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Linear arrays used in ultrasonic evaluation

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Abstract. Ultrasonic arrays are used in many applications including medical imaging. In this specific case is important to achieve precise information about the magnitude and position of the peak pressure and intensity produced by the probe. This paper presents three types of arrays which were simulated and the results were compared

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1. Introduction

The role of the acoustic transducer in high-quality image acquisition from medical ultrasound scanners is very important. In fact it determines the quality of an image. There are considerable efforts in designing transducers and determining the characteristics of the emitted field. There are technical difficulties in fitting a high number of elements and cables on the surface of a transducer. It is therefore favorable to reduce the number of elements without loss of imaging quality. This issue appears in many papers that have dealt with design of the flat 2D-arrays. Field II program [1, 2] for Matlab was used. This program was developed by J.A. Jensen, it can simulate all kinds of ultrasound transducers using linear acoustics and it utilizes the Tupholme-Stepanishen method for calculating spatial impulse responses. The calculation of the spatial impulse response assumes linearity [3] and any complex-shaped transducer can therefore be divided into smaller apertures and the response can be found by adding the responses from the sub-apertures. The aim of the work is to give a coherent analysis of 2-D array transducers design. This analysis permits to optimize their design for a particular application.

There are three different kinds of images acquired by multi-element array transducers: linear, convex and phased. The linear arrays acquire a rectangular image, and the arrays can be quite large (often 128 or 256 elements) to cover a sufficient region of interest.

2. Spatial Impulse Theory

The pressure field generated by the aperture is found by the Rayleigh integral [5]

$$p(\overrightarrow{r_1},t) = \frac{\rho_0}{2\pi}\int_S \frac{\frac{\partial \nu_n(\overrightarrow{r_2},t-\frac{|\overrightarrow{r_1}-\overrightarrow{r_2}|}{c})}{\partial t}}{|\overrightarrow{r_1}-\overrightarrow{r_2}|} dS \ . \tag{1}$$

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where the field point is denoted by $\overrightarrow{r_1}$ and the aperture by $\overrightarrow{r_2}$, is the velocity normal to the transducer surface. Using the velocity potential ψ, and assume that the surface velocity is uniform over the aperture making it independent of $\overrightarrow{r_2}$, then:

$$\psi\left(\overrightarrow{r_1}, t\right) = \nu_n(t) * \int_S \frac{\partial\left(t - \frac{|\overrightarrow{r_1} - \overrightarrow{r_2}|}{c}\right)}{2\pi|\overrightarrow{r_1} - \overrightarrow{r_2}|} . \tag{2}$$

where * denotes convolution in time. The integral in this equation

$$h(\overrightarrow{r_1}, t) = \int_S \frac{\partial\left(t - \frac{|\overrightarrow{r_1} - \overrightarrow{r_2}|}{c}\right)}{2\pi|\overrightarrow{r_1} - \overrightarrow{r_2}|} . \tag{3}$$

represent the spatial impulse response. The continuous wave field can be found from the Fourier transform of

$$p(\overrightarrow{r_1}, t) = \rho_0 \frac{\partial\nu(t)}{\partial t} * h(\overrightarrow{r_1}, t) . \tag{4}$$

The impulse response includes the excitation convolved with both the transducers electro-mechanical impulse response in transmit and receive. The final signal for a collection of scatters is calculated as a linear sum over all signals from the different scatters [8].

3. Results and discussion

Before star to evaluate the various linear arrays it is necessary to define what sort of properties a good array should have. It can into account broad bandwidth, axial and lateral resolutions resolution, directivity and spatial impulse response. We turn to spatial impulse response.

The calculation of the impulse response is facilitated by projecting the field point onto the plane of the aperture. In this way, the problem became two-dimensional and the field point is given as a (x, y) coordinate set and a height z above the plane. The spatial impulse response is, thus, determined by the relative length of the part of the arc that intersects the aperture. Thereby it is the crossing of the projected ultrasonic waves with the edges of the aperture that determines the spatial impulse responses as a function of time.

By using FIELD II program were created three linear arrays with the same characteristics, but with different number of elements: 16 elements, 32 elements and respectively 64 elements. We limited out study to flat 2D linear arrays because curved linear arrays are not supported in FIELD II.

For the simulations the transducer center frequency was set to $f_0 = 3MHz$. The speed of sound in tissue is $\lambda = c/f_0 = 1540m/s$, which gives a wavelength of mm. The sampling frequency used was $f_s = 100MHz$. The elements had a width el_x and height el_y of 1mm respectively 0.5mm. The focal-point was set to 40mm. Figures 1, 2 and 3 show the transducers surface in two different views.

Then the spatial impulse response for this aperture was calculated and plotted by time. Figures 4, 5 and 6 show the spatial impulse responses arrays for different spatial positions from the front face of the transducer. The responses are found from the center of the rectangle and out in steps of 2 mm in the x direction to 10 mm away from the center of the array. The impulse response is zero before the first spherical wave reaches the aperture. When the edges of the aperture are met the response drops of. The decrease with time is steep, and the response becomes zero when the projected waves all are outside the area of the aperture.

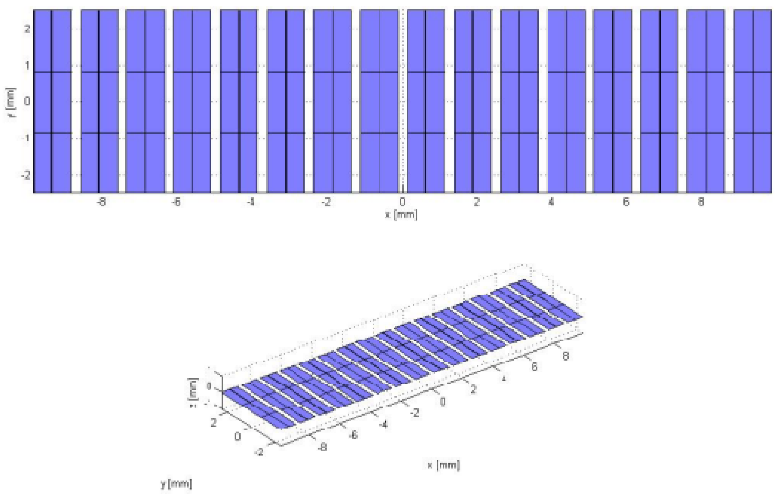

FIGURE 1. Linear array with 16 elements.

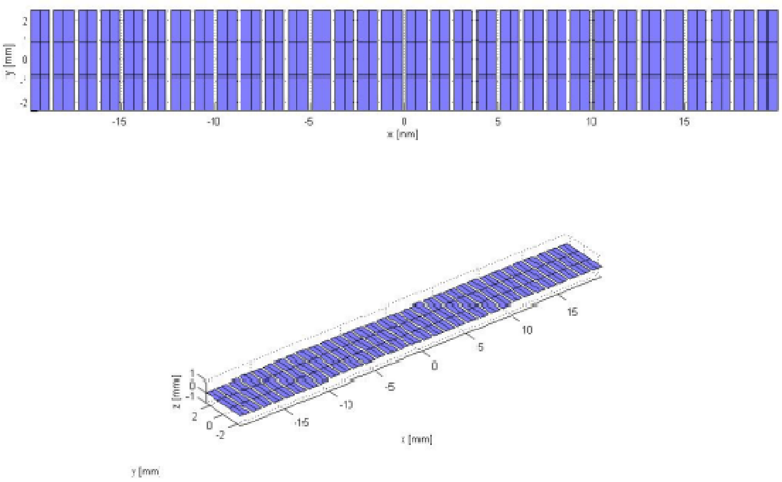

FIGURE 2. Linear array with 32 elements.

The received signal from a collection of scatters and for each of the elements in the receiving aperture was calculated. The individual responses and the summed response were plotted (figures 7-12).

All the responses for the arrays with the 16x1 aperture were simulated with a focal length of 20 mm. For arrays 16x2 and 32x2 apertures the focal lengths are 20mm.

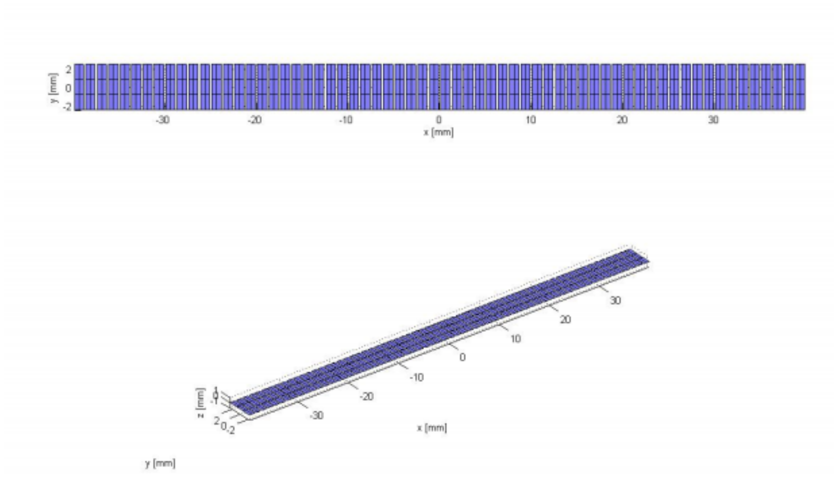

FIGURE 3. Linear array with 64 elements.

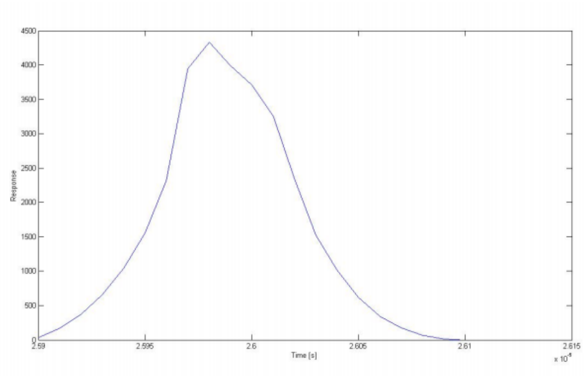

FIGURE 4. Spatial impulse responses from 16 element linear array.

But to compare the results, the responses of the arrays with smaller apertures should then be simulated with a smaller focal length. The field examples simulation is suited for showing the spatial variation of the point spread function for a particular transducer, focusing, and apodization scheme (fig. 7, 9, 11). Also, it can be seen how the spatial impulse response changes as a function of relative position to the aperture (or time variation) in fig. 8, 10, 12.

By increasing the number of elements, the effective transducer diameter will increase so the main and side lobes and the distance of the maximum pressure point were increased. Axial resolution increases with bandwidth, while lateral resolution decreases with bandwidth. The total response for the array system is the combined effect of the element response and the beamforming [10, 11]. Note that only the beampattern is affected by the steering, the element response is not possible to change by beamforming.

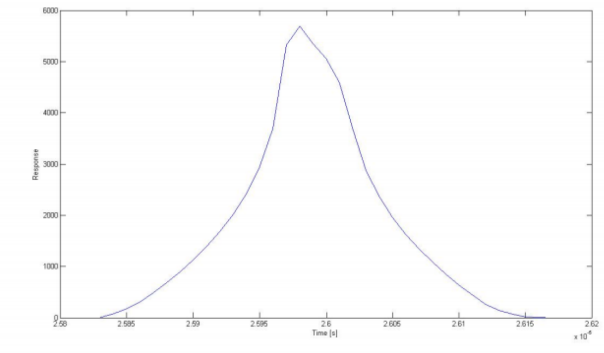

Figure 5. Spatial impulse responses from 32 element linear array.

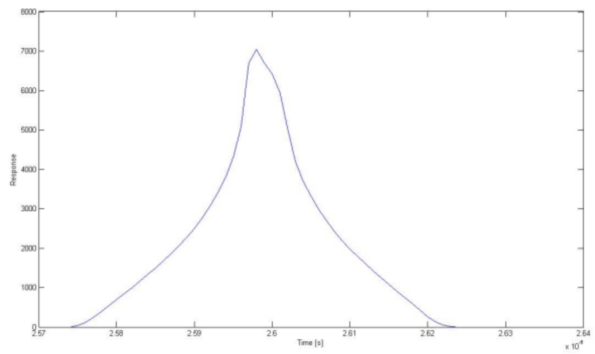

Figure 6. Spatial impulse responses from 64 element linear array.

4. Conclusion

The paper attempts to present a coherent analysis of the focusing strategies for 2-D array transducer design and properties, based on linear acoustics. The effect of changing the array element number and the beam profile are studied. Modern ultrasound scanners have attained a very high image quality through the use of digital beamforming. The delays on the individual transducer elements and their relative weight or apodization are changed continuously as a function of depth. This yields near perfect focused images for all depths and has increased the contrast in the displayed image, thus, benefitting the diagnostic value of ultrasonic imaging.

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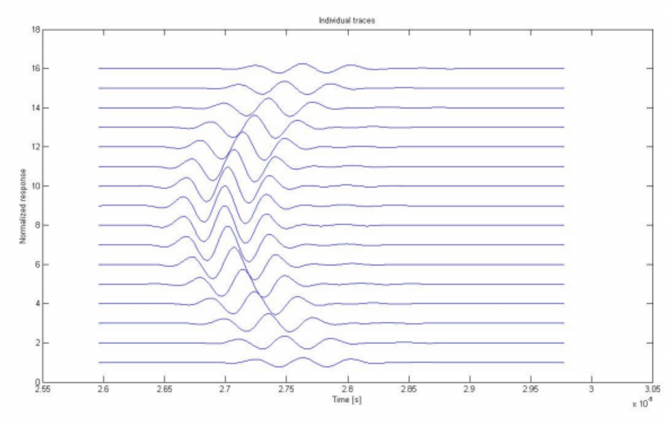

Figure 7. The individual responses from 16 element linear array.

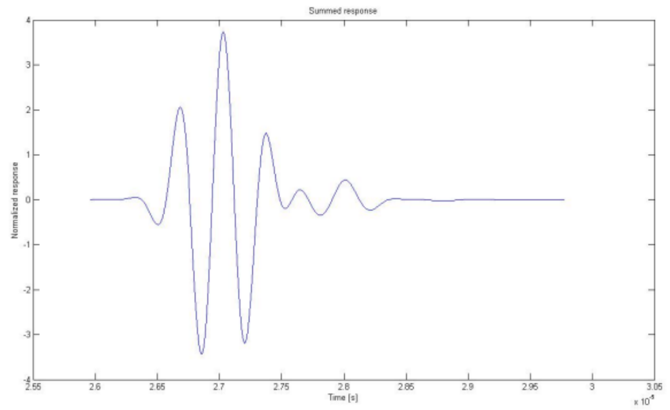

Figure 8. The summed response from 16 element linear array.

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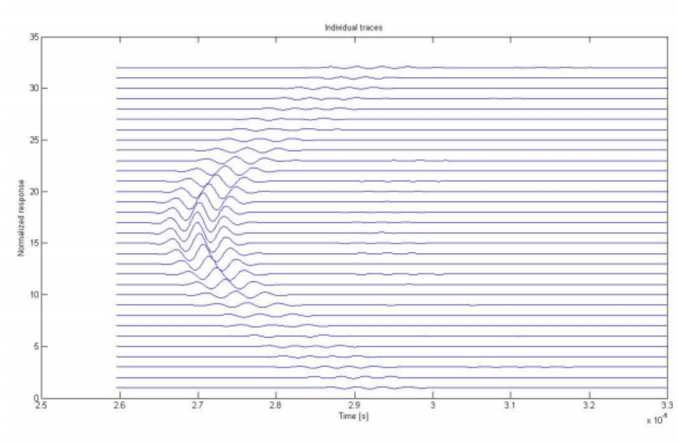

FIGURE 9. The individual responses from 32 element linear array.

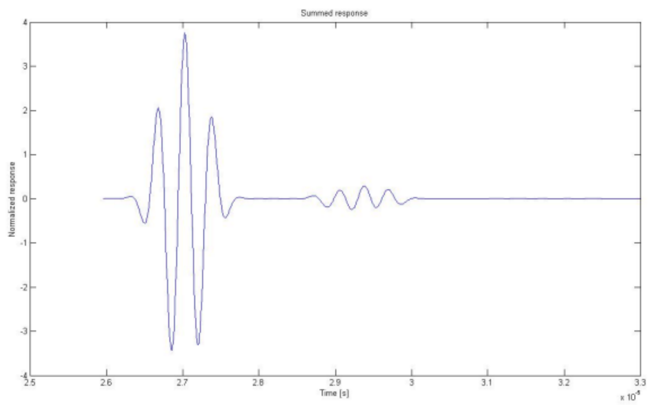

FIGURE 10. The summed response from 32 element linear array.

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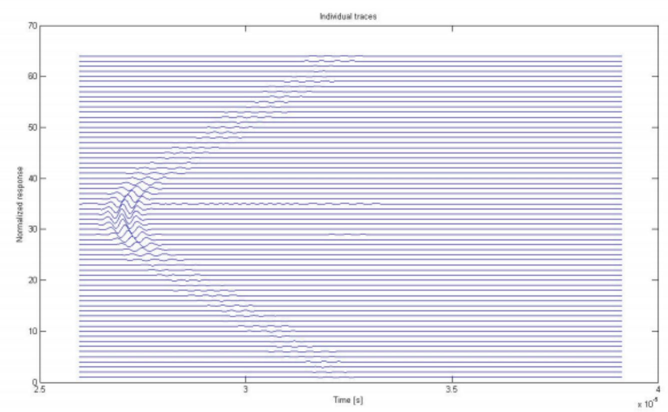

FIGURE 11. The individual responses from 64 element linear array.

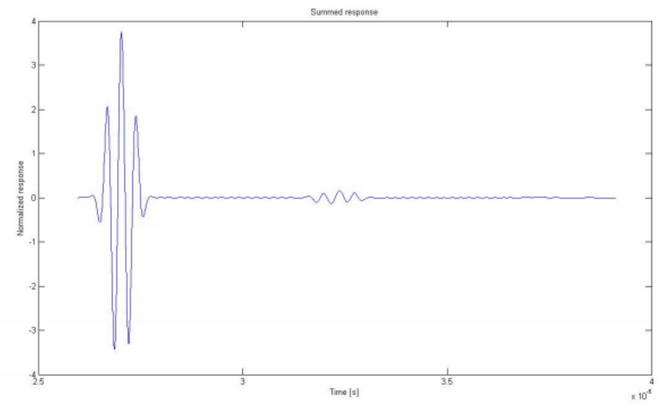

FIGURE 12. The summed response from 64 element linear array.