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CHARACTERIZATION OF ANNULAR ARRAY TRANSDUCER

Luminita Moraru[1], Laura Onose [1, 2], Ana-Maria Chiselev[1]

[1] *''Dunărea de Jos" University of Galati, Faculty of Sciences, Physics Department*
[2]*Mettalurgical High School, Galati*

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Abstract
The aim of the current study was to compare the beam patterns for annular array with different annular number of elements in a homogenous medium. An alternative approach to linear arrays is to employ an annular array transducer, with a relatively small number of annular elements to focus the beam in the axial direction, resulting in 2D ultrasonic images with significantly increased DOF (depth-of- focus). Even it is expected that heterogeneous and attenuating biological media will degrade annular array performance we proved an improvement in DOF with annular array-focusing. This likely indicates that focusing with our annular array is more effective in the far-field than in the near- field of the transducer. First, we made this comparison for simulated transducer with equal area and different number of elements (4, 6 and 8 ring annular arrays) and 3.25 MHz frequency. Second, the frequency was changed and the results were compared. Finally the results obtained were interpreted and discussed.

1. Introduction

A transducer can be designed to produce a focused ultrasound beam by using a concaved element. Transducers are designed with different degrees of focusing. Relatively weak focusing produces a longer focal zone and greater focal depth. A strongly focused transducer will have a shorter focal zone and a shorter focal depth. The focusing characteristic of transducers can be adjusted to a specific depth for each transmitted pulse. The transducer is composed of several elements rather than a single element as in the fixed focus transducer, obtaining an array. There are two basic array configurations: linear and annular. In the linear array the elements are arranged in either a straight or curved line. The annular array transducer consists of concentric transducer elements. Although these two designs have different clinical applications, the focusing principles are similar.

Focusing is achieved by not applying the electrical pulses to all of the transducer elements simultaneously. The pulse to each element is passed through an electronic delay. The transducer elements are pulsed follows in next sequence: the outermost element (annular) or elements (linear) will be pulsed first; this produces ultrasound that begins to move away from the transducer. The other elements are then pulsed in sequence, working toward the centre of the array. The centremost element will receive the last pulse. The pulses from the individual elements combine in a constructive manner to create a curved composite pulse, which will converge on a focal point at some specific distance (depth) from the transducer.

The focal depth is determined by the time delay between the electrical pulses. This can be changed electronically to focus pulses to give good image detail at various depths within the body. One essential distinction between the two transducer designs is that the annular array focuses the pulse in two dimensions whereas the linear array can only focus in the one dimension; that is, in the plane of the transducer.

When mechanical sector probes are used with transducers that exhibit circular geometry, either fixed-focus transducers or annular arrays, the beam profile is the same in the scanning plane and in the elevation plane. However, when one-dimensional multi-element arrays are used, such as linear, curved, or phased arrays, focusing in the elevation plane is generally obtained by means of the cylindrical curvature of the probe or an acoustic lens. These results are quite different from those by means of electronic focusing in the scanning plane, because the beam profile in the elevation plane is obtained with a fixed focus and aperture. However, this elevation beam profile should be checked as one of the probe performance features.

The standard approach in annular array design is to make all elements equal in area witch leads in equal load for the amplifiers but not necessarily fewest elements.

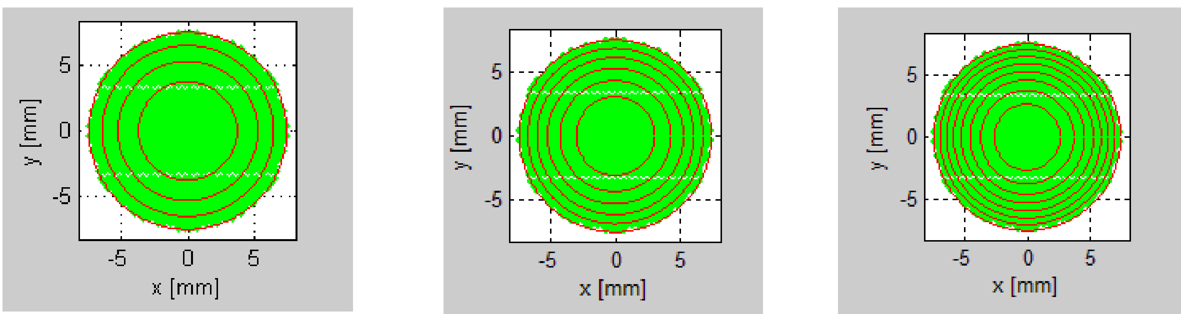
Simulating the acoustic fields is simpler and more economical than experimental tasks in order to determine the field pattern emitted from various type and shapes of acoustic transducers.

2. Experimental

The method used in our simulation is based on the Rayleigh integral as a mathematical form of Huygens' Principle that the field is found by integrating the contributions from all the infinitesimally small area elements that make up the aperture. The software is Ultrasim by Holm et. al., [4–7]. This application is able to calculate with a good accuracy both the near-field and the far-field.

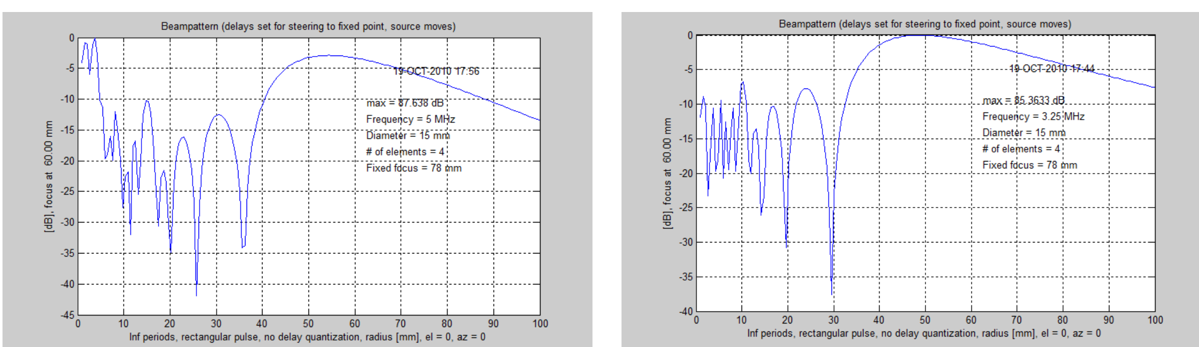
This computer simulation is used to investigate the beam characteristics of broadband annular arrays. Using this simulation, the beam properties of four-ring, six-ring and eight-ring annular array have been investigated. The aperture was 15 mm in diameter, this being a common transducer that is useful in B-scan applications, and was focused to fixed depth of 78 mm and 60 mm and segmented into 4, 6 and 8 equal area annuli. Figure 1 presents the transducer geometry in xOy-plane for all three annular array transducers simulated.

The fixed-focus is 78 mm. The focus properties are studied for 78 mm and 60 mm depth. We use no apodization; as result, we expect big side lobes and a small main lobe. These parameters do not necessarily represent optimal choices for an imaging system.



a b c

Figure 1. Transducers geometry in xOy-plane: four-ring annular array transducer (a), six-ring annular array transducer (b) and eight-ring annular array(c)



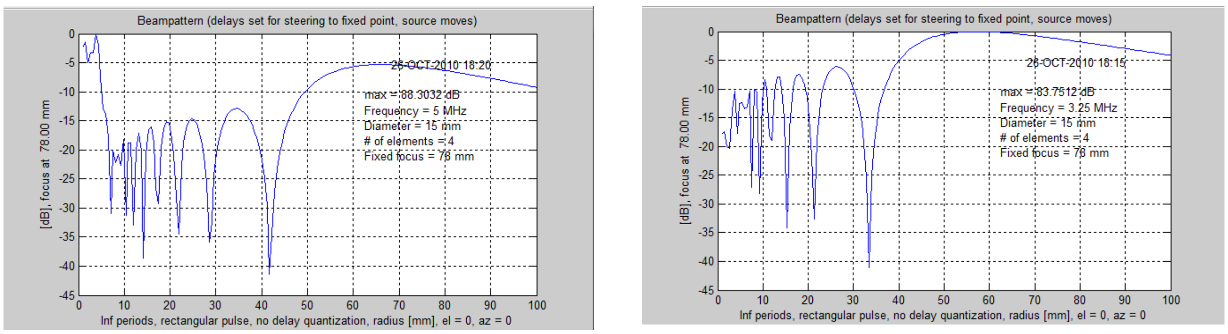
2.a 2.b

Figure 2. Intensity plot along acoustic axis for continuous excitation for a four-ring annular array at 5 MHz (2.a) and 3.25 MHz (2b) at 60mm depth

As evident from figure 2.b the near field focusing properties of the 3.25 MHz four-ring annular array are superior to those of the 5 MHz geometric identical transducer (fig. 2.a). The focus depth is 60 mm.

The results presented in Fig. 2 suggest that four-ring annular array produces a sharp focus in the near field for 3.25 MHz that gradually weakens as a function of frequency.

In the focal region, the beam pattern of the 3.25 MHz transducer exhibits higher sidelobes than the 5 MHz transducer. Therefore, the 3.25 MHz transmitter presents a high resolution technique that produces superior beam pattern in near field, but exhibits higher sidelobes as a function of frequency.

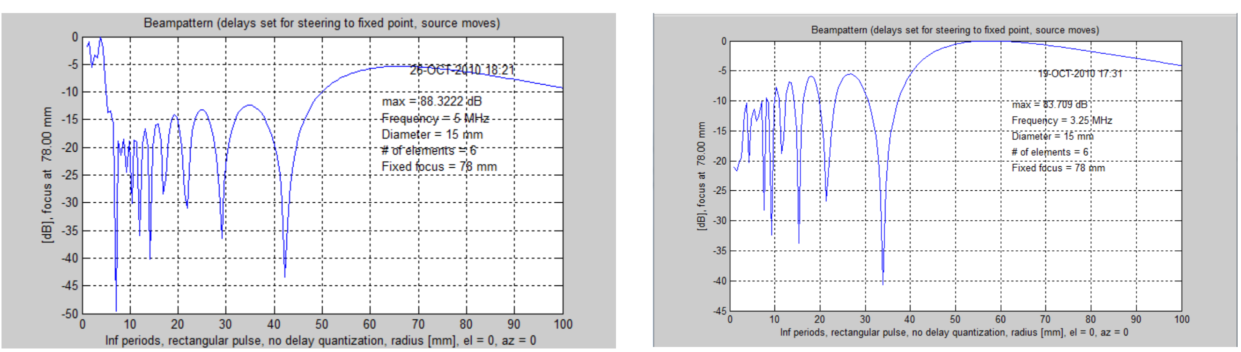


3.a 3.b

Figure 3. Intensity plot along acoustic axis for continuous excitation for a four-ring annular array at 5 MHz (3.a) and 3.25 MHz (3b) at 78 mm depth

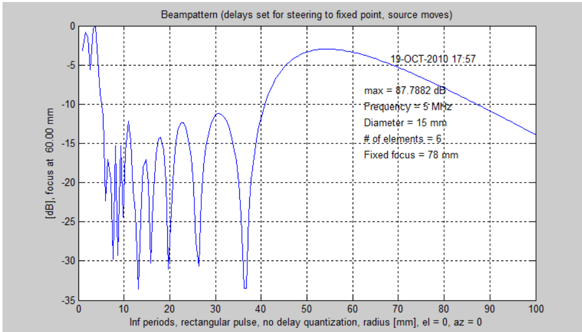
The same situation it was observed when the focus depth is set at 78 mm (figure 3). The 3.25 MHz transducer exhibits higher sidelobes than the 5 MHz transducer, but the plot shape is better.

Figures 4, 5, 6, 7 present results obtained with six-ring annular array and eight-ring annular array. In each case it was observed that sidelobes are higher for 3.25 MHz.

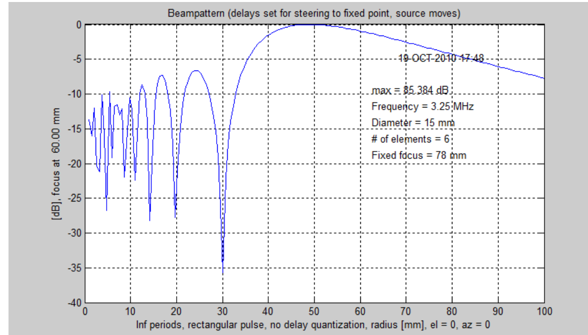


4.a 4.b

Figure 4. Intensity plot along acoustic axis for continuous excitation for a six-ring annular array at 5 MHz (4.a) and 3.25 MHz (4.b) at 78 mm depth

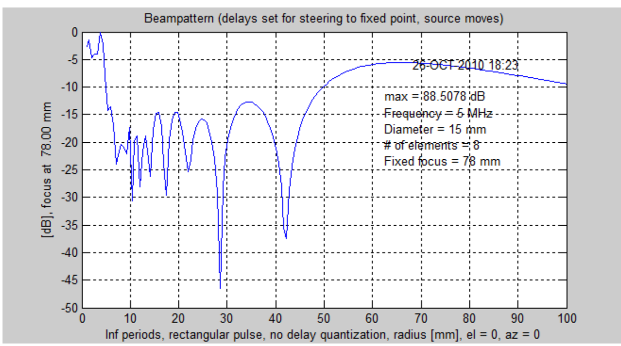


5.a

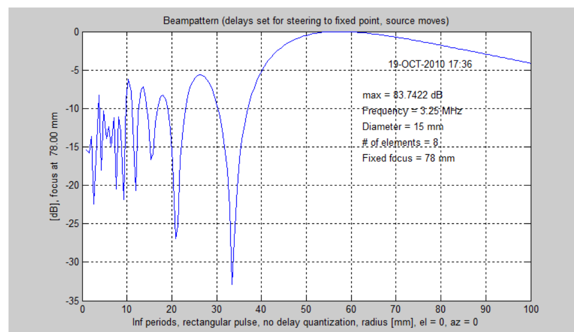


5.b

Figure 5. Intensity plot along acoustic axis for continuous excitation for a six-ring annular array at 5 MHz (5.a) and 3.25 MHz (5.b) at 60 mm depth

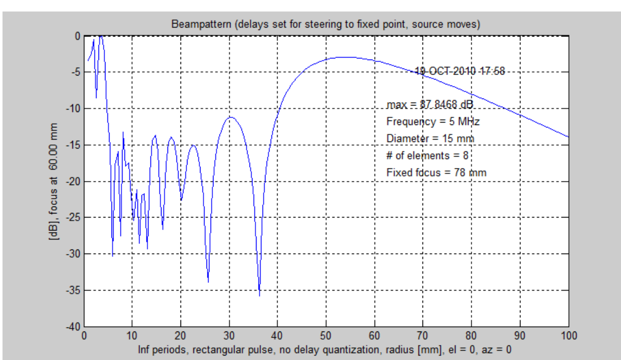


6.a

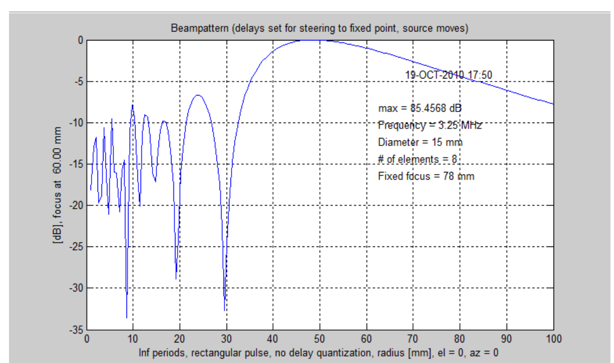


6.b

Figure 6. Intensity plot along acoustic axis for continuous excitation for an eight-ring annular array at 5 MHz (6.a) and 3.25 MHz (6.b) at 78 mm depth



7.a



7.b

Figure 7. Intensity plot along acoustic axis for continuous excitation for an eight-ring annular array at 5 MHz (7.a) and 3.25 MHz (7.b) at 60 mm depth

The ability to use a proper annular array as fixed-focus receiver greatly reduces the complexity and cost of the received electronics.

An obvious approach to increase depth-of- focus (DOF) in ultrasound images is to employ multi-element array transducers. Linear arrays are most common for conventional ultrasound imaging, because of the advantages of electronic focusing and steering, eliminating the need for mechanical scanning of the transducer. However, the technical challenges of fabricating linear array transducers with large numbers of elements, and element-element spacing on the order of a wavelength or less has impeded progress for high frequency [1]. An alternative approach is to employ an annular array transducer, with a relatively small number of annular elements to focus the beam in the axial direction, resulting in 2D images with significantly increased DOF [2, 3].

Conclusions

We described the development of a 4, 6 and 8-element, 3.25 and 5 MHz annular array transducer for ultrasound imaging. The operational capability of this transducer was verified using a simulation array-focusing method. Beam pattern simulations demonstrated that the field profile was enhanced in near field and the 3.25 MHz transducer exhibits higher sidelobes than the 5 MHz transducer. When frequency increased, increase of the maximum pressure for the same DOF was observed.

It is expected that heterogeneous and attenuating biological media will degrade annular array performance compared to wire phantom experiments.

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