

DolphiCamTM 1.3 Technical Paper

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1 Introduction

This document describes version 1.3 of the DolphiCamTM acoustic camera. DolphiCamTM is a hand-held real-time imaging ultrasound camera with a dry-coupling front surface which enable inspection of, in particular, carbon fiber reinforced plastics (CFRP) without any liquid couplants.¹ The DolphiCamTM comes in two versions where the first version is designed for 8 mm CFRP and the second version is designed for 16 mm CFRP, respectively. Hereafter, we refer to the 8 mm version as *CF08* and the 16 mm version as *CF16*. The CF08 version can deliver 2 or 4 ultrasound images per second and the CF16 camera 1 or 2 images per second.

2 System Overview

Figure 1 shows an overview of the DolphiCamTM.

¹The DolphiCamTM is build according to IP54 and can be used with liquid couplants, such as ultrasound gel or water, if desired.

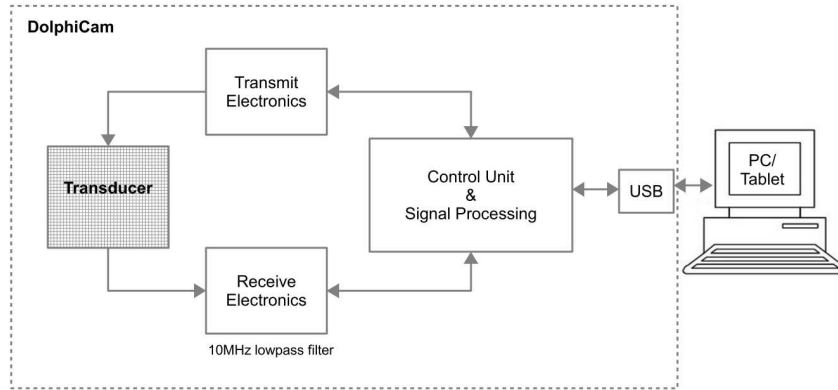


Figure 1: DolphiCam™ system overview.

The transmit/receive control and on-camera signal processing is performed by a field-programmable gate array (FPGA). Version 1.3 of the DolphiCam™ has 8 different pre-defined CF08 pulses and 4 CF16 pulses which drives the 2D transducer array using a high voltage driver. The received signals are first amplified and then filtered by an analog anti-aliasing filter with a cut-off frequency at 10 MHz. Second, after digitization, the acquired data are processed using the FPGA to increase the SNR and time-resolution. The system also have a user controlled averaging to improve the SNR further (2 or 4 averages). Finally, the FPGA performs basic feature extraction on the signal (amplitude and time) and sends data to the camera host. The software on the camera host controls settings on the camera and present images, such as

- envelope A-scans,
- X- and Y-directional envelope B-scans,
- amplitude and time-of-flight C-scans.

These images are presented as live video on the display device.

3 Transducer Specification

The transducer consists of a piezoelectric two dimensional 124×124 element array (15376 elements) which is illustrated in Figure 2).

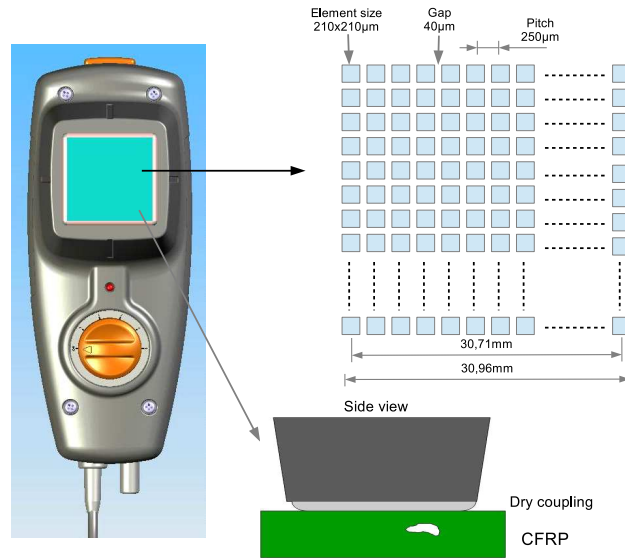


Figure 2: Illustration of the DolphiCam™ transducer.

When a high voltage pulse is applied to one or several transducer elements in the array, an acoustic wave is generated which travels through a (dry) coupling pad and into the material under inspection. The reflected waves are then picked up by the elements in the array which then converts the mechanical energy to electrical signals. The geometry for the array is also presented in Table 1. The transducer-to-air impulse and frequency

Number of transducer elements	$124 \times 124 = 15376$
Element size	$210 \times 210 \text{ } [\mu\text{m}]$
Element spacing	$40 \text{ } [\mu\text{m}]$
Transducer width/length center-to-center	$30.71 \text{ } [\text{mm}]$
Transducer width/length edge-to-edge	$30.96 \text{ } [\text{mm}]$
Dry coupling thickness	$3.0 \text{ (CF08) or } 6.3 \text{ (CF16) } [\text{mm}]$
Dry coupling speed of sound	$\approx 0.95 \text{ } [\text{km/s}] \text{ @ } 20 \text{ } [^\circ\text{C}]$

Table 1: DolphiCam™ specs.

responses of the (CF08) transducer is shown in Figure 3.

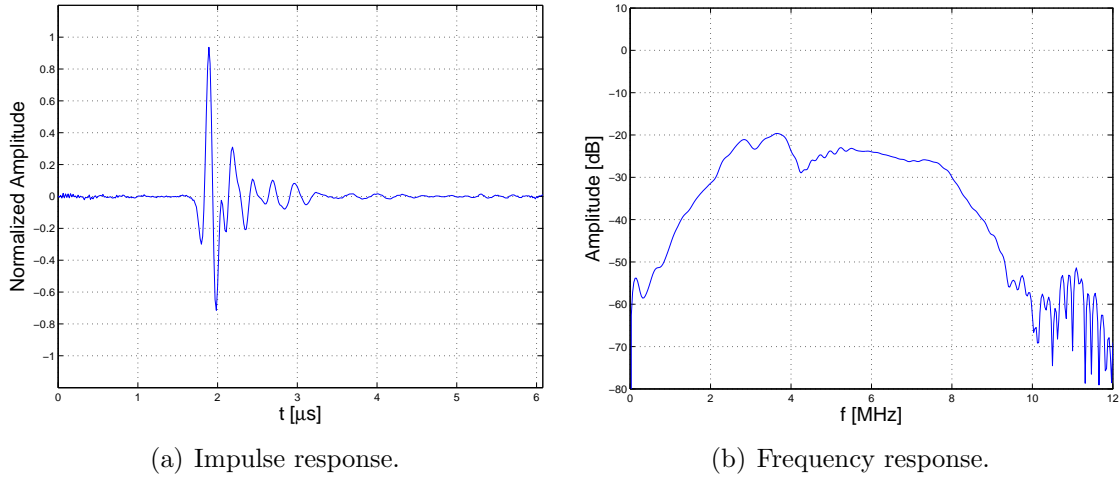


Figure 3: Impulse and frequency response of the CF08 DolphiCam™ 1.3 transducer measured with the transducer in free space (air).

4 Pulses

4.1 CF08 Pulses

The input transmit pulses are shown in Figure 4; the rise- and fall-time is ≈ 18 [ns].² Note that Pulse 1 is similar to pulse 2, pulse 5 to pulse 6, and pulse 7 to pulse 8, respectively; these pulses are kept in DolphiCam™ 1.3 for compatibility with earlier releases of the system. The corresponding spectra of the input pulses are shown in Figure 5.

²The data were acquired with an Agilent MSO-X 4052A digital oscilloscope using an Agilent N2894A (700 MHz) probe.

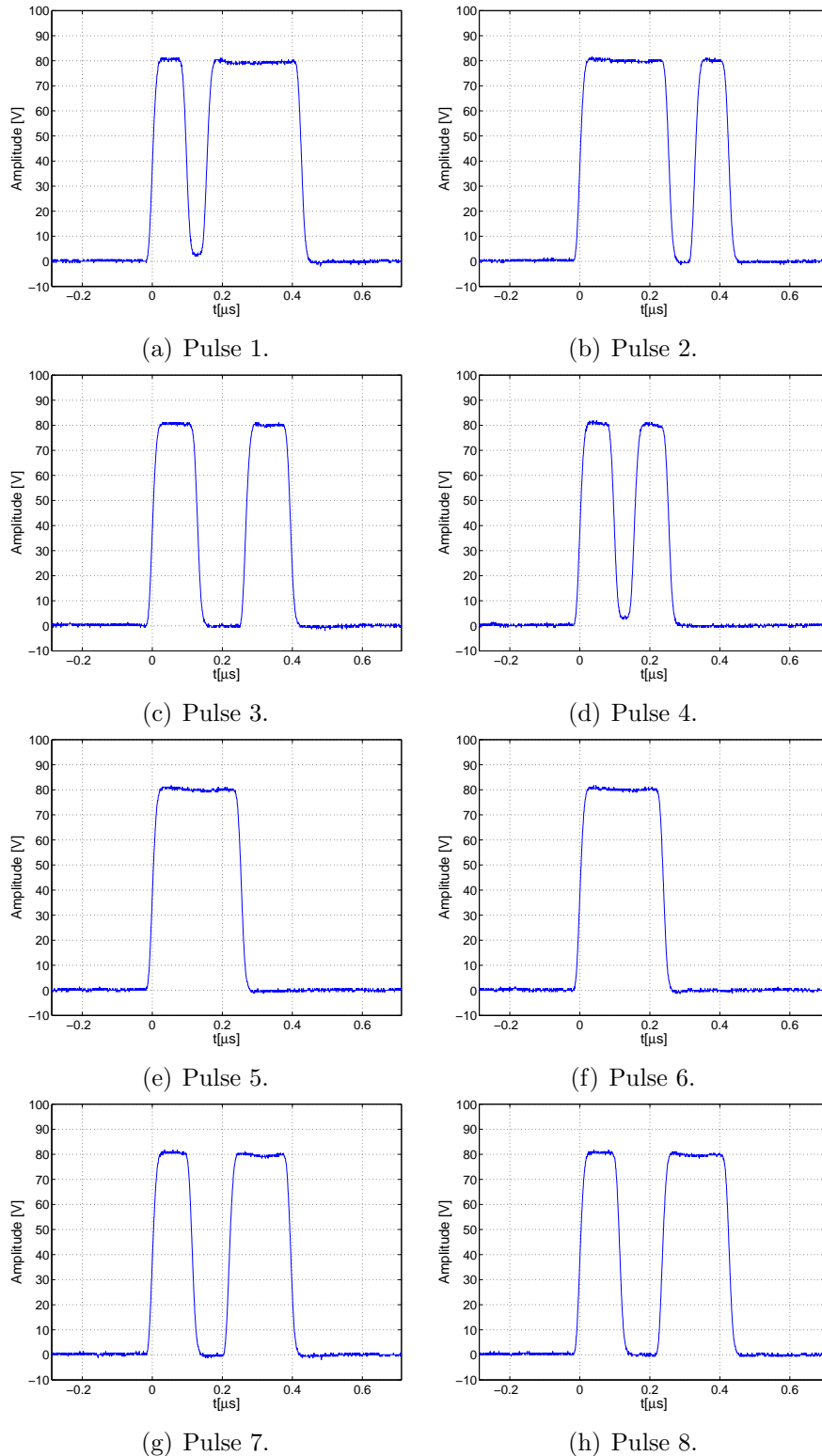


Figure 4: The CF08 input pulses for DolphiCam™ 1.3 measured with an Agilent MSO-X 4052A digital oscilloscope.

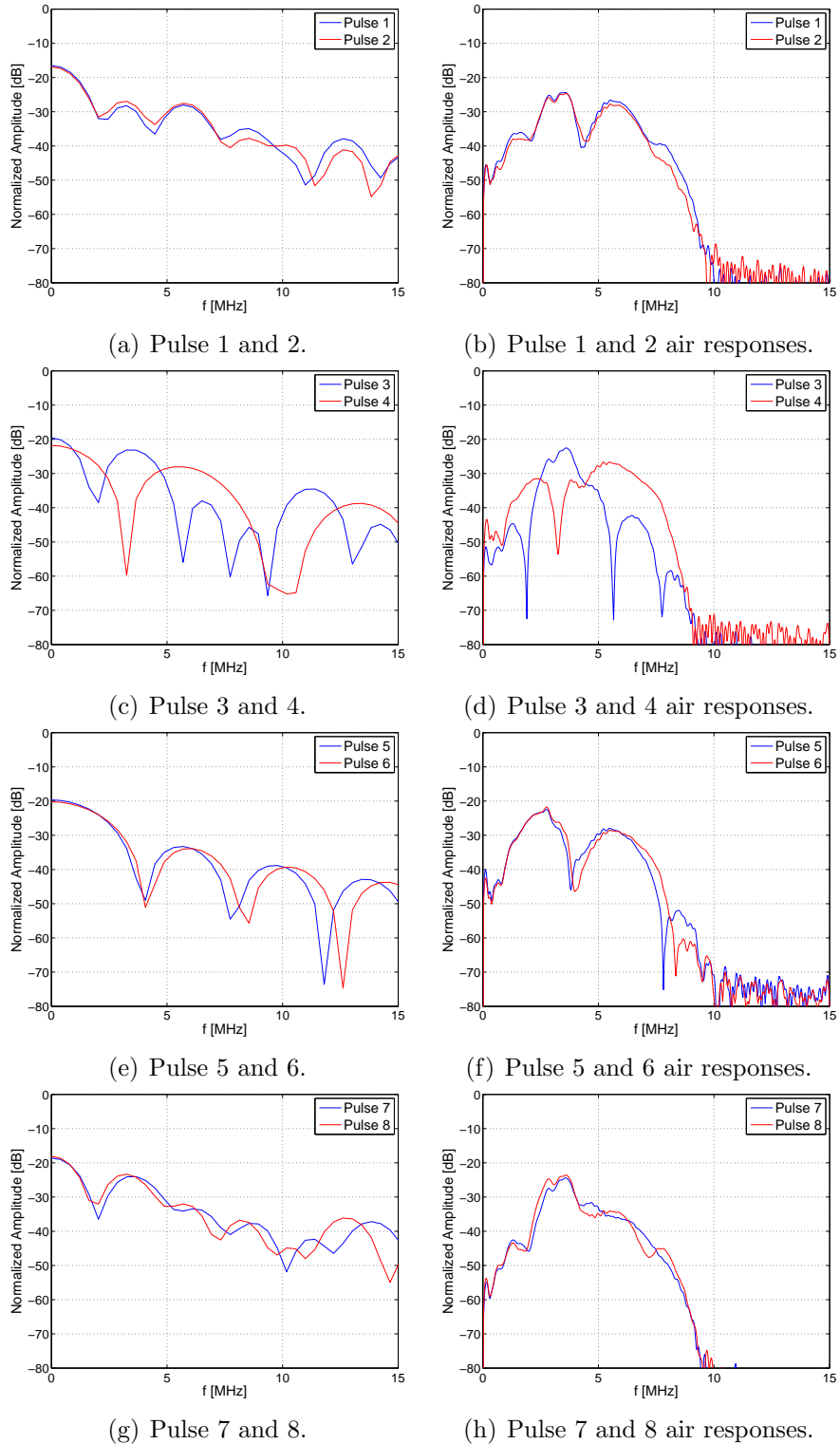


Figure 5: Spectra of the CF08 DolphiCam™ input pulses and the corresponding transducer-to-air frequency responses.

4.2 CF16 Pulses

The input transmit pulses for the CF16 version is shown in Figure 6. Pulse 1 is designed for high temporal resolution and Pulse 2 for high pulse energy. Pulse 3 is aimed at the high frequency region and pulse 4 at the low frequency region. The spectra for all the CF 16 pulses and the corresponding frequency responses measured with the camera in open air is shown in Figure 7.

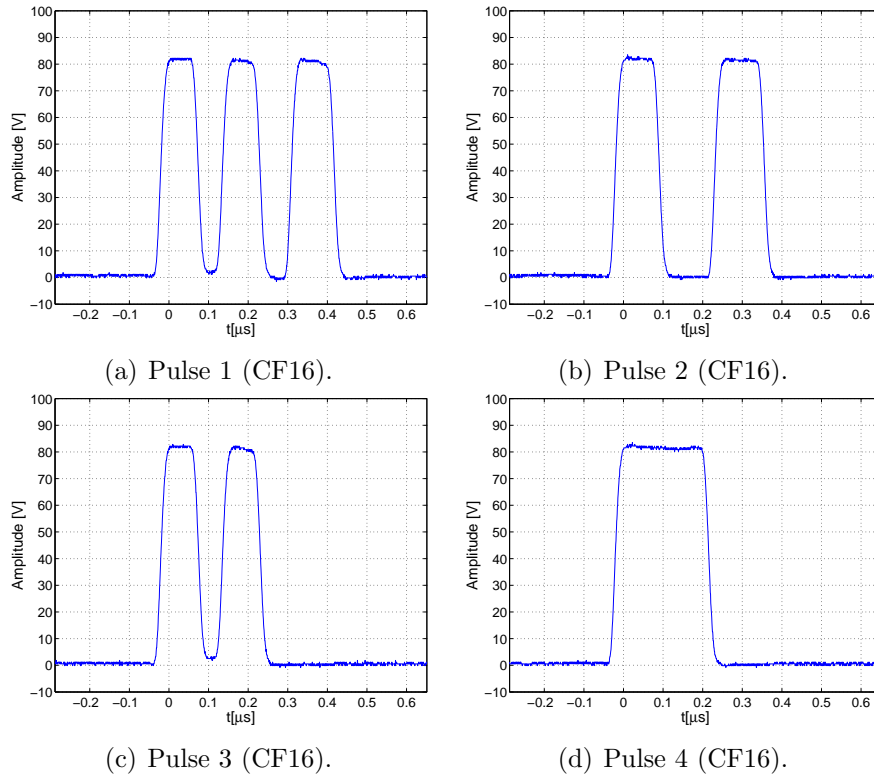


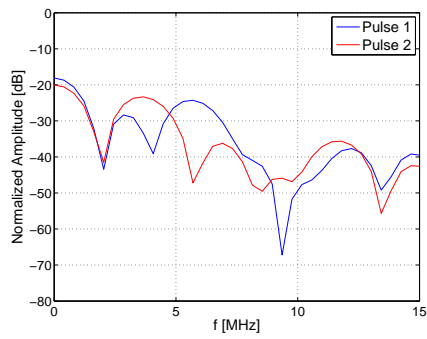
Figure 6: The CF16 input pulses for DolphiCamTM 1.3 measured with an Agilent MSO-X 4052A digital oscilloscope.

4.3 Filtering

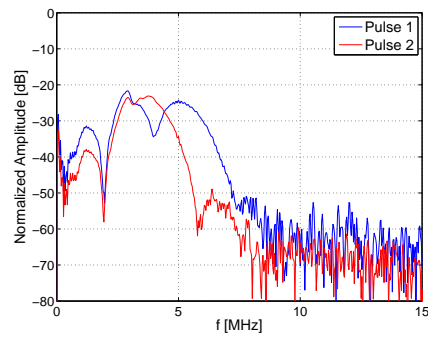
The DolphiCamTM performs real-time filtering of sensor data to improve the SNR. That is, for each corresponding pulse, a matched filtering is performed with the (double-path) transducer-to-air response. This can be expressed,

$$\begin{aligned}
 y_{mf}(t) &= p_{air}(-t) * y(t) \\
 &= \int_{\tau=-\infty}^{\infty} p_{air}(t + \tau)y(t)d\tau
 \end{aligned} \tag{1}$$

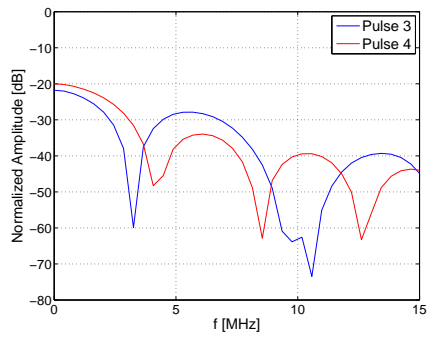
where $*$ is the convolution operator, $p_{air}(t)$ the transducer-to-air response, $y(t)$ the sensor data (unprocessed A-scan), and $y_{mf}(t)$ the matched filtered data. Here we perform discrete



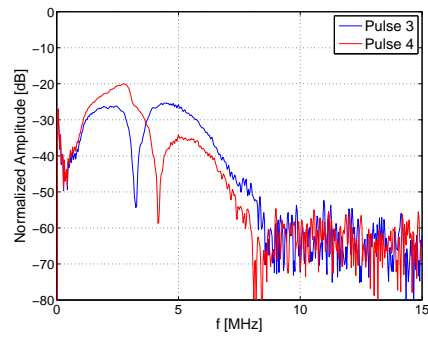
(a) Pulse 1 and 2 (CF16).



(b) Pulse 1 and 2 air responses (CF16).



(c) Pulse 3 and 4 (CF16).



(d) Pulse 3 and 4 air responses (CF16).

Figure 7: Spectra of the CF16 DolphiCam™ input pulses and the corresponding transducer-to-air frequency responses.

time filtering where the pulse length of $p_{\text{air}}(t)$ currently is 64 samples (this may change in the future). An illustration of the matched filtering is shown in Figure 8. The time-of-

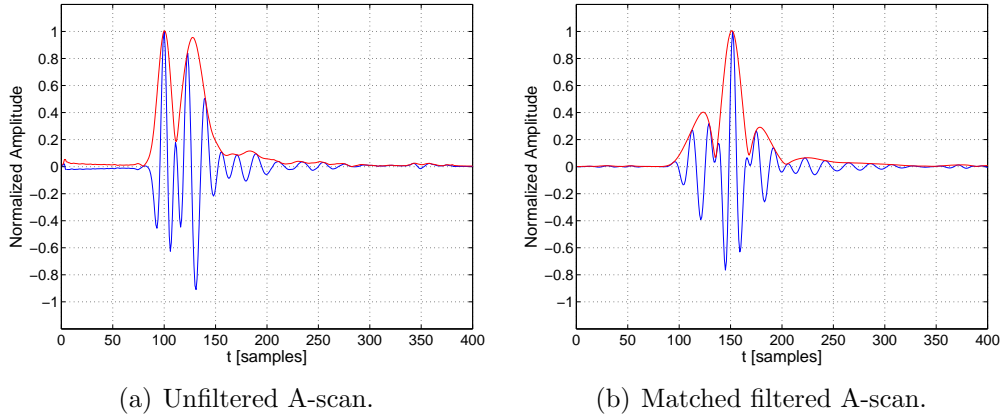


Figure 8: Illustration of the DolphiCamTM matched filtering (the envelop of the pulse is shown in red color).

flight and amplitude C-scans displayed in the DolphiCamTM application are both based on matched filtered data.

Note that in the *DolphiCamTM Research* version of the camera, where one can save sensor data to disk, one needs to be aware of whether filtering is switched on or not (see the DolphiCamTM Research user manual for more information).