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The effect of transducer angulation on pulse-echo amplitude scan signal formation

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This paper describes a simple simulation of the signal formation process in an ultrasonic pulse-echo amplitude scan line. It includes transducer angulations, radiation coupling and transducer responses. The simulation is used to estimate the effect of oblique incidence on signal formation.

Key words: ultrasonic A-scan, transducer, simulation, convolution.

INTRODUCTION

The displayed images from ultrasonic scanning systems depends strongly on the characteristics of the overall signal path. These include the reflection or scattering processes that form the echoes, the characteristics of the transducers, the electronic systems and radiation coupling phenomena [1, 2].

In our simulation using simple impulse excitation to the transducer and consider the received echo waveform and its frequency spectrum, at the terminals of the same transducer. The simulation of the signal path includes

(i) radiation coupling response from the transducer to the target and back again,
(ii) transducer reflector angulations,
(iii) the electro-acoustic properties of the transducer.

The approach taken is to assume that these three processes are linear, time invariant and separable from each other. The overall signal pathway is assumed to be the convolution of three impulse responses representing, respectively , the acoustic field, transducer reflector and the transducer impulse response. In our simulation it is possible take either a time domain or a frequency domain approach for each phenomenon by means of fast Fourier transform (FFT) [3] .

Wells [4] has measured the relation between echo amplitude and angle of incidence for a plane flat target in water, using a pulse-echo system. Also, Chivers et al. [5] was shown that the form of back scattered echo spectra varied with orientation of the tissue sample. This paper describes the use of a simulation of signal pathway to investigate the relation of the echo pulse frequency spectrum with the angle of incidence of the signal at the transducer face.

1. RADIATION COUPLING RESPONSE

For disc transducers of equal diameter, the force coupling impulse response has been formulated by Rhyne [6] as

$$r(t)=\begin{cases}0 & 0\le t\le t_1,\\ \delta(t-t_1)-\dfrac{c^2t}{a^2\pi}\left[\dfrac{t_2^2-t^2}{t^2-t_1^2}\right]^{1/2} & t_1\le t\le t_2,\\ 0 & t\ge t_2.\end{cases} \quad (1a)$$

where c is the wave propagation velocity, a is the transducer radius, t_1 is the time of arrival of the face wave, and t_2 marks the termination of the edge wave contribution to the force coupling impulse response:

$$t_1 = l/c \ , \quad (1b)$$

$$t_2=\sqrt{l^2+4a^2}\,/c \ . \quad (1c)$$

In the interval ($t_1 \le t \le t_2$), the first term represents the face wave component, and the second term represents the edge wave. According to Rhyne, The formulation of equation (1) can be used to represent radiation coupling between a disc transducer to a plane reflector and back to the same disc transducer.

2. TRANSDUCER REFLECTOR IMPULSE RESPONSE

Challis [7] has found a closed form solution of the time domain impulse response for the area of a circular transducer irradiated by a plane compressive wave of infinite extent and propagation velocity *c*, striking the transducer face at angle θ. The time domain impulse response can be written in the form

$$angle(t)=\frac{2ca}{\sin\theta}\sqrt{\frac{2ct}{a\sin\theta}-\left(\frac{ct}{a\sin\theta}\right)^2} \ . \quad (2)$$

3. THE TRANSDUCER RESPONSES

There are many computer models describing the behaviour of ultrasonic piezoelectric transducer [8]. In this paper, the simulation was carried out by using a previously developed digital computer model [9] to evaluate the pulse-echo responses of circular ultrasonic piezoelectric thickness expanders. The model is split into two parts. First, the basic transfer function of the loaded piezoelectric element is evaluated in discrete form using the *z*-transform technique. Secondly, the sampled time-domain responses is obtained by filtering the desired input with the previously calculated digital filters by using an algorithm also capable of handling digital filters supplied in the contracted format. The transducer can be connected to any passive electrical network and furthermore the voltage response at any point in this network can be obtained.

The above simulation was applied using typical data for transducer constructed with a load zirconate titanate (PZT-5A) piezoelectric element with tungsten-epoxy [10] ($z = 19\times10^6$ kg $m^{-2}s^{-1}$) back block. The transmitter response is obtained for a 10 mm diameter pulse-echo transducer of 5 MHz center frequency. The impedance of the generator is assumed to be 50 ohms resistance. Figure 1 shows the expected waveform at the transducer terminals when the device acts as a receiver; that is, in pulse-echo mode with no radiation coupling, target or other field effects. The simulation were carried out at an effective sampling time of 5 ns. Figure 2 shows the pulse-echo transducer frequency response of figure 1.

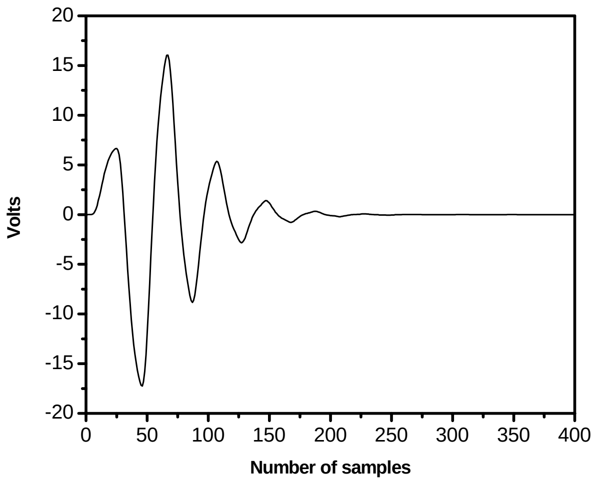

Figure 1.

The voltage at the transducer terminal when an echo is received from a plane reflector in a lossless medium

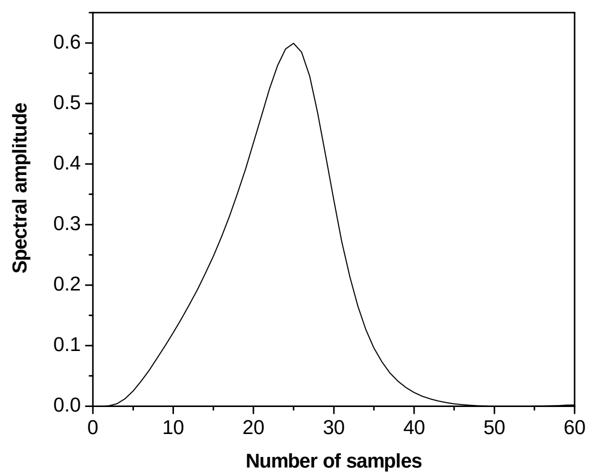

Figure 2.

Frequency spectrum of pulse-echo response of Fig. 1

4. SIMULATION RESULTS

The signal pathway of a pulse-echo system consists of the responses of the transducer in transmission and reception combined with the radiation coupling response, and the impulse response due to transducer reflector angulations. The signal transfer process can be modeled by a series of convolution. If $x(t)$ is the input voltage drive to the pulse-echo transducer and $y(t)$ is the output voltage at the transducer terminals in reception, then

$$y(t) = f_T(t) * r(t) * angle(t) * f_R(t) * x(t), \tag{3}$$

where $*$ represents the convolution integral, given by

$$p(t) * q(t) = \int_{-\infty}^{+\infty} q(\tau) p(t-\tau) d\tau . \tag{4}$$

The symbols have the following meanings. $f_T(t)$ is the transmission transducer impulse response; $r(t)$ is the impulse response of transient radiation coupling; $angle(t)$ is the impulse response of transducer reflector angulations; $f_R(t)$ is the receiver transducer impulse response.

The real frequency model is obtained from the impulse responses by Fourier transformation and replacing the time domain convolution by frequency domain multiplication. The simulations were carried out by multiplying the transfer functions of the two transducer responses by the radiation coupling response and the transfer function of transducer reflector in the frequency domain. The resulting response was then converted back into the discrete time domain by inverse Fourier transformation. The pulse-echo response of the transducer shown in figure 1 has been combined with the radiation for a depth 2 cm in biological tissue and transducer reflector response with incidence angle 1°. The overall time domain response at the receiver terminal is shown in figure 3. From this figure it can be seen that the amplitude of the signal decreases with incidence angle. Figure 4 shows the frequency spectrum of figure 3. The spectrum domain with incidence angles 2° and 3° is shown in figure 5. It is clear from this figure that lobe appear in the spectrum at higher frequencies and the spectrum shift down. Figure 6 shows the pulse-echo response with incidence angles 5° and 7°. Figure 7 shows the spectrum of figure 6. From these figure it can be seen that the number of lobes are strongly dependent on the incidence angle. Also, the spectrum shift down strongly depends on the incidence angle.

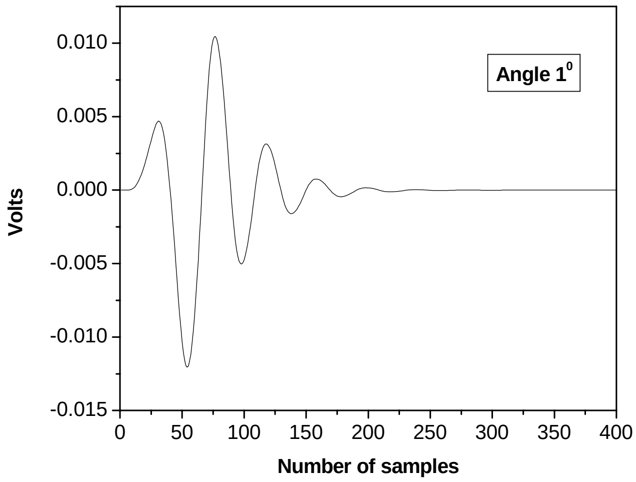

Figure 3.

Time domain pulse-echo response with a transducer reflector angulation 1°

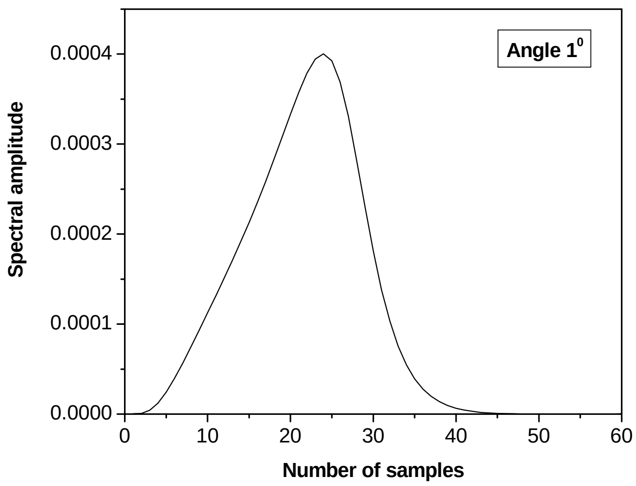

Figure 4.

Frequency spectrum of fig. 3

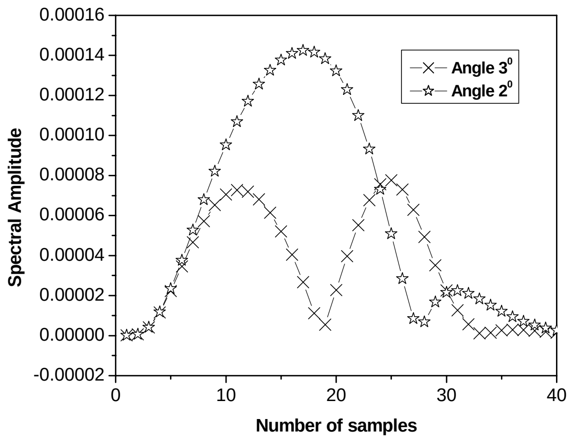

Figure 5.

Frequency spectra of pulse-echo responses with incidence angles 2° and 3°

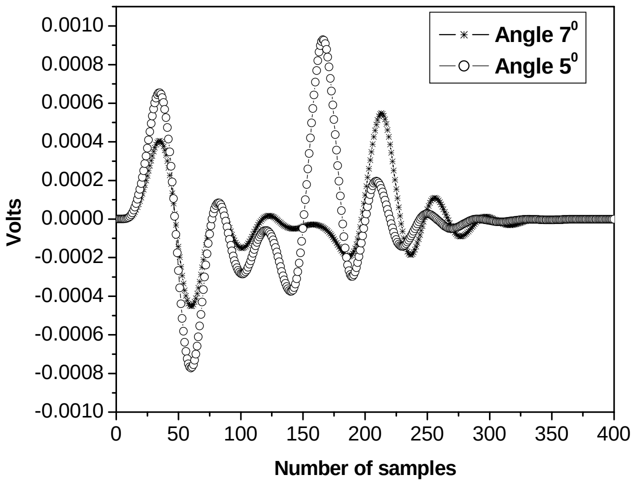

Figure 6.

Time domain pulse-echo response with incidence angles 5° and 7°

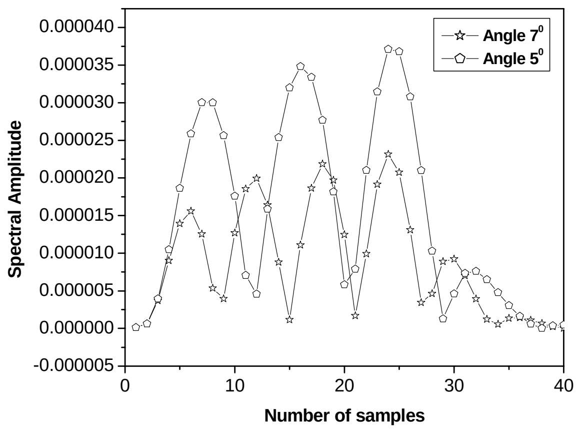

Figure 7.

Frequency spectra of pulse-echo responses of fig. 6

CONCLUSIONS

This paper has described a simple simulation of the signal formation process in a pulse-echo A-scan system. The simulation has been used to determine the frequency filtering effect of oblique incidence by Fourier transformation. It is clear that small changes in incidence angle yield change in the form of the signal pathway received by a pulse-echo system. The model could be used to estimate the relation of pulse-echo amplitude scan signal to the angle of incidence.

REFERENCES

1. B. A. J. Angelsen, Ultrasonic imaging: waves, signals, and signal processing. Emantec AS, Trondheim, Norway, 2000.
2. Albert Goldstein and Raymond Powis, Medical ultrasonic Diagnostics: in Physical Acoustic, Vol 23. Academic press, 1999.
3. M. G. S. Ali and A. Raouf Mohamed. Cepstral predication analysis of the signal pathway in an ultrasonic A-scan. Journal of Sound and Vibration, 236 (4), 609–621, 2000.

4. P. N. T Wells. Ultrasonic in clinical diagnosis In: Scientific Basis of Medicine: Annual Reviews. Athlone Press, London, 38, 1966.
5. R. C. Chivers and C. R. Hill. A spectral approach to ultrasonic scattering from human tissue: methods, objective and back-scattering measurements. Phys. Med. Biol. 20, 799–809, 1975.
6. T. L. Rhyne. Radiation coupling of a disk to a plane and back or a disk to a disk. J. Acoust. Soc. Am, 61, 318–324, 1977.
7. R. Challis. The effect of transducer-reflector angulation on echoes received from targets using Ultrasonic pulse-echo equipment. Acustica, 50, 222–225, 1982.
8. G. K. Lewis. A matrix technique for analyzing the performance of multilayer front matched and backed piezoelectric ceramic transducers. Acoustical imaging, 8, 395–416, 1980.
9. M. G. S. Ali. Discrete time model of acoustic waves transmitted through layers. Journal of Sound and Vibration, 224(2), 349–357, 1999.
10. J. W. Hunt., M. Akditi and F. S. Foster. Ultrasound transducers for pulse-echo medical imaging. IEEE Trans Bio. Eng., 30, 454–463, 1983.