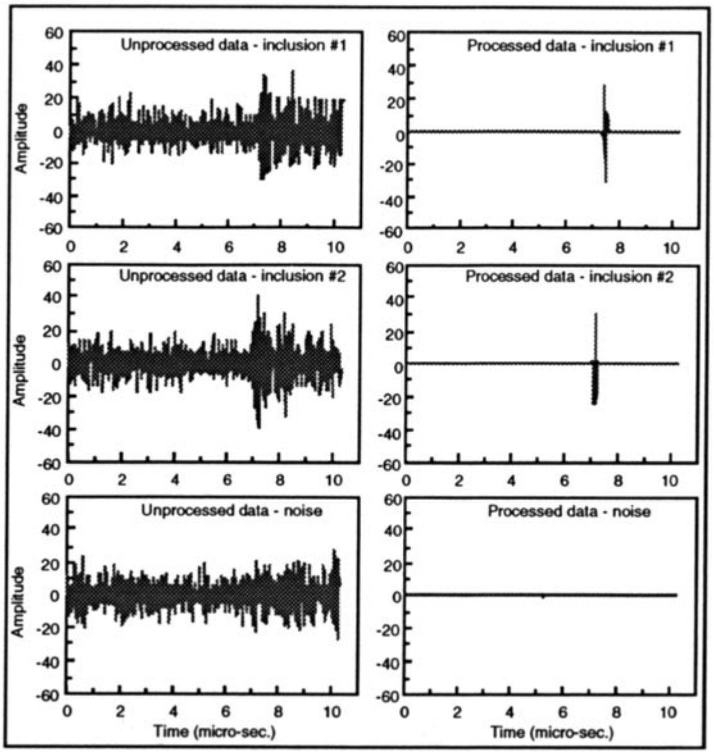


Figure 7. Shows sample raw unprocessed A-scans from #3 synthetic hard-alpha 1.6% nitrogen seeds, 2 indications and a region with material noise in the left column. The right half shows processed A-scans from the same locations.

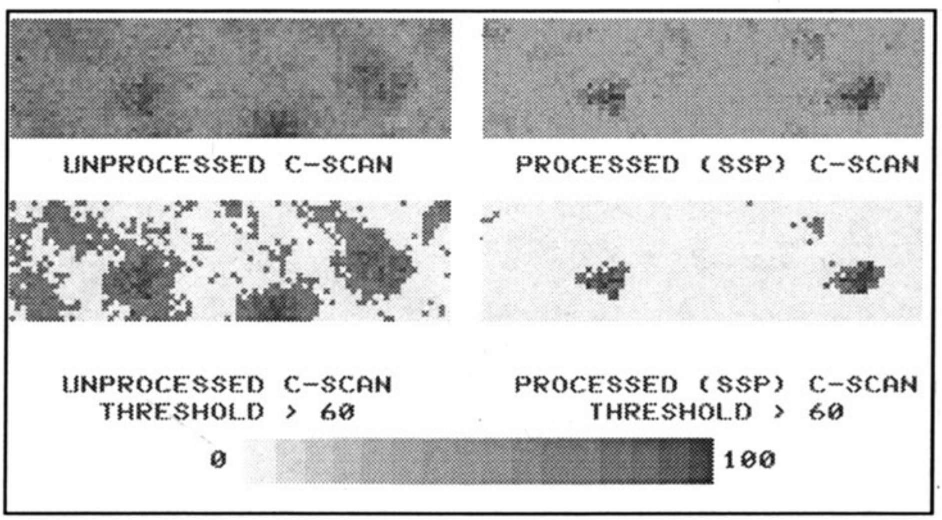


Figure 8. Shows the raw C-scans from the 2 indications (1.6% nitrogen seeds) on the left, with the corresponding image after thresholding at the bottom. The processed C-scans from the same locations are shown on the right, with the corresponding image after thresholding at the bottom.

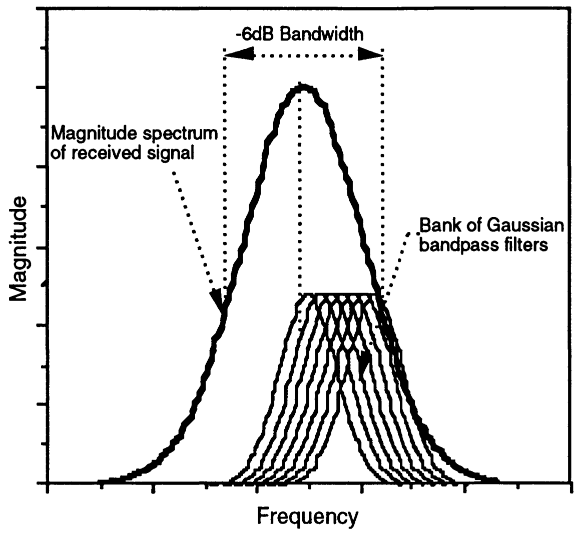


Figure 9. Shows a schematic of the filtering scheme used in the spectral decomposition technique. The transducer's center frequency was 10 MHz, -6 dB bandwidth of 7.5 - 14.5 MHz. Typical SSP filter location are first filters at 10 MHz and last at 15 MHz with a filter bandwidth of 0.364 MHz for each filter, with a total of fifty two filters.

## CONCLUSION

In this research we have shown that split spectrum processing shows significant promise in detecting small synthetic hard-alpha inclusions and small flat bottom holes. Split spectrum processing has demonstrated potential to suppress material noise in Ti64 and Ti17 alloys, while enhancing signals from targets as small as #1 FBH (1/64 in. or 0.4 mm) and #3 synthetic hard-alpha (3/64 in. or 1.2 mm) inclusions. The execution time of the SSP algorithm needs to be improved for field application, through dedicated DSP hardware.

## FUTURE WORK

In the future SSP will be evaluated fully to understand the effects of transducer characteristics such as frequency, F number, focusing into the material, target size, shape, composition and depth. This research will further investigate other signal processing techniques and evaluate the performance of all promising techniques. The evaluation criteria will be actual number of targets present in test sample verses the number of targets detected, normalized processing time and amount of raw data required per pound of material.

## ACKNOWLEDGMENTS

This work is supported by the FAA, Engine Titanium Consortium.

## REFERENCES

1. D.C. Copley and P.J. Howard, “Operational Performance of a Multizone Billet Inspection System”, Review of Progress in QNDE Vol. 14, Eds. D.O. Thompson and D.E. Chimenti Plenum, New York, 1994.

2. P. Karpur, “Split-Spectrum Technique as a Perprocessor for Enhanced Reliability in Ultrasonic Signal Analyses”, Materials Evaluation, pp: 793-797, June 1992.

3. J.L. Rose, P. Karpur and V.L. Newhouse, “Utility of Split-Spectrum Processing in Ultrasonic Nondestructive Evaluation”, Materials Evaluation, pp: 114-122, Jan. 1988.