Ultra-wide bandwidth array for new imaging modalities

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***Abstract*— A dual frequency probe composed of two outer low frequency arrays and one inner high frequency array is designed through a simulation stage, manufactured and fully characterized. Electroacoustical, acoustical and electrical properties suited the imaging modalities requiring an ultra wide bandwidth. The presented array transducer is a 128 elements linear array for superficial imaging with targeted frequency range from 2MHz to 10MHz. Electroacoustic and acoustic performances measured are close to those simulated. The device provides an ultra wide bandwidth of 130% improving superharmonic imaging.**

***Index Terms* – dual frequency array, superharmonic imaging.**

I. INTRODUCTION

Nowadays, a large number of specific ultrasound diagnostic methodologies, like contrast and tissue superharmonic imaging, requires ultra wide bandwidth devices. The most common approach to address such imaging modalities uses dual frequency probes. In this paper we first propose a short state of the art describing the possible topologies: vertical and horizontal stack arrays or interleaved arrays. We focus our efforts on a horizontal stack composed of one central high frequency array and two low frequency arrays. Design strategy is to superimpose the acoustic pressure fields of the low and high frequency array transducers in the imaging region of interest and to match the high cut-off frequency of the lateral arrays with the low cutoff frequency of the central one. Acoustical and geometrical aspects of the design are tuned by simulation thanks to the FIELD II program. Based on the simulation results, the prototype is manufactured and encapsulated. Finally the array was fully characterized to evaluate electrical, electro-acoustical and acoustical performances.

II. DUAL FREQUENCY ARRAY: CONCEPT AND EXISTING TOPOLOGIES

Many ultrasound applications are covered by dual frequency arrays. Therapy, elastography, drug delivery, contrast and harmonic imaging were widely investigated through different transducer approaches.

We present hereafter the three main topologies, their advantages and drawbacks.

A. Vertical Stack

The most popular configuration consists in a stack of two active layers with different central frequency [1]. The low frequency layer is commonly placed between the backing material and the high frequency layer.

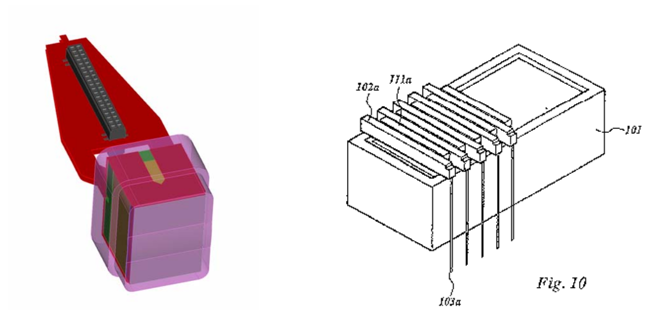

Figure 1 : vertical stack (left) and interleaved (right) topologies

This topology presents many advantages such as the limited footprint dimensions, the easy manufacturing process and the total overlapping of the low frequency pressure fields with the high frequency pressure fields.

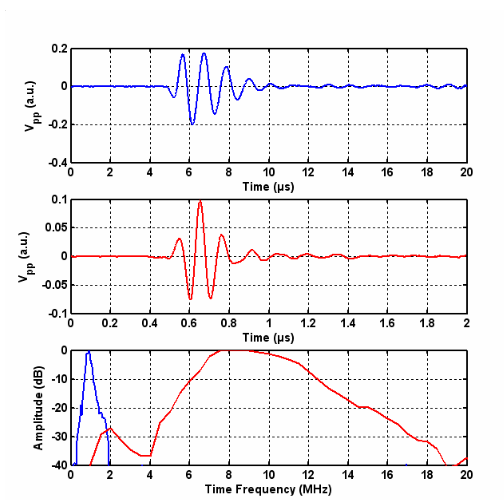

Figure 2 : electroacoustical performances of 1-10MHz vertical stack designed by VERMON.

The mechanical mismatching imposed by the topology alters the individual performances of both sub arrays. Optimization is mandatory but difficult to perform due to electromechanical coupling between the two active layers.

A simple case of dual frequency probe consists in stacking two active layers with very different central frequencies. Independent electromechanical behavior of the low and high frequency layers is then obtained as presented Figure 2. The low frequency array is 1MHz centered with 40% fractional bandwidth and the high frequency array is 10MHz centered with a 60% fractional bandwidth. These electroacoustical performances are not sufficient to address contrast and tissue superharmonic imaging.

B. Interleaved arrays

The interleaving topology was mainly studied by Bouakaz and N. De Jong [2][3] who demonstrate the improvement of contrast and tissue imaging at higher harmonics. This topology consists in alternatively placing elements with different central frequencies according to the azimuthal direction.

This topology exhibits a reduced footprint and a total overlapping of the high and low frequency pressure fields. A difficult tradeoff has to be managed between the sensitivity and the grating lobes position. Due to the interleaving, pitches of the low and high frequency arrays are twice the elementary width. To suppress the artifacts related to the grating lobes requires to reduce the element width which decreases the sensitivity.

C. Horizontal stack

In this paper we focus our work on the horizontal stack topology. This kind of transducer has been initially investigated [4] for therapy applications. Two low frequency arrays are laterally positioned on both sides of the central high frequency array. A tilt according to the elevation direction may be tuned to overlap the two acoustic beams.

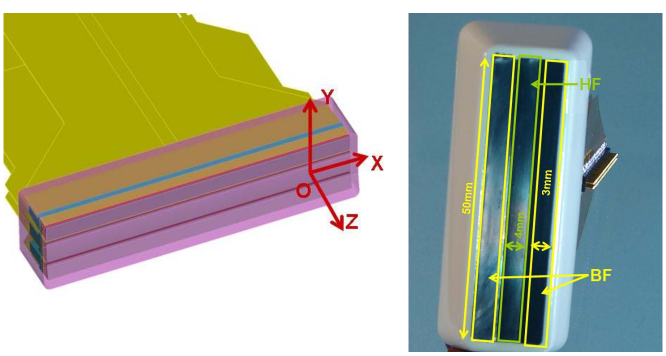

Figure 3 : Horizontal stack topology.

This design does not modify the initial performances of the three arrays. Such a device has nevertheless a larger footprint and a limited overlapping area.

Investigating the different degrees of freedom (elevation apertures, tilt and elevation position) enables us to adapt the device to the given specifications.

III. DESIGN STRATEGY

Design strategy is to manufacture an integrated device dedicated to superficial applications with an imaging region of interest (ROI) around 20mm depth, fully compatible with existing imaging platforms and exhibiting an ultra wide bandwidth enabling contrast and tissue superharmonic imaging (over 130%).

Based on the VERMON technology, each sub-array provides a 90% fractional bandwidth without any tradeoff on the other electroacoustical performances. The three radiated pressure fields must be superimposed in the targeted imaging ROI. Matching the high cut-off frequency of the lateral arrays with the low cut-off frequency of the central one, considerably expands the bandwidth of the global device. The targeted frequency range is comprised between 2 and 10MHz.

The first step in the development of this probe is to simulate the electroacoustic response of both array configurations. Preliminary geometrical and acoustical properties are reported in the following Table 1.

	Low freq.	High freq.
Number of element	128	128
Pitch	0.2mm	0.2mm
-6dB Bandwidth	90%	90%
-6dB Low cutoff Frequency	2MHz	4 MHz
-6dB High cutoff Frequency	4 MHz	10 MHz
Focus	none	20mm

Table 1 : Horizontal stack specifications

The electroacoustical performances of the two array configurations being defined, the acoustic radiation pattern formed by the three radiated fields is then simulated through the FIELD II program developed by J. Jensen [5]. This simulation stage enables us to set the different geometrical degrees of freedom such as the elevation aperture, tilting and spacing between arrays to address the final superficial applications requirements.

A. High frequency array design

A 7.5MHz central frequency array with a 4mm elevation aperture and a 20mm elevation focus provides optimum spatial resolutions and contrast capabilities. Simulated radiated pressure field is presented Figure 4.

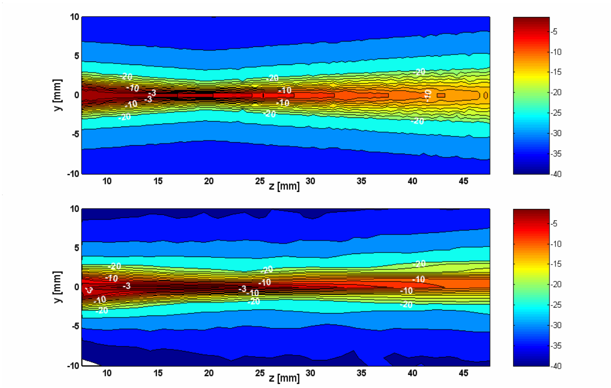

Figure 4: Simulated and measured radiated pressure field. Simulations features with Field II program according to the following parameters: Transmitting mode, Electronic excitations: Dirac pulse. -3dB Gaussian impulse response: 90% bandwidth. 7.5MHz centered.

B. Low frequency arrays design

Imaging ROI corresponding to the overlapping area of the two low frequency radiated pressure fields must be set between 10mm to 40mm depth to address superficial applications. A 15° angle between high frequency and low frequency arrays and a minimum spacing between sub arrays are mandatory to obtain such a ROI.

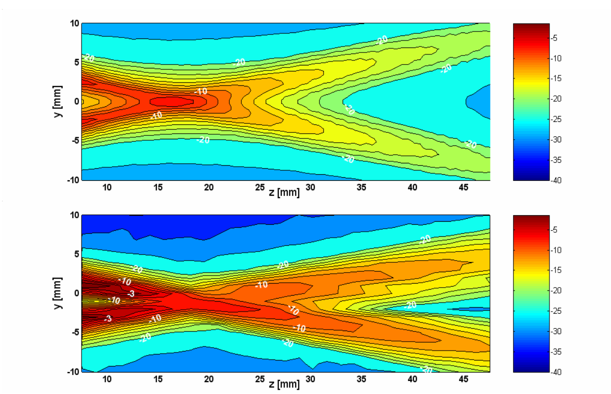

Figure 5 : Simulated and measured radiated pressure field Tilt and position of both array incorporated. Simulations features with Field II program according to the following parameters: Transmitting mode, Electronic excitations: Dirac pulse. -3dB Gaussian impulse response: 90% bandwidth. 3.5MHz centered.

Final elevation aperture (3mm) of the two low frequency arrays was then selected for sensitivity provisions.

IV. Performance Assessment

Based on the simulation results, the prototype is manufactured and fully characterized.
Measurements are performed into a water tank, 20°C. Transient excitation is provided using a Panametrics pulser/receiver (5072PR / Energy 1 / Damping 50Ω / Gain 0dB / Full BW) through a 50Ω coaxial cable, 50cm long.

A. Radiation pattern

Radiated pressure fields were measured in a transmission mode using a 0.2mm diameter hydrophone (Precision Acoustic) as a receiver connected to an amplifier through a DC coupler. The hydrophone is first positioned along the propagation direction of one central element of the high frequency array and then moved to scan pressure field in the [YOZ] plan (Figure 3). Both pressure field measurements were performed according to the setup described above.
Radiated pressure fields of the high frequency array (Figure 4-b) and of the low frequency arrays (Figure 5-b) are close to the simulated ones.
The three beams overlap in the desired ROI. The 15° angle between high frequency array and the two low frequency arrays is respected. A slight tilt according to the azimuthal direction between the two outer elements is observed, highlighting the complex assembly of the complete device.

B. Electroacoustical performances

1) Axial electroacoustical performances

Electroacoustical performances were measured in an E/R mode using a flat steel target normally positioned to the propagation axis of the high frequency array. Pulse/echo responses were acquired for different depths of the target to scan the propagation axis from 10mm to 40mm. High and low frequency arrays were separately considered.

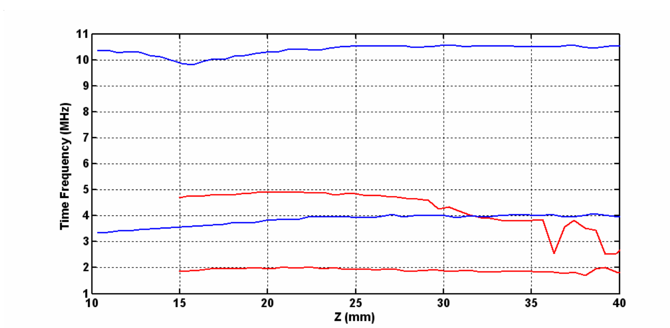

Figure 6 : Axial electroacoustical performances. Red curves represent the -6dB high and low cut-off frequencies of the two outer arrays. The blue curves represent the low and high cut-off frequencies of the central array.

Both bandwidths are joined from 10mm to 35mm depth. Figure 6 shows indeed the high and low cut-off frequencies of the arrays with respect to the target position. The two frequency responses exhibit a 90% fractional bandwidth each and a continuous bandwidth from 2MHz to 10MHz in the region of interest.

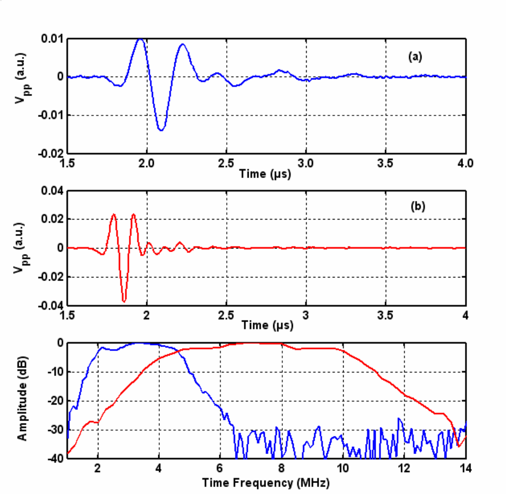

Figure 7 : Time and frequency response of the low frequency elements (blue curves) and high frequency element (red curves) measured at 20mm depth.

Figure 7 presents the time and frequency responses of the lateral and central elements at 20mm depth. Sensitivity level is quite different between the two radiated pressure fields. The central high frequency element exhibits a higher sensitivity level due to its favorable capacitance reported in Figure 8 (green curves). To overcome this problem we connected the three elements in parallel through a 1.5D connectivity.

2) 1.5D Connectivity

The lateral and central arrays can be addressed separately or with a total 1.5D connectivity. To test this functional mode, all the elements of a row were wired in parallel with a common ground.

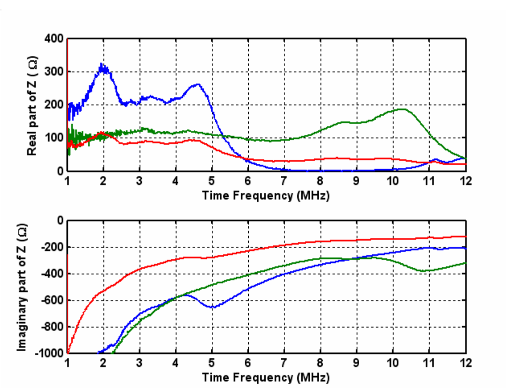

Figure 8 : Real part (top) and imaginary part (down) of the electrical impedance of the low frequency arrays (blue), high frequency array (green) and all arrays in 1.5D connectivity(red). Electrical measurements: 5100A Network analyzer. 1.5MRayls Medium

In this configuration, the resulting element exhibits a favorable imaginary part of the electrical impedance (Figure 8) and a real part closer to 50Ω. Insertion loss measurements on this 1.5D configuration lead to an uniform sensitivity level (see Figure 9: under harmonic excitation provided by a function generator (Agilent3055A / burst: 15 Cycles / 200KHz pitch)).

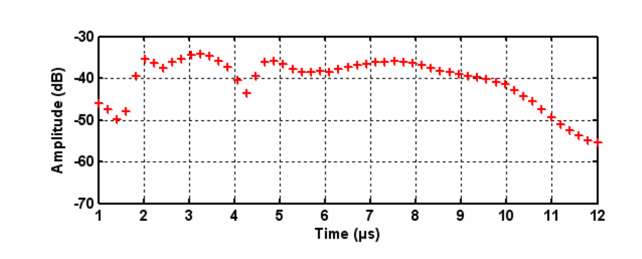

Figure 9 : Insertion loss measurement, E/R mode, water loaded at 20mm depth.

The harmonic transfert function exhibits a -35dB sensitivity level and an ultra wide bandwidth (@-6dB), over 130% (from 1.8MHz to 10MHz).

V. Conclusion

We reported the design, the manufacture and the characterization of a specific probe with three arrays addressing contrast and tissue superharmonic imaging. Prototype performances fit the design strategy previously described. Final 1.5D-connectivity probe exhibits an uniform and a continuous bandwidth from 2MHz to 10MHz in the imaging region of interest from 10mm to 35mm. The harmonic transfert function shows a performant sensitivity level close to -35dB.

The complex assembly of the complete probe was successfully achieved although a slight tilt occurred according to the azimuthal direction. New mechanical assembly tools are under development to avoid this tilt.

The probe will next be plugged on electronic system to perform contrast and tissue superharmonic imaging assessment on a mimicking phantom.

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