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Design of Linear Array Transducer Using Ultrasound Simulation Program Field-II

Rodge S.A, Dr. Gandole Y.B..
Associate Professor, Dept. of Electronics Adarsha Science J.B.Arts and Birla Commerce Mahavidyalaya, Dhamangaon Rly-444709 (India)
Head, Dept. of Electronics Adarsha Science J.B.Arts and Birla Commerce Mahavidyalaya, Dhamangaon Rly-444709 (India)

ABSTRACT— *This paper analyze the effect of number of elements of linear array and frequency influence the image quality in a homogenous medium. Linear arrays are most common for conventional ultrasound imaging, because of the advantages of electronic focusing and steering. Propagation of ultrasound in biological tissues is of nonlinear in nature. But linear approximation in far-field is promising solution to model and simulate the real time ultrasound wave propagation. The simulation of ultrasound imaging using linear acoustics has been most widely used for understanding focusing, image formation and flow estimation, and it has become a standard tool in ultrasound research. . In this paper the ultrasound field generated from linear array transducer and propagation through biological tissues is modeled and simulated using FIELD II program.*
KEYWORDS—*Ultrasonic, biological tissues, linear array transducer, medical imaging.*

I. INTRODUCTION

In the biomedical field, the systems for images processing are very important calling for new techniques, much more advanced and performing than they used to be, in order to provide a correct analysis and diagnosis. The FIELD II program [1,2] is widely used within several ultrasound imaging research areas. It is suitable for simulating RF-data for signal processing and testing of several transducer geometries. However, Field II requires knowledge of each of the transducer elements' surface acceleration to perform calibrated pressure predictions. Direct measurement of the impulse response may then be needed. Measuring the impulse response is an expensive and cumbersome method, hence a direct simulation of the transducer and its driving circuits could be beneficial. Such an approach would also ease the development of new multilayered transducers and prediction of their pressure field responses. To simulate the pressure response from transducers, a model which can predict the volt-to-surface acceleration conversion of multilayered transducers is needed. Methods for modeling piezoelectric transducers are well known in literature [3-8]. Most of these models are based on electrical equivalent circuits benefiting from transmission line theory to represent the electromechanical coupling and acoustic wave propagation, and others rely on deriving impedance matrices for describing the transducer behavior. All of these methods have their advantage and disadvantages depending on the application of use. There are considerable efforts in designing transducers and determining the characteristics of the emitted field. Field II program [9], developed by J.A. Jensen, can simulate all kinds of ultrasound transducers using linear acoustics and it utilizes the Tupholme-Stepanishen method for calculating spatial impulse responses. The program is capable of calculating the fields for both the pulsed and continuous wave case for a large number of different transducers and allows visualization of simulating transducers. The calculation of the spatial impulse response assumes linearity [10] 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.

II. SPATIAL IMPULSE THEORY

The pressure field generated by the aperture is found by the Rayleigh integral [9]

$$p(\vec{r_1},t)=\frac{\rho_0}{2\pi}\int_s \frac{\partial v_n\left(\vec{r_2}.t-\frac{\left|\vec{r_1}-\vec{r_2}\right|}{c}\right)}{\left|\vec{r_1}-\vec{r_2}\right|}ds \quad (1)$$

where the field point is denoted by $\vec{r_1}$ and the aperture by $\vec{r_2}$, 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 $\vec{r_2}$, then: where the field point is denoted by $\vec{r_1}$ and the aperture by $\vec{r_2}$, 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 $\vec{r}_2$, then:

$$\Psi(\vec{r}_1, t) = v_n(t) * \int_s \frac{\partial\left(t - \frac{|\vec{r}_1 - \vec{r}_2|}{c}\right)}{2\pi |\vec{r}_1 - \vec{r}_2|} \qquad (2)$$

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

$$h(\vec{r}_1, t) = \int_s \frac{\partial\left(t - \frac{|\vec{r}_1 - \vec{r}_2|}{c}\right)}{2\pi |\vec{r}_1 - \vec{r}_2|} \qquad (3)$$

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

$$p(\vec{r}_1, t) = \rho_0 \frac{\partial v(t)}{\partial t} * h(\vec{r}_1, t) \qquad (4)$$

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 [11].

III. SIMULATION SET UP

There are considerable efforts in designing transducers and determining the characteristics of the emitted field. The focusing and apodization of the transducers can be controlled dynamically, and thus it is possible to simulate all kinds of ultrasound imaging systems. For simulation purpose the ultrasound package FIELD II [12] for Matlab was used. The program consists of three types of m-functions which are used to initialize the program, defining and manipulating transducers, and to perform calculations. The names of initializing routines are preceded by field, the transducer commands by xdc, and the calculation routines by calc. Help in using the routines can be obtained by typing help <routine name>.

The calculation of the spatial impulse response assumes linearity 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 executable code for the program can be downloaded, free of charge, from the http://www.es.oersted.dtu.dk/staff/jaj/field/, and can be run from a directory by writing:

path(path,'/home/user/field_II/m_files');

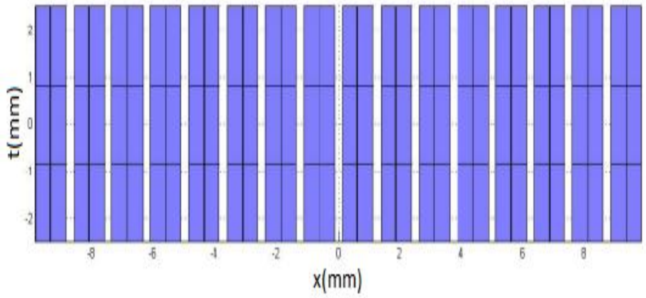
field_init.

The command field_init must be the first routine that is called and initializes the Field II program system.

Field simulations follow this type of a sequence:

• define an array;
• define the impulse response of a transducer element from that array;
• define the waveform of the transmitted signal;
• define targets that will be imaging;
• calculate the scattered response from these targets for each image line position;
• envelope detect and compress;
• display the image.

Here a 16 element linear array transducer is designed using FIELD-II program as shown in the Fig.1, height, width and kerf of individual element are taken as 5 mm, 0.2 mm and 0.02 mm respectively. The transducer is situated at the center of the coordinate system. The electronic focusing is incorporated to achieve focal length of **30** mm from the center of transducer



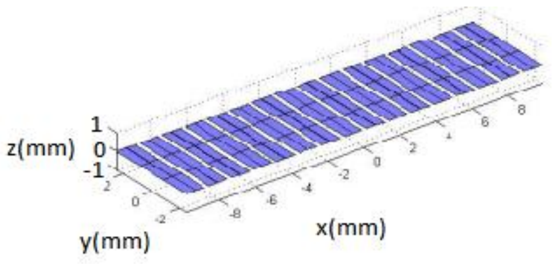


Fig.1 Design of linear array transducer (Height=5mm, Width=0.2mm, Kerf=0.02mm)

IV. RESULT AND DISCUSSION

For the above linear array transducer, an excitation signal of four cycles of sinusoidal pulses is given in Fig. 2(a). The impulse response pattern obtained for each element is shown in Fig. 2(b).

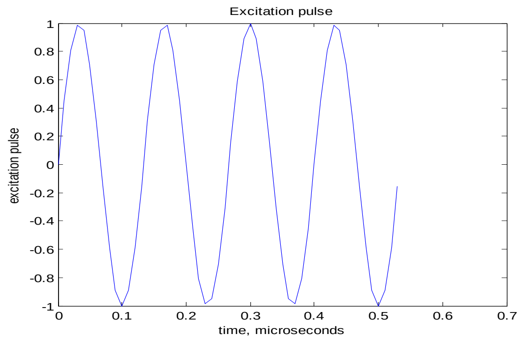


Fig.2(a)

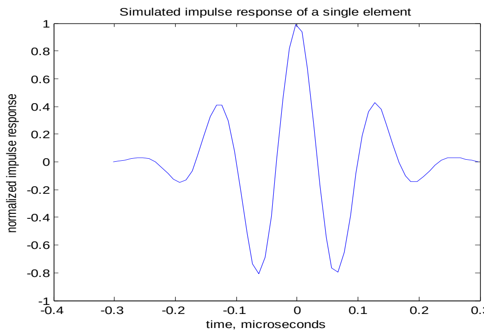


Fig.2(b)

For this specified linear array, acoustic field generated is propagated through human kidney and is observed at a focal distance i.e. (0, 0, 30) whose plots are shown in Fig. 3. Fig.3(a) shows the field generated while Fig. 3(b) shows the pressure profile at focal distance. Fig.3(c) illustrates the lateral beam pattern generated Similarly Fig.4 (d) shows the detected image by the assumed linear array transducer.

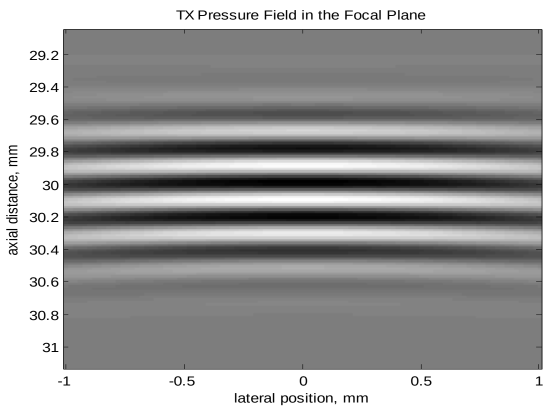


Fig. 3(a)

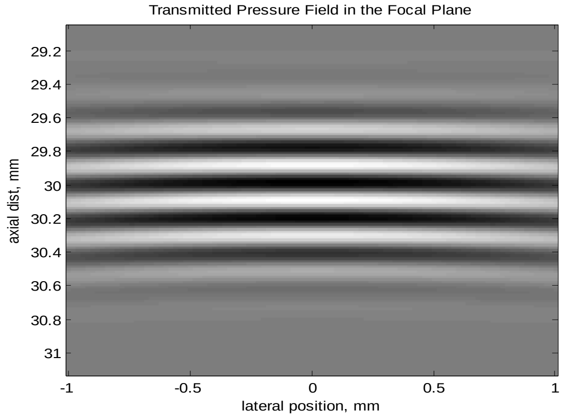


Fig.3 (b)

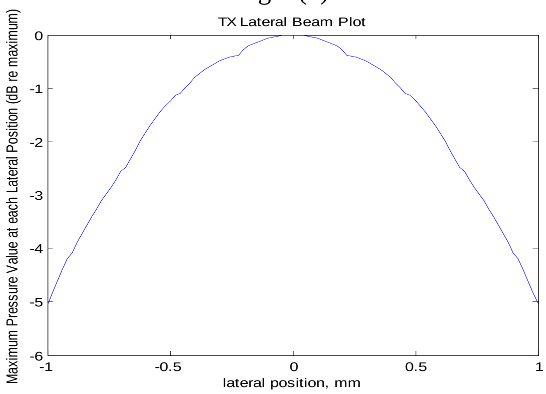


Fig. 3(c)

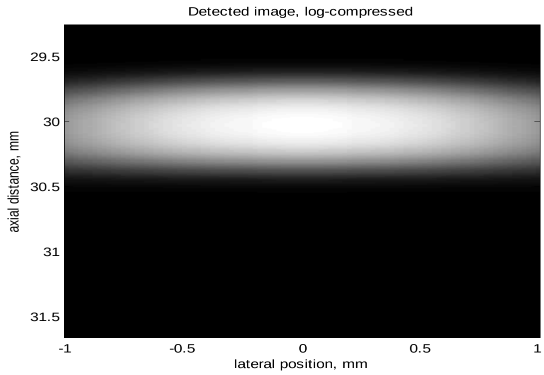


Fig.3(d)

The other simulation parameters chosen are central transducer frequency (f0) =5 MHz, acoustic speed (c0) =1540m/s , fractional bandwith 50%, center frequency of excitation pulse = 7.5 MHz, Number of cycle=5.
By using FIELD II program were created two linear arrays with the same characteristics, but with different number of elements: 32 elements and 64 elements respectively. For the simulations the transducer center frequency was set to $f0 = 5MHz$. The speed of sound in kidney tissue is $c=f0 = 1570$ *m/s*, which gives a wavelength of mm. The sampling frequency used was $fs = 100MHz$. The elements had a width and height of 0.25mm and 5mm respectively. The focal-point was set to 30mm. Then the normalized spatial impulse response for this aperture was calculated and plotted by time. Figures 4 (a), 4(b), 4(c) , 4(d) and 4(f) shows the normalized spatial impulse response, Transducer Pressure field, Lateral beam plot, Transmitted Pressure and detected image respectively for 32 elements. Similarly Figures 5 (a), 5(b), 5(c) ,5(d) and 5(f) shows the normalized spatial impulse response, Transducer Pressure field, Lateral beam plot, Transmitted Pressure and detected image respectively for 64 elements.

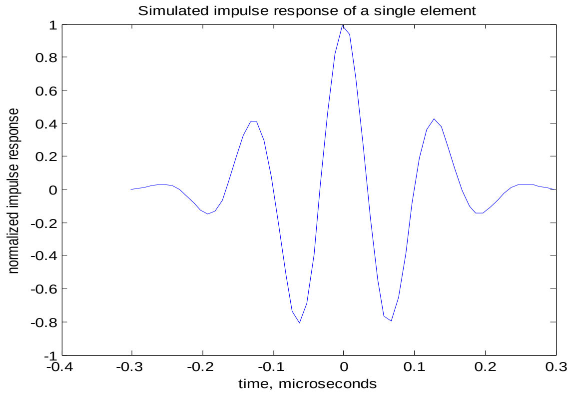


Fig. 4(a)

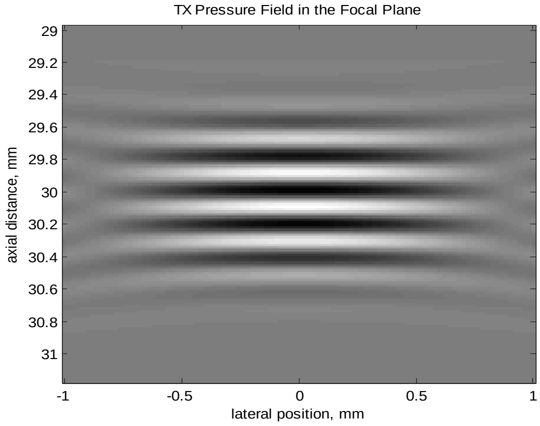


Fig. 4(b)

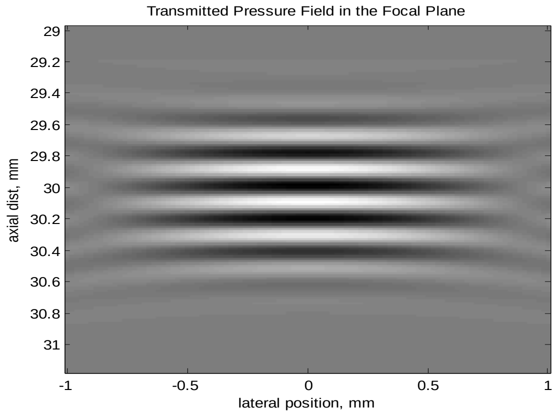


Fig. 4(c)

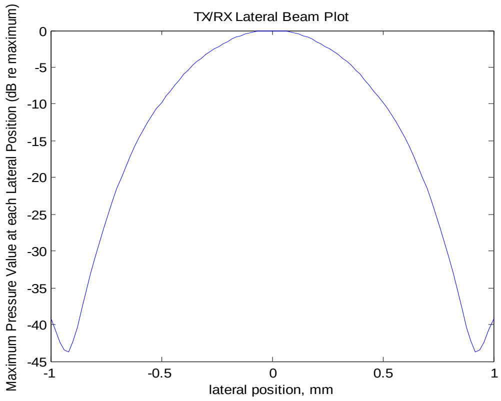


Fig. 4(d)

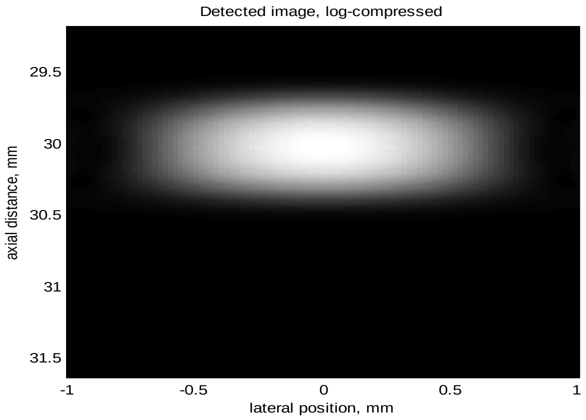


Fig. 4(f)

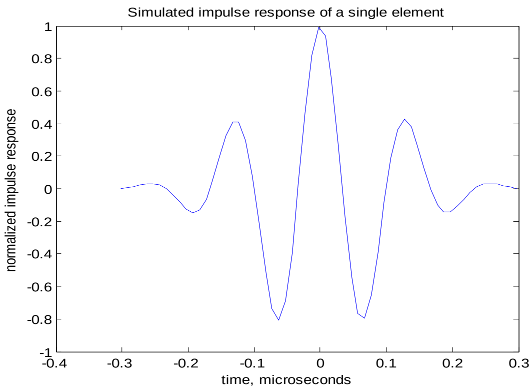


Fig. 5(a)

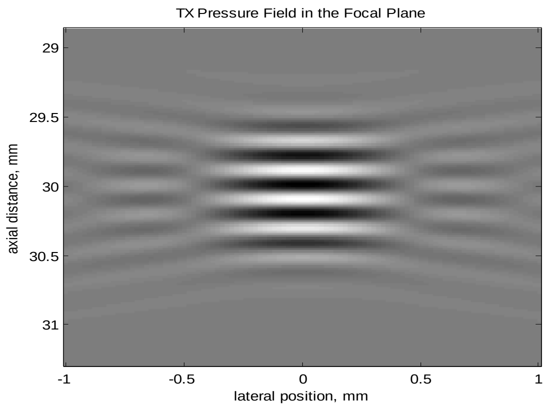


Fig. 5(b)

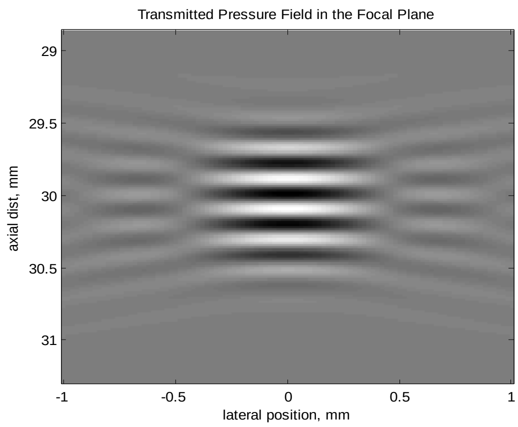


Fig. 5(c)

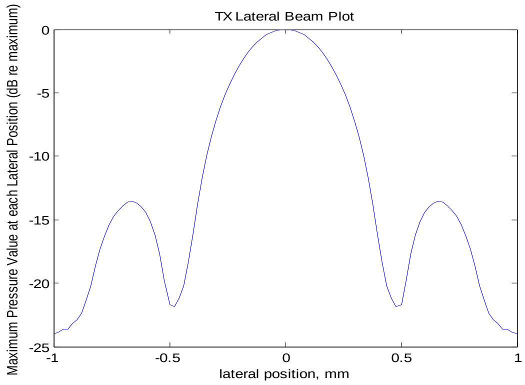


Fig. 5(d)

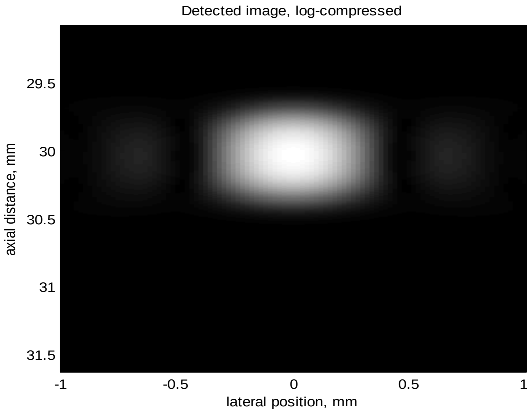


Fig. 5(f)

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