Application of Phased Array Radar Theory to Ultrasonic Linear Array Medical Imaging System

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Basic principle of ultrasound medical imaging is a direct adaptation of that of phased array radar. Modern ultrasound scanners use large either linear or phased array of piezoelectric (PZT, for instance) transducers. Designing electronic beam-forming network for ultrasound pulsed echo system is thus very much similar to the adaptive antenna array system design in a different modality.

When ultrasound propagates through human tissue layers having different acoustic impedance at each tissue layer interface it gives an echo. The attenuation co-efficient, speed, viscosity, density, compressibility and other acoustic parameters of the medium directly control the characteristics of the back scattered components that is received by the same transducer utilized in transmitting the ultrasound signal. The interaction of ultrasound with human tissue, thus, is a multi parameter one being capable of delivering more information about the medium. As a result while with X-rays we get only a shadow image of the system, with ultrasound we get more detailed image of different tissues. However, it is necessary to pursue R&D work in each block of the ultrasound pulse echo imager to improve the image quality. Making Improvements in adaptive beam forming algorithms is one of such efforts.

Authors in this paper first introduce the subject through a brief survey of the devices utilized and technique involved, and then describe the simulation of a delay-sum digital beam-former of a linear ultrasound array imaging system. Simulation has been performed for 8-, 16-, and 64-element linear transducer array. A near-real situation has been effected in the simulation by taking a pulse modulated 2MHz sinusoidal signal. Effect of modulating pulse width on directivity and amplitude of the side lobes have been studied and results presented.

INTRODUCTION

Quality of an ultrasound medical image depends largely on the transmit/receive probe used that normally is a piezoelectric transducer. This entails that a large portion of historical development of diagnostics is captured by the history of development of the transducer technology that includes material research, understanding of the physics of wave and its propagation through fluid and solid and particularly through tissue media.

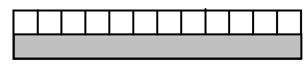
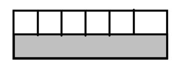
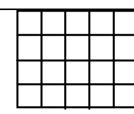
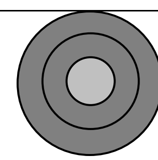
The complexity of the interaction of ultrasound with human tissue is resulted because of the composition of the media. It is highly inhomogeneous, non-linear and anisotropic. It is embedded with different types of tissue types, namely, hard, soft, softer etc. some example being, bone, muscle, blood, fat and so on. During interactions of ultrasound with such a medium the physical processes that become important are attenuation, reflection, and scattering. The tissue acoustic parameters that play major role are acoustic impedance, sound velocity, attenuation coefficient, viscosity, and various relaxation processes. Frequency-dependent attenuation and dispersion are very complex processes in tissue and need deep understanding for properly designing the diagnostic ultrasound system and of course the front-end part; design of the transducer, the foremost part being the most crucial. In a complete diagnostic system ultrasound probe is singularly the most expensive and delicate part.

The basic scanning process followed in ultrasound scanning machines has a good overlap with *radar techniques*. Thus there has been a growing need for replacing single element transducer with an array; this is mainly for improving various resolutions like axial, lateral and elevational, and to improve image quality. At the present state of development application of *single element* transducer is almost confined to amplitude mode of imaging i.e. the A-mode, all other modes like B-mode, *transducer-array* is used. The terminologies expressed in italics are borrowed from the literatures on radar because of, as mentioned elsewhere, the very similar principle of operation followed in both the cases; difference of course lies in the modalities involved in these two cases. This difference creates ultimately a lot of typicality in each system's design criteria including the devices needed and algorithm followed for implementation.

TANSDUCER ARRAYS

Non-invasive nature of diagnostic capability of ultrasound is made possible only through proper probe; both mechanical design and beam profile have important roles to play. In single element transducers beam profile has a direct relevance to the transducer diameter which varies from 4-6mm to 19-20mm. Transducer with larger cross sectional area generates a beam that covers wider area while sweeping at the cost of lateral resolution. These transducers can be either focused or unfocussed. In focused transducers focal length is always shorter than the near zone. For imaging axial region around the minimum cross sectional area of the beam is used.

TABLE 1
TRANSDUCER TYPES

Linear Array - Transducer shape determines display image format - Generally more elements than Phased Array	
Phased Array - Key Feature: Dynamic focusing and steering of beam - Display Image Format: Sector only	
Two-dimensional Array -Allows for full volume imaging Hardware complexity increases by N^2	
Annular Array Two-dimensional focusing, but no beam steering	

A micro motor that physically swings the crystal executes the steering of the beam. Using oil damper in the surroundings of the crystal controls Single Pulse Length. Major limitations in this single element transducers that were felt are (i) usual sluggishness of the mechanical system is reflected in the scanning operation (ii) no provision for controlling the transducer aperture and dynamic focusing. Primarily because of the limitation (ii) almost all present generation ultrasound imagers use array transducers. Extra benefits obtained are electronic steering and automatic identification of the targeted object by incorporating *adaptive array signal processing* in the *beam former.*

The majority of ultrasound systems employ transducers with many individual rectangular piezoelectric elements arranged in linear or curvilinear arrays. Typically, 128 to 512 individual rectangular elements compose the transducer assembly. Each element has a width typically less than half the wavelength and a length of several millimeters. Two modes of activation are used to produce a beam. These are the 'linear' (sequential) and 'phased' activation/receive modes.

Linear Arrays

Linear array transducers typically contain 256 to 512 elements; physically these are the largest transducer assemblies. In operation, the simultaneous firing of a small group of ~20 adjacent elements produces the ultrasound beam. The simultaneous activation produces a synthetic aperture (effective transducer width) defined by the number of active elements. Echoes are detected in the receive mode by acquiring signals from most of the transducer elements.

Phased Arrays

A phased-array transducer is usually composed of 64 to 128 individual elements are activated nearly (but not exactly) simultaneously to produce a single ultrasound beam. By using time delays in the electrical activation of the discrete elements across the face of the transducer, the ultrasound beam can be steered and focused electronically without moving the transducer. During ultrasound reception, all of the transducer elements detect the returning echoes from the beam path, and sophisticated algorithms synthesize the image from the detected data.

Table above lists some of the common variety of array transducers along with an idea of their structure.

BEAMFORMING

The job of an imager is to *pick up* the intended object from a crowd of many and form its *clear* image. Beamformer performs the first part. So essentially it is *spatiotemporal* filter implemented either in analog or digital domain changing thereby the terminology accordingly. In an array transducer there occurs some side lobes. As in the case of radar it depends upon the number of elements, their separation, and individual dimension etc. It is often necessary to *apodize* the side lobes by using apodizing multiplier and incorporate *interpolation* filters for improving image quality.

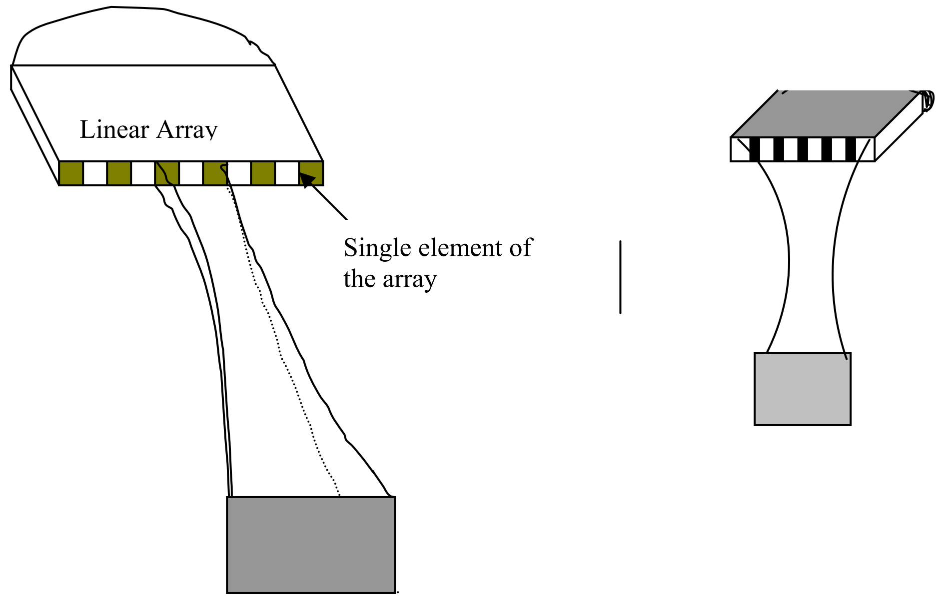


Figure 1 **The Beam Cross Section of linear and phased arrays**

BASIC PRINCIPLE AND SIMULATION OF BEAMFORMING

A simple beam-forming algorithm by an array of sensors and related formulas, relevant to the physical situation, will be discussed in this section. Naturally, sensors are placed in an ordered way to receive the signal. The sensed and combined signal of the sensors is a function of number of sensors, their separations and orientation. Generally these sensors receive the external disturbance and accordingly convert into electrical signal. These transducers also act as transmitter as well as receiver in real case. They receive signals between two successive transmissions.

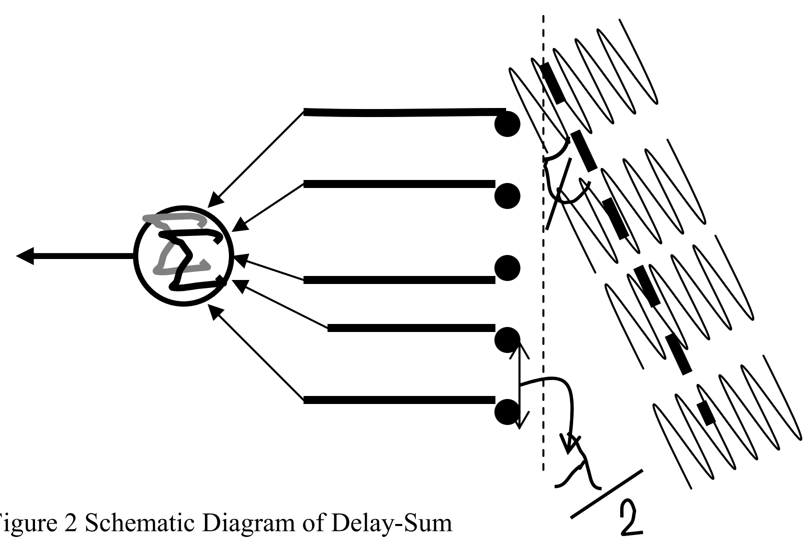


Figure 2 Schematic Diagram of Delay-Sum Beamformer

Let us consider a plane wave, as shown in the figure 2 incident on the transducers. We assume that the incident wave is pulse modulated sinusoidal, of angular frequency 2MHz. This range of frequency matches absolutely with the medical imaging application targeted.

In the MATLAB simulation of the linear array system two variable parameters have been taken. The number of elements in the array, three cases have been studied 8-element-, 16-element- and 64-element-linear arrays. In commercial transducers (TELEMED, for instance) 64-element is the minimum array length. The other variable parameter is the modulating pulse width. It has been varied by changing the number of sinusoidal cycles it is allowed to include. Three cases have been considered.: 3, 5, and 7 cycles. Seperation between the transducer elements has been kept fixed to a realistic value of $\lambda/2$ (Fig.2).

In this set up for simulation we get in total nine combinations: for each of 8-, 16-, and 64-, element case, three different pulse widths has been simulated. From the simulation results we will discuss suitability of the structure of the transducers for medical imaging.

SIMULATION RESULTS

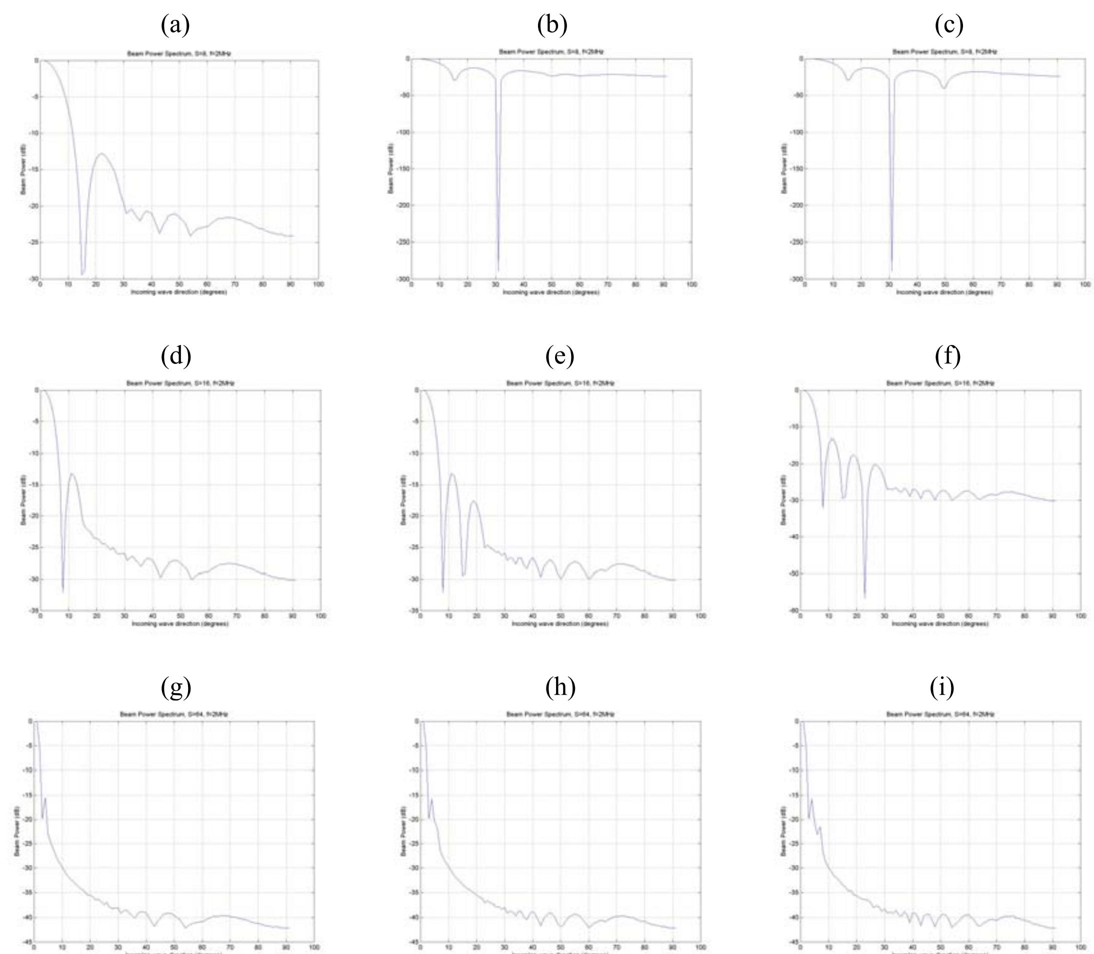


Fig. 3 Summed Output of the Delay-Sum Beamformer for different incident beam directions

(a), (b), (c) are the out put when the Number of Elements is 8, for three different pulse widths

(d), (e), (f) are the out put when the Number of Elements is 16, for three different pulse widths

(g),(h), (i) are the out put when the Number of Elements is 64, for three different pulse widths

CONCLUSION:

In the simulation as mentioned above we have taken as much as possible all the realistic cases that is faced in ultrasound medical imaging system. Three different transducers are found to have different outputs as expected. Since in imaging purpose especially for scanning we desire to have the close approximation to a ray, in other words, narrow beam with good directivity is needed. As we increase the number of elements in the transducer the level of the sidelobes decreases, as also the case for narrower pulse.

The future scope of this work is for taking the gaussian pulse instead of rectanular pulse, and also to include interpolation and apodising filter to achieve better image.

REFERENCE

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