Full-Matrix Capture with a Customizable Phased Array Instrument

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Abstract. In recent years, a technique known as Full-Matrix Capture (FMC) has gained some headway in the NDE community for phased array applications. It's important to understand that FMC is the method that the instrumentation acquires the ultrasonic signals, but further post-processing is required in software to create a meaningful image for a particular application. Having a flexible software interface, small form factor, excellent signal-to-noise ratio per acquisition channel on a 64/64 or 128/128 phased array module with FMC capability proves beneficial in both industrial implementation and in further investigation of post-processing techniques. This paper will provide an example of imaging with a 5MHz linear phased array transducer with 128 elements using FMC and a popular post-processing algorithm known as Total-Focus Method (TFM).

INTRODUCTION

The field of Non-Destructive Evaluation (NDE) evolves with technology, as emergent techniques provide improved inspection quality and broaden the scope of applications. The advent of Phased Array (PA) imaging revolutionized the inspection process by providing multidimensional spatial information that was difficult – at best – to obtain using single-element methods. The utilization of PA inspection can be found in all areas of NDE and increased the demand for instrumentation and image-processing algorithms to accommodate the diverse range of applications. It is essential that instrumentation and software remain flexible in order to support this wide array of applications as new techniques are introduced. In addition to providing a platform for researching new technologies, versatility reduces the cost of implementation by permitting equipment to adapt rather than be replaced. To illustrate the advantages of flexibility, this paper will outline the adaptation of an open-platform PA instrument to a new technique, Full-Matrix Capture (FMC), and the benefits it provides by applying a post-processing algorithm, Total-Focus Method (TFM).

FULL MATRIX CAPTURE (FMC)

FMC is a developing technique that describes a pulse/receive method implemented during data acquisition. There is no beam forming performed in the hardware, and consequently there is no loss of information from individual elements. Once the data is streamed to a PC, software must implement a post-processing or visualization algorithm. The underlying concept of FMC is that each element of an array is pulsed individually, and the reflected signal from this emission is received on all elements in parallel. The following illustration (Figure 1.) gives an example of the FMC sequence for an array of four elements.

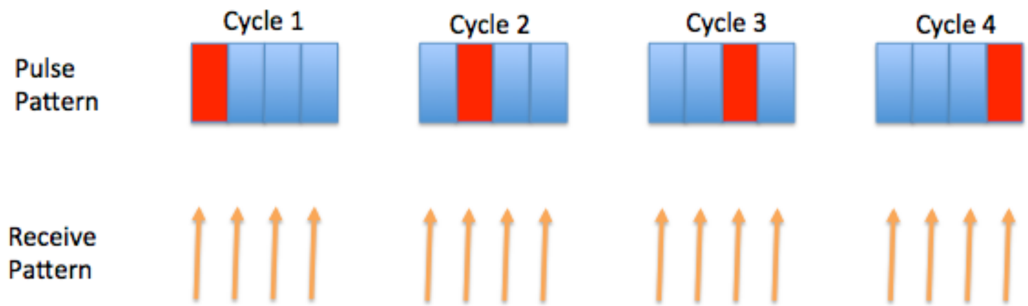
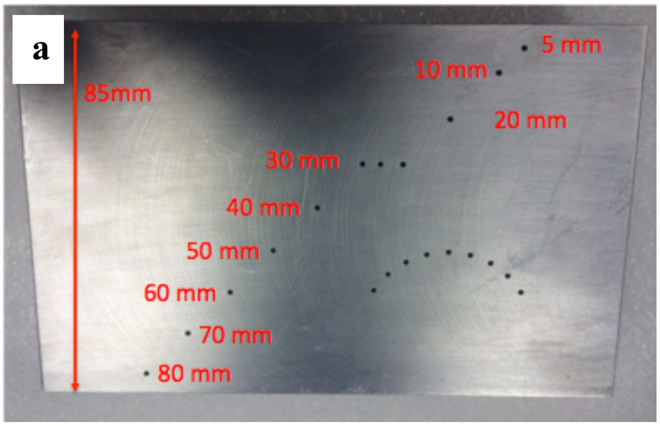


Figure 1. Pulse/receive pattern for a FMC acquisition using a linear array with four elements.

As can be seen in Figure 1., the number of data acquired is the square of the number of pulses. This results in a large amount of data, particularly for arrays with higher number of elements. For example, a 64-channel OEMPA with a 64-element transducer will produce 64^2, or 4,096 raw A-scans. Although this abundance of data can pose challenges for data throughput and storage, the information contained in this multitude of raw A-scans can be used to construct an incredibly detailed image.

TOTAL FOCUSING METHOD (TFM)

TFM is a popular algorithm for image reconstruction following data acquisition using the FMC method. Since FMC contains the entirety of raw acquisition data, TFM has the ability to apply delay laws to focus at any point within the matrix. While this article will not go into the details of numeric calculations, Hunter *et al.* (2008) describes the process in detail. The advantages of this method become obvious when compared to standard PA imaging, as can be seen in Figure 2. For each image, a 64-element linear 5 MHz array with a 1 mm pitch was used. For the linear PA case, an aperture of 16 elements was used. Data acquisition and TFM processing was performed using the software InspectionWare (Weber *et al.*, 2012).



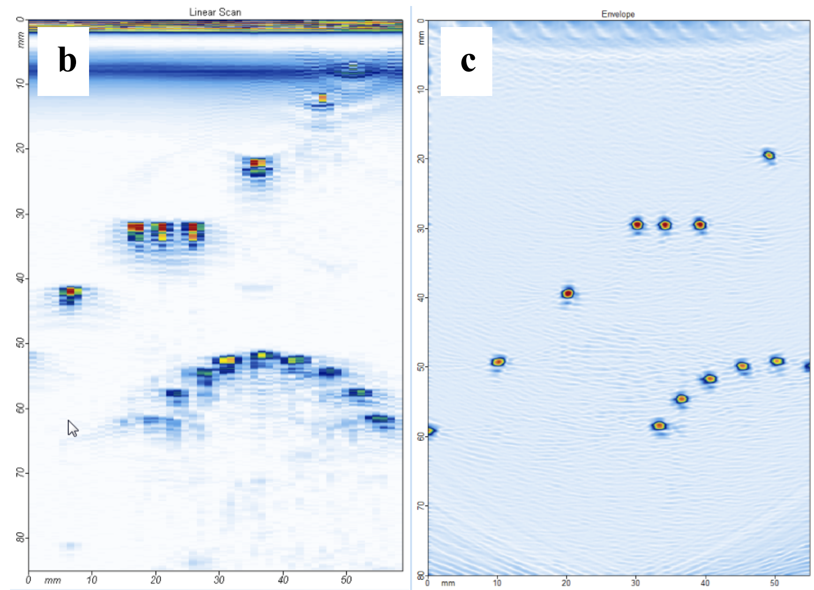


Figure 2. Comparison of image obtained using (b) standard linear PA and (c) FMC processing. An aluminum test block (a) with 1 mm side-drill holes was imaged.

It is clear from these images that the FMC/TFM algorithm provides a clear advantage over traditional PA. Benefits of FMC/TFM include:

- Better perspective
- Improved vertical resolution
- Improved lateral resolution
- Improved flaw definition allows for better sizing
- Reduced misinterpretation of geometry echoes vs. defects

While reduced, artifacts experienced in standard PA imaging also apply to FMC/TFM. For example, if we compare images of the same test block using both 5 MHz and 3 MHz linear arrays with equal pitch, we can see that the grating lobes are more pronounced at 5 MHz:

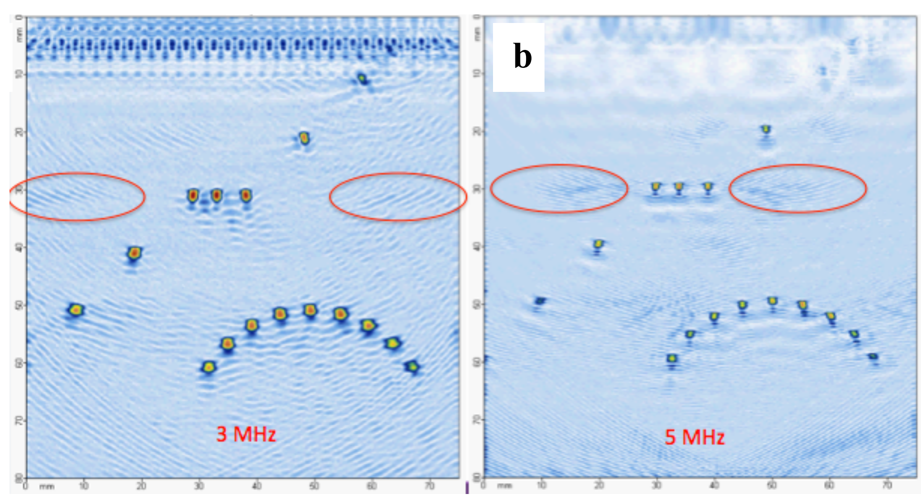


Figure 3. Comparison of grating lobes when imaged with a (a) 3 MHz linear probe and (b) 5 MHz linear probe. An aluminum test block with 1 mm side-drill holes was imaged, shown in Figure 2.

In addition to increased lateral and horizontal resolution, TFM permits increased characterization of non-point defects at different orientations. Using an aluminum test block with 5 mm slits, we can compare the images produced with standard linear PA and TFM (Figure 4).

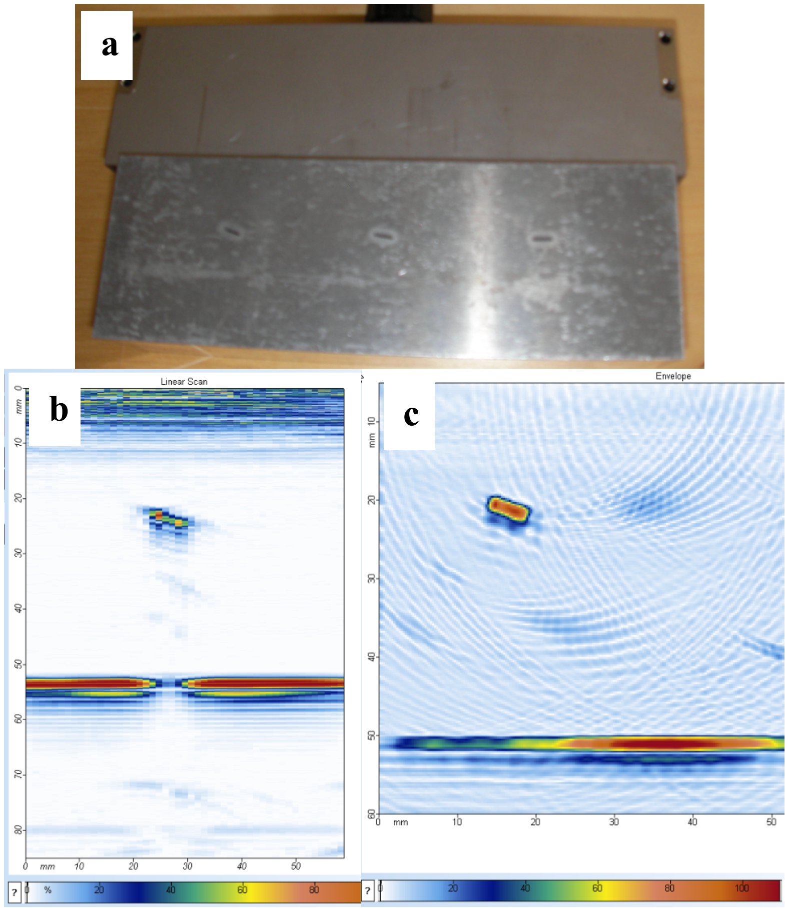


Figure 4. Comparison 5 mm slit detection using a 5 MHz, 128 element linear array. (a) Image of test block and linear array (b) standard linear PA (c) TFM.

Using standard linear PA, there are clear indications from the upper and lower tip of the slit; however, the center of the slit has a reduced signal. This can be misidentified as two side-drill holes in close proximity. Using TFM, the slit can be clearly recognized as a single contiguous flaw.

INSTRUMENTATION

From an integration perspective, an ideal instrument will have the capabilities to perform the intended inspection without the complexity and cost of additional features. While a full-featured software suite can provide a favorable first impression, the reality is that an end-user application will suffer performance reductions as unused features consume resources. Original Equipment Manufacturer Phased Array, or OEMPA (Dao, G. and Ginzel, R., 2013) was created to solve these problems and as a result can promote innovation and lead to new and improved solutions. Some important features of OEMPA are:

- Customizable software with an Application Programming Interface (API)
- Compatible with 3rd party software platforms
- Compact and lightweight design
- Advanced phased array features
- Re-brand bare OEM components into new products

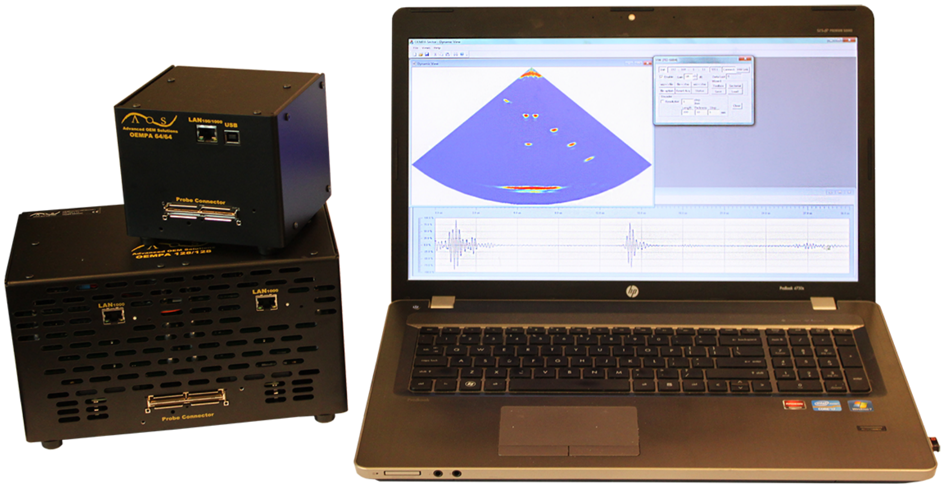


Figure 5. OEMPA 64/64 and 128/128 with a Data Acquisition Notebook PC

FLEXIBILITY

The key underlying factor to OEMPA's flexibility is the open-platform design, which enables application in many NDE fields and promotes advancements in technology. It is important to provide a versatile platform that allows more opportunities to create new and cutting-edge solutions to fit end-user needs. A tight-lipped control over technological advances can hinder the overall growth of industry. Other markets (information technology, software and internet) have shown that when developers share technology breakthroughs, they can create an echo system of powerful technology. In NDT, this equates to combining the best hardware, software, and mechanical system, and creating an ideal solution. By using an open-platform design, technology leaders are free to develop along their specific expertise – a specific application – without repeating the groundwork prepared many times before.

OEMPA as a concept promotes this flexibility. The fundamental API is open, allowing software developers to customize a Graphical User Interface (GUI) specific to their application, and provide the according visualization and analysis; without repeating the low-level core-programming interface required to operate a PA device. For example, with an open-platform base, it is possible to quickly create a portable PA system that provides a single inspection, repetitively, without the need to code base drivers, and without the computational overhead of processing unused features (frequency analysis, design GUI's, etc.)

Different applications require different number of channels. A modular platform also means being able to choose the appropriate phased array hardware configuration (16/16, 32/32, 16/128, 32/128, 64/64, 128/128 and 256/256) without wasting additional resources on software development due to changing channel count. There is more freedom in scaling up and/or down.

From a research and academic point of view, the OEM concept provides the flexibility to adjust the aspects of the instrument required for novel applications. In every new application, there is the chance that the existing software will need modification. For example, research on new beam-forming techniques, such as those used in TFM, current delay calculators may be insufficient. The open platform of OEMPA API permits the creation of custom focal-law calculators that can then be output to the instrument, full control of low-level parameters and acquisition of untainted raw data that has been beamformed or raw pre-beamformed channel data as in FMC. The OEMPA ideology would permit the modification of these properties to accomplish the desired configuration.

Figure 6. Bare OEMPA 16/16

There are two aspects that classify OEMPA as an OEM product. OEMPA can be purchased in its bare electronics form and integrated, added onto, or modified to create a completely new system or product, and the company has the opportunity to market the newly created product under their own brand. The focus no longer is on a “brand” but on the application itself and how well it works.

CONCLUSIONS

As advances are made in imaging techniques and algorithms, it is vital that NDE instrumentation remains open and flexible in order to adapt to new requirements. FMC and TFM have clear advantages over traditional PA in terms of focal resolution and flaw characterization, however this comes at a price of increased data throughput. In fast-moving environments, there may be insufficient time for FMC data collection. Therefore, it is important for hardware to easily switch to suit the ideal inspection method for a particular scenario. Example comparisons were given on how OEMPA can be integrated both using traditional PA and FMC/TFM using the same hardware and software.

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