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# THE EFFECTS OF TRANSDUCER-TARGET ANGLE ON PULSE-ECHO SIGNAL TRANSMISSION.

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## INTRODUCTION

The application of frequency analysis to back scattered signals received by ultrasonic pulse-echo systems has been suggested by many workers as a method of characterising flaws in engineering materials (1,2) and as a means of recognising biological tissue structure (3). Generally emphasis has been placed on the scattering properties of the target rather than on the properties of the measuring system. However, an important component in the signal pathway is the physical process of the incidence of back-scattered waves at the receiver transducer (4). In particular the angle at which an acoustic wave strikes the face of a transducer has a strong effect on the form of the measured spectrum. In this paper the effect of oblique incidence of wideband signals on a circular receiving transducer is investigated. A simple geometrical model is developed which relates the time domain signal at the transducer terminals to the incident acoustic pressure waveform as a function of incidence angle in terms of an equivalent impulse response function for plane waves of infinite lateral extent. The frequency domain filtering effect of oblique incidence is determined by Fourier transformation of the impulse response. Two experiments are presented which assess the applicability of the model.

## IMPULSE RESPONSE THEORY

We consider a circular transducer of radius $R$ and a plane compressive wave of infinite lateral extent incident at angle $\theta$ at time $t = 0$, fig.1. The pressure waveform is assumed to be a Dirac impulse in time. It is assumed that the transducer has infinite bandwidth and that its electrical output is proportional to the instantaneous pressure on the receiving face integrated with respect to area, irrespective of whether or not all points on the face are irradiated with equal pressure. Referring to fig.1 we can calculate the area of the transducer face irradiated in interval dt.

$$dx = dz/\sin\theta = c\,dt/\sin\theta \qquad (1)$$

This corresponds to an irradiated area

$$dA = 2y\,dx = 2yc\,dt/\sin\theta \qquad (2)$$

Now

$$y^2 = R^2 - (R - x)^2 \qquad (3)$$

Whence

$$\frac{dA}{dt} = \frac{2cR}{\sin\theta}\sqrt{\frac{2ct}{R\sin\theta} - \left(\frac{ct}{R\sin\theta}\right)^2} \qquad (4)$$

In the limit as dt approaches zero dA/dt becomes the differential coefficient of irradiated areas with respect to time. This is the time domain impulse response of irradiated area as a function of $\theta$. It is valid in the interval $0 < t < (2R\sin\theta)/c$. Fig.2 shows the impulse response evaluated for a 14mm diameter transducer set in water for two incidence angles. The Fourier transforms of these responses are shown on fig.2b. The lobes in these spectra are caused by the sharp discontinuities in the impulse response at $t = 0$ and $t = (2R\sin\theta)/c$. The loss of high frequency energy (low pass filter effect) is caused by the lengthening of the original impulse in the time domain.

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## FREQUENCY DOMAIN EXPERIMENT

Methods: A commercially built single circular transducer (14mm dia.) and pulse echo system was used in conjuction with a gated rf spectrum analyser built by Weight (5). The transducer could be tilted through a measured angle and the target consisted of a flat steel plate (10cm x 10cm x 2cm) set in water 3cm from the transducer. The transducer face was aligned parallel to the target and the reference spectrum recorded from the received signal (fig.3a). The transducer was then tilted through measured angles and the echo spectra recorded in each case (fig.3b,c). The dotted lines on fig.3 are the received signal spectra predicted by multiplying the reference spectrum by the Fourier transform of the calculated impulse response.

Results: The widths and relative heights of the spectral lobes were reliably predicted for small angles. At larger angles (not shown) the positions and widths of the spectral peaks were still reliably predicted but the measured spectra showed less energy than predicted at the lower frequencies. This was due to the fact the wavefronts were bounded and not of infinite extent in the experimental situation, leading to shorter irradiation time at the transducer face.

## TIME DOMAIN EXPERIMENT

Methods: Transmitting and receiving transducers each consisting of unbacked cylinders (10mm dia. x 10mm length) of PXE4 material (Philips Ltd) were set in a water tank with their active faces alligned coaxially at a range of 3cm. The receiver could be rotated so as to set its face at a measured angle with respect to the transmitter face. The transmitter was excited with 115v step waveforms (rise time<10ns) and the receiver was terminated resistively (50Ω). Both elements were connected to an oscilloscope (rise time 18ns). The transducers were operated as "thick" devices used to generate and receive short pulses (6). The 10% - 90% rise time of the step waveforms at the receiver were measured as a function of angle between the face planes.

Results: Fig.4 shows received signal rise time plotted as a function of receiver face angle. The 75 ns/degree line represents the theoretical rise time calculated by integrating the impulse responses of fig.2 to get the corresponding step response. In the range $2^{\circ} < \theta < 9^{\circ}$ there was good agreement between the measured and predicted results. Above $9^{\circ}$ the measured rise times were less than predicted because the experimental wavefronts were not of infinite lateral extent, leading to shorter incidence times at the receiver. Below $2^{\circ}$ the measured rise times were greater than predicted due to the fact that the transducer face planes were out of parallel in a direction over which the experimenter had no control.

## CONCLUDING REMARKS

The results of these experiments show that the effect of oblique wave incidence can be calculated on the basis of simple geometrical theory; this is particularly interesting since the theory is for plane waves of infinite lateral extent whereas the experimental wavefronts were bounded laterally and subject to diffraction effects. Oblique incidence has a low pass filtering effect which causes received transient signals to be prolonged in time. Discontinuities in the impulse response describing oblique incidence cause lobes to be imposed on the received signal spectra. These effects may mask spectral information characteristic of a target or they may present information to the experimenter which may be mistaken as being characteristic of a target.

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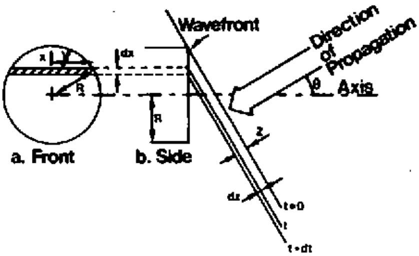


*Fig.1* Circular transducer irradiated by plane wavefront at angle θ. The hatched region shows the increment in face area irradiated in interval t to t + dt

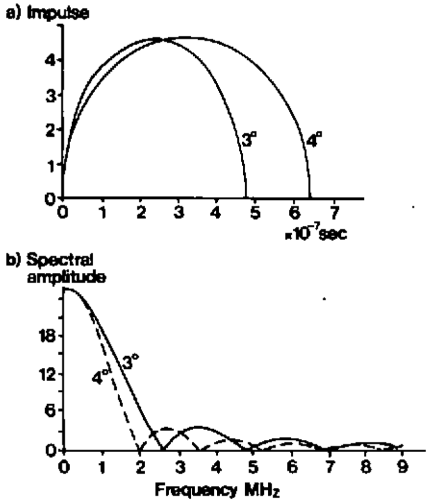


*Fig.2* a) Calculated impulse responses, b) Equivalent frequency response.

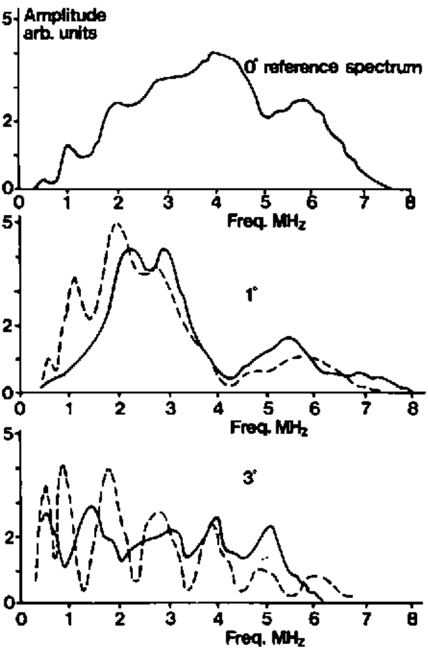


*Fig.3* Spectra recorded in frequency domain experiment. a) reference spectrum b) 1° incidence, c) 3° incidence.

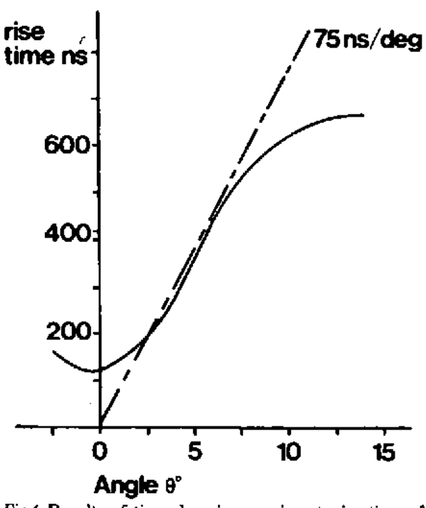


*Fig.4* Results of time domain experiment, rise time of recieved step waveform vs angle between the transducer face planes.