

Ultrasim - a toolbox for ultrasound field simulation

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Abstract – Ultrasim is an interactive, menu-oriented simulator for finding the sound field from transducers. It is a tool for design of transducer arrays and transducer geometry, and will increase the user's understanding of acoustic wave propagation. The simulator has primarily been developed for medical ultrasound, but has also been used for sonar analysis and non-destructive testing.

The simulator has been developed over the last ten years and it is implemented as a freeware toolbox in MATLAB.

1 Introduction

There are basically two approaches to making a simulator. One is to provide a set of routines for all the required operations that the user may put together to form a batch program for his particular simulation. This is effective for large processing-intensive simulations where many perturbations of the parameters shall be tested. The other approach is to make an interactive tool with a graphic user interface that guides the user into setting up the right parameters and perform the simulation. Both kinds of simulators may be found on the world wide web, [1]. Ultrasim follows the second approach as it is an interactive, menu-oriented simulator for finding the sound field from ultrasound transducers. One of the advantages of this approach is that it is simple for a new user to get started.

Ultrasim is started from the Matlab command prompt by typing 'ultrasim'. Two windows, each with a menu bar, will then appear. They are the Plottool window, where the results are plotted, and the Configuration window, where the configuration needed to perform a simulation and the method of simulation are selected. In addition, parameters are entered in the Matlab command window. Ultrasim is used routinely on both the Windows and UNIX platforms under Matlab versions 4, 5, and 6.

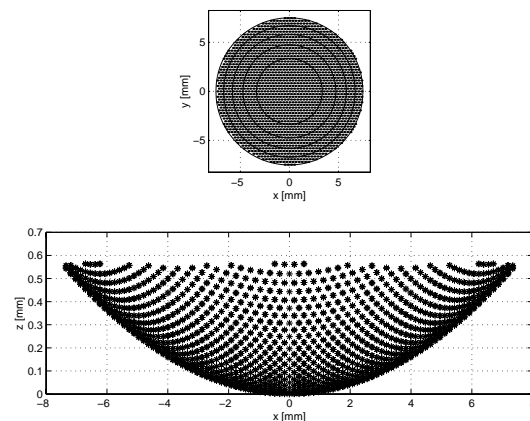


Figure 1: *Top and side view of annular array of diameter 15 mm, and fixed focus at 50 mm and with 5 equal-area elements.*

This paper describes the basic properties of the simulator and the method used for simulation. There is an ultrasim web-page, [2], where the toolbox and the user's manual can be downloaded. The web-site also contains examples, frequently asked questions, and references to papers that build on ultrasim.

2 Simulation of Acoustic Fields

2.1 Transducer Geometries

In ultrasound imaging a whole range of various transducers are common. Ultrasim is a general purpose simulator tool that handles most of these, including [3]:

1. Pre-focused annular arrays divided into rings using the equal-area principle, see Fig. 1.
2. Rectangular arrays divided into elements of dimension $0.5 - 2 \lambda$, where λ is the wavelength, with pre-focusing in the short-axis dimension, see Fig. 2.

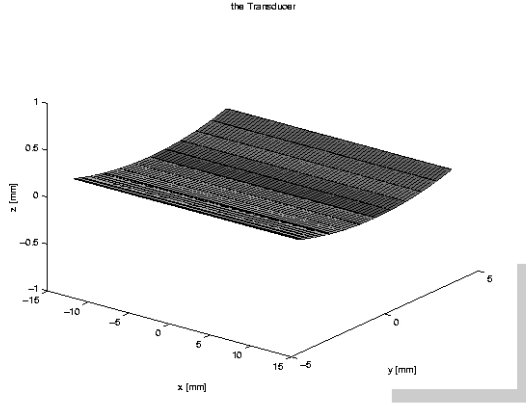


Figure 2: View of rectangular array with aperture 14.08 mm (64 half wavelength elements at 3.5 MHz) by 9 mm and fixed focus 60 mm.

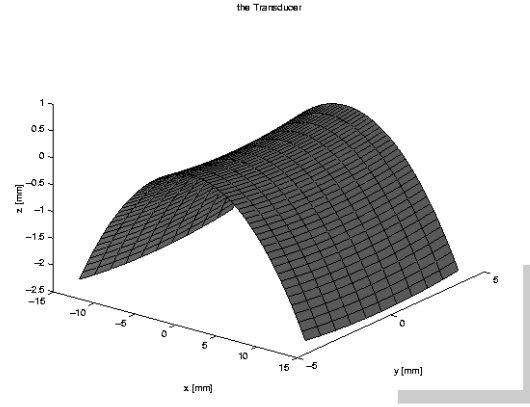


Figure 3: View of curved array with aperture 28.16 mm (64 wavelength elements at 3.5 MHz) by 9 mm, fixed focus 60 mm, and radius of curvature 40 mm.

3. Curved arrays divided into elements of dimension $1 - 2 \lambda$ with pre-focusing in the short-axis dimension, see Fig. 3.
4. 1.5D arrays which have a possibility for varying the focus in the elevation direction by phasing 3 or 5 elements, see Fig. 4.

In addition, transducers of more complex shapes such as oval or elliptic ones can be handled (Fig. 5). One can also analyze the fields generated by 2-dimensional transducers. Fig. 6 shows for instance a sparse array where a subset of 500 elements in a 2D aperture of 2500 elements are active. The example is from [4]. Ultrasim can also find the field from limited diffraction geometries such as axicons and Bessel transducers, see [5].

2.2 Simulation Method

In order to find the field it is common to assume that the Rayleigh integral applies:

$$\phi = \frac{1}{2\pi} \iint \frac{u_n(r_0, t - r/c)}{r} dS$$

where the velocity potential, ϕ , is given by the normal velocity, u_n integrated over the active transducer surface. The source is assumed to be planar, i.e. the lateral dimensions and the radius of curvature are large compared to the wavelength [6], and thus curved transducers used in ultrasound are covered by this assumption. There is also a possibility to handle an aberrating

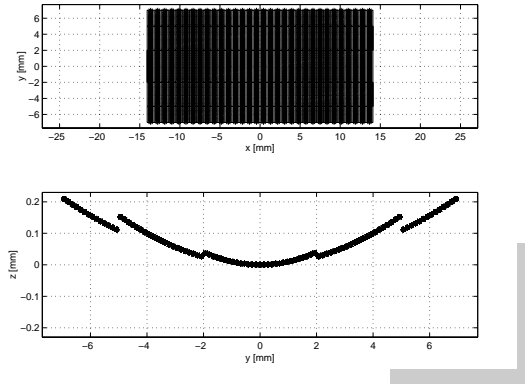


Figure 4: Top view and side view of 1.5 D array. Aperture is 28 mm by 14 mm. The short-axis dimension is divided into 5 symmetric sections of size 2, 3, 4, 3, 2 mm. The focal points for the short-axis apertures are 115, 80, and 50 mm.

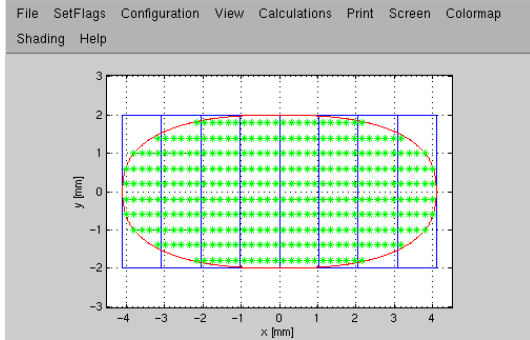


Figure 5: View of 8 element array with a superelliptic footprint, aperture is 8 mm by 4 mm.

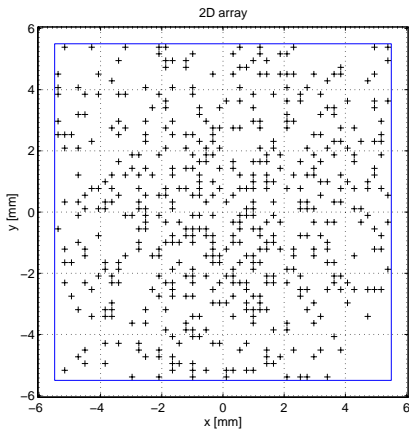


Figure 6: Element layout for optimized 2D array with 500 elements out of 50 x 50, optimized for minimum beamwidth. The grid is shown for a frequency of 3.5 MHz and a velocity of sound of 1540 m/s corresponding to a wavelength of $\lambda = 0.44$ mm.

medium by taking different medium properties into account for each path from source to field point [7], [8], although this method is not so well integrated into the program at the moment.

The Rayleigh integral is solved by discretizing the radiating surface, assuming that the plane source vibrates in a single mode (thickness mode) [9], and thus that the surface velocity is separable in a spatial and a temporal part:

$$u_n(r, t) = O(r) \cdot u(t)$$

The observation plane is also discretized and the integration is done by finding the distance and quantized time delay [10] from each source point to each of the observation points. The time waveform is either a continuous wave or a pulse that resembles the pressure pulse measured at the focal point on the acoustical axis. At this point one will get coherent summation of the Rayleigh integral. This means that we excite with a measured approximation of the surface velocity.

2.3 Examples

The following four figures give examples of the output from the simulator. In Fig. 7, a contour plot of the continuous wave field from the transducer in Fig. 2 is shown.

The surface plot of Fig. 8 shows the distribution of energy at a certain point in time and space on a linear or logarithmic energy scale.

The beampattern can be found either with continuous wave or pulse wave excitation as shown in Fig. 9.

It is also possible to show the energy along any axis in Cartesian or spherical coordinate systems, for instance along the acoustic axis as shown in Fig. 10.

In addition it is possible to generate animations of travelling ultrasound pulses using the display of Fig. 8, or to take the maximum at all locations of an animation and generate a contour plot like in Fig. 7, but in this case based on a pulse excitation. More examples can be found on the web page.

3 Conclusion

Ultrasim is an interactive simulator for finding the sound field from acoustic radiators in medical ultrasound applications and in sonar. The simulation is based on a discrete version of the Rayleigh integral. The simulator can handle all the array geometries in common use, and finds the acoustic field in the nearfield or

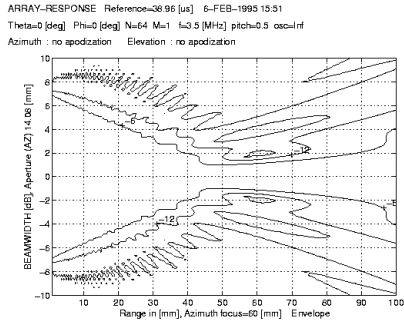


Figure 7: Plot of beamwidth contours (-6, -12 and -20 dB) for continuous wave excitation at 3.5 MHz for the array of Fig. 2.

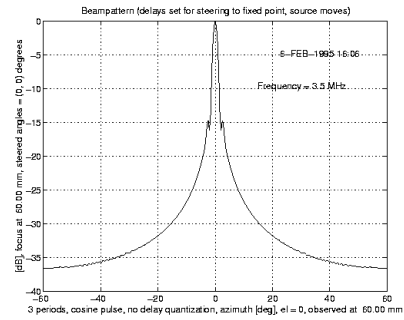


Figure 9: Beampattern obtained by summing energy over all time at a distance equal to geometric focus (60 mm) for the array of Fig. 2.

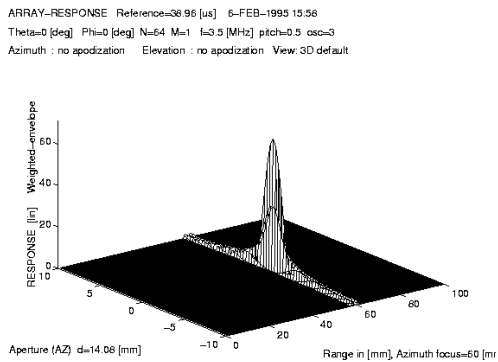


Figure 8: Plot of pulse in focus as sent from the array of Fig. 2. Pulse form is 3 periods shaped with a cosine.

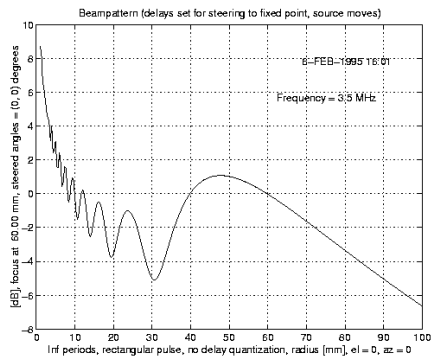


Figure 10: Intensity plot along acoustic axis for continuous excitation for array of Fig. 2.

the farfield with a continuous wave or a pulsed wave excitation. The simulator is freeware and is available under GNU public license [2].

4 Acknowledgement

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