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# An Investigation into the Performance of Complex Plane Spilt Spectrum Processing Ultrasonics on Composite Materials

**Manfred S JOHANNES**
**CSIR**
**P O Box 395, Pretoria, 0001**
**E-mail: mjohannes@csir.co.za**

**Philippe RUBBERS**
**SCM**
**15 Tesla Crescent, Sunnighill, 2157**
**E-mail: philippe.rubbers@eskom.co.za**

**Abstract**

A number of signal processing techniques exist to improve signal to noise ratio of ultrasonic signals. One such technique is called Complex Plane Split Spectrum Processing (CSSP). This technique is a modification to the Split Spectrum Processing (SSP) technique. CSSP is capable of being able to surpass SSP in terms of improvements in signal to noise ratios, while maintaining linearity in both the amplitude and the energy content of a flaw's signal.[1]

CSSP makes use of an additional mathematical dimension (the complex plane) when solving for the probability that a signal originates from a real reflector such as a flat bottom hole. This paper outlines work performed on laminate composite materials (carbon fibre and G11 phenolic sheet material) to assess the efficacy of the CSSP technology on these materials. This paper also serves to formalize some of the validation steps required of CSSP such that it may be ported from the laboratory to industrial application as an ultrasonic testing technology.

**Keywords:** Laminate composite materials, CSSP, Ultrasonic Testing

## 1. Introduction

Fibre reinforced composite materials are increasingly being used in engineering applications in the aircraft industry as they display an excellent weight to strength ratio. The limitation on the use of these materials in load bearing applications is largely brought about by the difficulties in inspecting these materials in a non-destructive manner. Also, the lack of mechanical behaviour data for these materials in general e.g. fractures toughness, which could provide information regarding the size of critical defects, contribute to the challenges in inspections.

In order to establish a generic composite reference standard that will accommodate nondestructive inspections on the full array of glass fibre and carbon fibre laminates found on aircrafts, the Engineering Society for Advanced Mobility Land Sea and Space International (SAE) issued an Aerospace Recommended Practice ARP 5605[2]. This document details the requirements for NDI Reference Standards for the inspection of Solid Composite Laminates. In this document it is proposed that reference samples for Ultrasonic Testing (UT) can be manufactured from G11 phenolic sheet material, as this material displays the same or similar properties for the sound velocity, acoustic impedance and attenuation values as those from fibre glass and carbon graphite composites.

Samples for this exercise were manufactured from both G11 Phenolic sheet material and Carbon Fibre composites in line with ARP5605. Two types of Carbon fibre blocks were obtained i.e. one manufactured by the “paint and bucket method”, where dry fibres are manually covered with epoxy and then cured; the other was manufactured from pre-impregnated fibres and then cured in the same fashion. The reflectors introduced into the blocks were machined flat bottom holes (FBH) viz. 2, 4, 6, 8 and 10mm diameter respectively at three depths of 5, 10 and 15 mm.

The CSSP Ultrasonic system used in this project was designed and manufactured by Eskom personnel to overcome problems encountered in course grain materials such as austenitic castings and cast materials in general. Details of the system can be found in the publications mentioned below.[1 and 3]

Composite materials are inherently non-homogeneous materials and the fabrication process invariably affects the service reliability of the materials. It has been shown that ultrasonic attenuation can be used to indicate the fatigue life of the material.[6] The material parameters such as dispersion of the energy and the high attenuation due to absorption and scattering of the ultrasonic energy, affect the detection of UT signal. Apart from the attenuation from the composite material, the presence of voids and small air bubbles further deteriorate the UT signal and increase the attenuation. As a result the reflected UT signal can be in the noise and in order to detect these signals some signal processing algorithm is required. [4]

For this work the aim was to assess to what degree CSSP can be used to detect UT signals which lie in the noise of the reflected signal. Of further interest was the establishment of procedures for the selection of the CSSP frequency bands and phase spread depending on flaw size and material properties.

## 2. Methodology

Flat bottom holes were introduced by milling tools into the test blocks with the respective diameters as indicated. The bottoms of the holes were examined visually and were found to be flat, whilst the surfaces displayed some surface roughness.

Equipment used for the ultrasonic inspection comprised of a Lecoeur USBox pulser connected to a laptop computer, which runs the CSSP software. The probe used for the assessment was a broad band Karl Deutsch normal probe with a crystal diameter of 12 mm. The band width of frequencies excited by the probe extends from 1 MHz to 8 MHz (S12 HB1-8).

Scanning of the blocks was performed manually and care was taken to ascertain the repeatability of the results obtained. Screen dumps were recorded and readings from these images are tabulated in the results below.

The details of the test blocks are as follows

| **Block nr.1** | |
|---|---|
| Type of material | G11 Phenolic Sheet Material |
| Dimensions | 150 mm x 100 mm – Thickness = 25,2 mm |
| Longitudinal velocity | 3347 m/s |

| | |
|---|---|
| **Block nr.2** | |
| Type of material | Carbon Fibre Block – Pre-impregnated fibres |
| Dimensions | 150 mm x 100 mm – Thickness = 23,7 mm |
| Longitudinal velocity | 2884 m/s |
| **Block nr.3** | |
| Type of material | Carbon Fibre Block – Manufactured from dry fibres |
| Dimensions | 150 mm x 100 mm – Thickness = 24,2 mm |
| Longitudinal velocity | 2458 m/s |

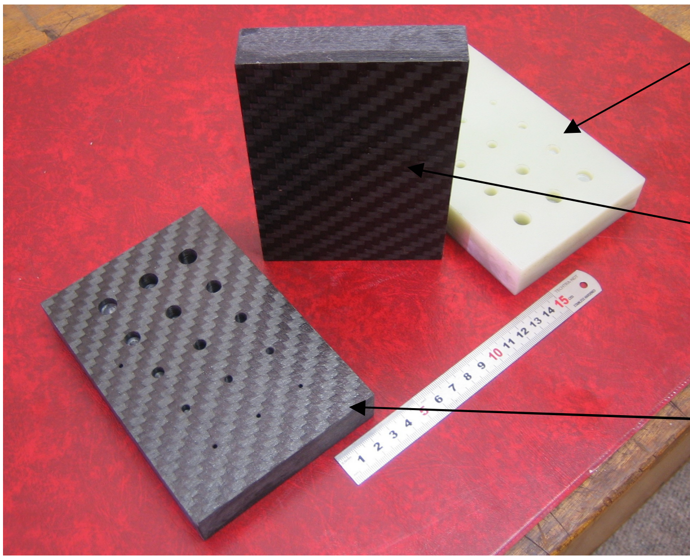



**Figure 1: Test blocks**

## 3. Results

Carbon block 1 was UT tested, with the back wall as follows:

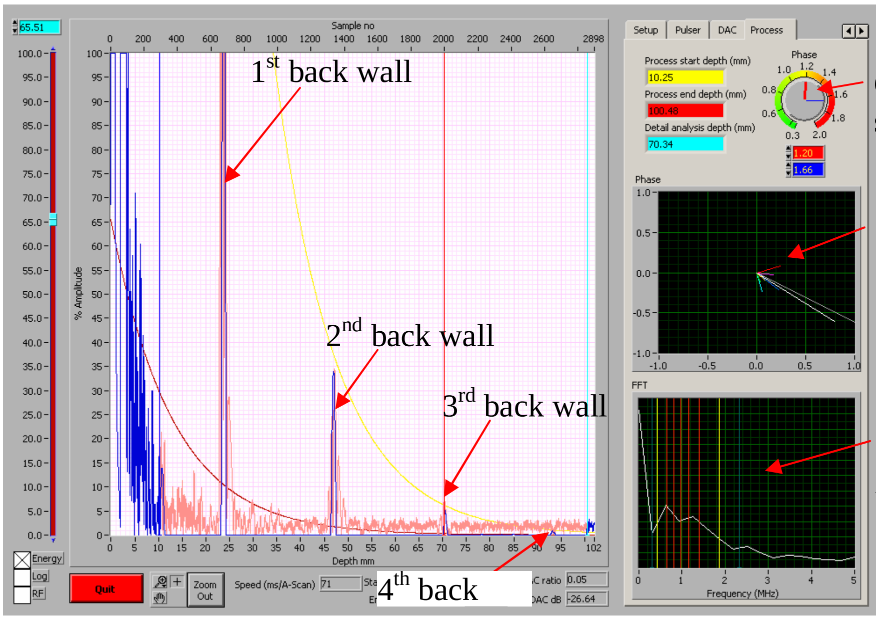



**Figure 2: Carbon block 1 back wall reflections where blue depicts the CSSP UT signal and pink the Original unprocessed UT signal**

Similar printouts were produced for every measurement and the results obtained are as follows:

### 4.1 Block nr.1: G11 Phenolic sheet material:

Reference sensitivity at 48dB, with first back wall at 80%

| FBH Φ | CSSP Amplitude %FSH | Noise level %FSH | S/N Ratio (dB) | Unprocessed Amplitude %FSH | Noise level %FSH | S/N Ratio (dB) | Improvement (dB) |
|---|---|---|---|---|---|---|---|
| 10 mm | 95 | 1 | 40 | 95 | 5 | 26 | 14 |
| 8 mm | 67 | 1 | 37 | 67 | 4 | 24 | 12 |
| 6 mm | 60 | 1 | 36 | 60 | 3 | 26 | 10 |
| 4 mm | 35 | 1 | 31 | 35 | 6 | 15 | 16 |
| 2 mm | 8 | 1 | 18 | 11 | 5 | 7 | 11 |

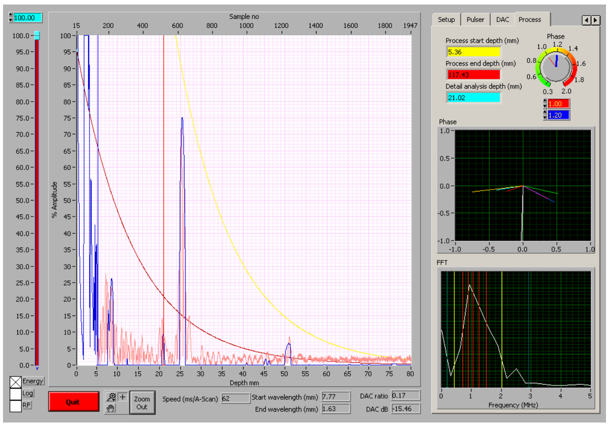


**Figure 3: Screen dump of the data obtained from the 2 mm FBH**

In the unprocessed data the signal to noise ration was 7dB. This was improved to 18dB after CSSP processing.

### 4.2 Block nr.2: Pre-impregnated Carbon Fibre Composite Material

Reference sensitivity at 48dB, with first back wall at 80%

| FBH Φ | CSSP Amplitude %FSH | Noise level %FSH | S/N Ratio (dB) | Unprocessed Amplitude %FSH | Noise level %FSH | S/N Ratio (dB) | Improvement (dB) |
|---|---|---|---|---|---|---|---|
| 10 mm | 100 | 1 | 40 | 100 | 5 | 26 | 14 |
| 8 mm | 98 | 1 | 40 | 98 | 5 | 26 | 14 |
| 6 mm | 60 | 1 | 36 | 60 | 5 | 22 | 14 |
| 4 mm | 36 | 1 | 31 | 36 | 5 | 17 | 14 |
| 2 mm | 5 | 1 | 14 | 12 | 5 | 8 | 6 |

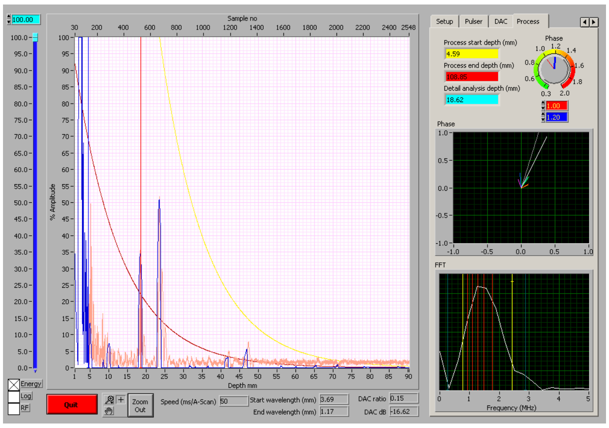


**Figure 4: Screen dump of the data obtained from the 4 mm FBH**

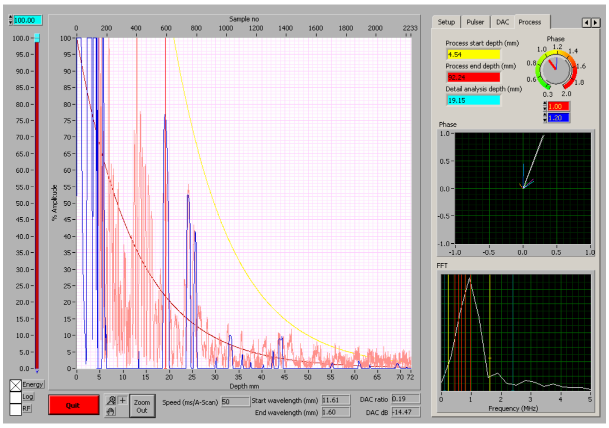
### 4.3 Dry-fibre Carbon Composite Material

Reference sensitivity at 62dB, with first back wall at 80%

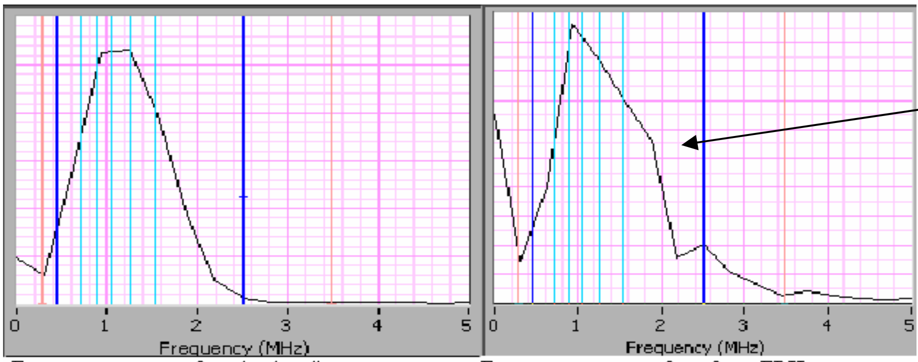
| FBH Φ | CSSP Amplitude %FSH | Noise level %FSH | S/N Ratio (dB) | Unprocessed Amplitude %FSH | Noise level %FSH | S/N Ratio (dB) | Improvement (dB) |
|---|---|---|---|---|---|---|---|
| 10 mm | 60 | 1 | 36 | 85 | 35 | 8 | 28 |
| 8 mm | 63 | 1 | 36 | 90 | 20 | 13 | 23 |
| 6 mm | 45 | 1 | 33 | 60 | 35 | 5 | 28 |
| 4 mm | 20 | 1 | 26 | 40 | 15 | 9 | 18 |
| 2 mm | 20 | 1 | 26 | 25 | 20 | 2 | 24 |

**Figure 5: Screen dump of the data obtained from the 2mm FBH.**

In the unprocessed data the signal to noise ration was 2 dB. This was improved to 26dB after CSSP processing.



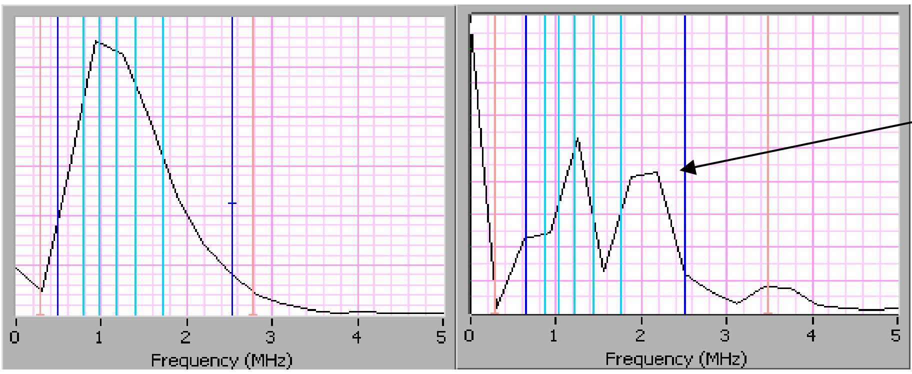
### 4.4 Frequency Response from the back wall of each test block and the 2 mm FBH




Higher frequencies reflected from 2mm FBH. Filter setting the same for back wall signals and signals from FBH.

Frequency response from backwall    Frequency response from 2mm FBH

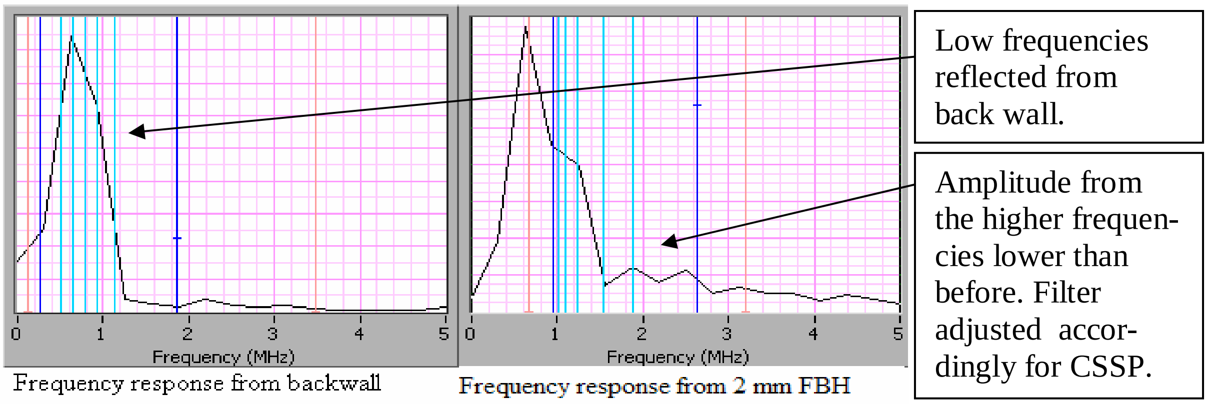
Block nr. 1 - G11 Phenolic material




Higher frequencies reflected from 2mm FBH. Filter setting the same for back wall signals and signals from FBH.

Response from backwall    Response from 2mm FBH

Block nr. 2 - Impregnated Carbon Fibre




Frequency response from backwall

Frequency response from 2 mm FBH

Block nr.3 - Dry Carbon Fibre

From the data it can be seen that the backwall reflects the lower frequencies stronger, whilst the 2 mm FBH also reflects higher frequency components. The filter settings had to be changed to exclude the low frequencies during the assessment of the 2 mm FBH by CSSP in the highly attenuative material from block nr. 3.

## 5. Discussion

### 5.1 Improvement in signal to noise ratio:

(1) The signal to noise ratio was improved in every instance. However, where the signal to noise ration was > 6 dB the improvement is of no consequence, as the signal can be detected in the unprocessed data as well.

(2) An advantage of the CSSP technology on the “clean materials” i.e. blocks nr. 1 and 2, lies in the better understanding of the material, which enables the user to use optimised narrow band probes, which invariably are cheaper to procure.

(3) On block nr. 3 the CSSP processing succeeded in filtering out the 2 mm FBH indication which lies in the noise band. It must however be noted, that the indication in essence could only be identified because of the prior knowledge, that the reflector was present. In a blind trial, this defect will be difficult to detect.

### 5.2 Frequency response from the back wall and the 2 mm FBH:

(4) The backwall reflects the lower frequency band stronger than the higher frequencies.

(5) In block nr.3 only the very low frequencies (< 1,2 MHz) are reflected from the back wall. This is due to the high attenuation of the material, which was found to be 14 to 16 dB higher than the attenuation in the G11 phenolic material.

(6)The reflection from the 2 mm FBH in every instance contained frequencies around 2 MHz. This is explained by the fact that the lower frequencies do not resolve the small reflector.

(7) It is often forgotten in highly attenuating materials that the wave length of the energy must be in the order of the indication which has to be detected. This point is proven by the higher frequencies which are reflected from the 2 mm FBH.

## 6. Conclusions

(1) Laminate composite materials can be easy to inspect by UT if they are manufactured correctly.

(2) CSSP improves S/N ratios significantly. However, the improvement is only significant in instances where the S/N ration is < 6 dB.

(3) Broad band probes together with CSSP allows better UT characterization for inspection design.

(4) CSSP is primarily a development tool and has no clear advantage for field use as yet.

## References

[1] P Rubbers and C Pritchard, Complex plane Split Spectrum Processing: an introduction, NDT.net, Nov 2003, Vol. 8 No. 11
[2] SAE, Aerospace Recommended Practice ARP 5605, Solid Composite Laminate NDI Reference Standards, http://www.sae.org.
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