

## ELECTRONIC SCANNING IN ACOUSTIC MICROSCOPY

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### INTRODUCTION

Scanning acoustic microscopy (SAM) employs mechanical scanning in both x and y directions. There is one great advantage in this configuration which is that imaging is done on axis, resulting in diffraction limited resolution. However a mechanical system is inherently slow and cumbersome, even though recent advances have brought the scanning time for an image at high frequencies down to the order of a second. For the inspection of inexpensive items such as integrated circuit chips, which is done at frequencies below 100 MHz, it is imperative to have a cheap and ideally real time system. The present work describes recent developments in our laboratory in this direction.

Most of the previous work on electronic scanning has involved various forms of phased arrays and time delay systems below about 10 MHz [1]. At higher frequencies Chen et al. [2] developed a device using surface to bulk wave conversion by scattering a chirped SAW from a periodic grating. Quate [3] suggested the use of ultrasonic drill technology to produce real time imaging, although this is ultra high speed mechanical scanning as opposed to electronic scanning. Cheeke et al. [4] reported preliminary results on the principle of the present work and Kubota et al. [5] published images obtained with a combined electronic-mechanical scan which has certain similarities to our method.

### EXPERIMENTAL DETAILS

The principle of the technique is relatively simple. We use a cylindrical lens, which is well known in acoustic microscopy. When irradiated with a single frequency this lens is incapable of supplying an acoustic image, and it is rather used for  $V(z)$  studies. In our system we use a wedge transducer source, in which the resonant frequency varies along its length, the latter being oriented parallel to the lens axis. Thus by sweeping the frequency we are able to electronically scan the ultrasonic beam down the focal line.

The detailed design considerations for this system will be treated elsewhere. Firstly it is necessary to use an intrinsically narrow band resonant transducer such as Lithium Niobate in order to

exploit the position dependence; ZnO will not work as it is locally wide band at all positions. Secondly, as is well known in such applications, the third harmonic gives a much cleaner radiation pattern than the fundamental and its use implies a limited bandwidth for the fundamental to avoid frequency overlap and hence spatial address duplication for the higher harmonics. The requirement of approximately normal radiation from the transducer imposes certain limits on the wedge angle and the lens geometry and dimensions have a direct effect on the diffraction broadening in the lens body, which is of importance to the resolution along the lens axis. The wedge angle is a key parameter: if it is too small the spatial resonance variation will be washed out, if it is too large there will be spatial overlap of the harmonic components and very poor resonance conditions due to the nonparallelism of the opposing faces.

The wedge transducers used in the present work were 2 x 5 mm plates of 36° rotated Y cut lithium niobate with fundamental resonance 10-17 MHz supplied by Valpey Fisher. The insertion loss as a function of frequency is shown in Figure 1. Despite its higher insertion loss the third harmonic was chosen for the reasons already given. The transducer was epoxy bonded to an aluminium block which had a 13 mm long, 3 mm diameter cylindrical lens ground in the opposing face. The surface of the block next to the transducer was slanted in order to compensate for the oblique radiation which is characteristic of wedge transducers [6].

The electronic system as shown in Figure 2 consisted of a Fluke 6060B synthesiser controlled by a GPIB IEEE interface bus. The signal is amplified and gated by a Matec 310 unit. The return signal from the lens is mixed with a signal from a second synthesiser at  $f \pm 60$  MHz and the resulting signal at 60 MHz is detected by a Matec 6000 receiver. The mechanical scanner was of the cantilever type and the images were stored and displayed in an IBM PC AT compatible system.

## RESULTS AND DISCUSSION

Results are presented in Figure 3 comparing pure mechanical and mechanical-frequency scanning for a 2 mm diameter hole drilled in a plexiglass block. The resolution is of the order of 700  $\mu\text{m}$  along the frequency axis and is approximately equal to the diffraction limited resolution, about 45 microns, along the mechanical axis. A second example is shown in Figures 4 (a) and (b) for the image of a periodic structure machined in an aluminium block. Again we observe the difference in resolution by comparing the two figures: in the perpendicular direction the edge is sharp when the scanning is mechanical (Figure 4 (a)) and more indistinct when it is electronic. Quantitatively the results are compatible with those of Figure 3. Using the same criterion (10%-90% amplitude variation) for the resolution our results are similar to those of Kubota et al. who obtain 370  $\mu\text{m}$  using an array of 128 elements along the cylinder axis. Our earlier work [4] suggests that it should be possible to obtain a resolution of the order of 200-500  $\mu\text{m}$  at frequencies in the 60-80 MHz range.

The system has also been applied to the case of subsurface imaging. The same hole in a plexiglass plate imaged in Figure 3 was viewed from the opposite face of the plate; the extremity of the hole was about 0.5 mm from the surface. Figure 5 shows the image of this blind hole using conventional acoustic microscopy. The white area

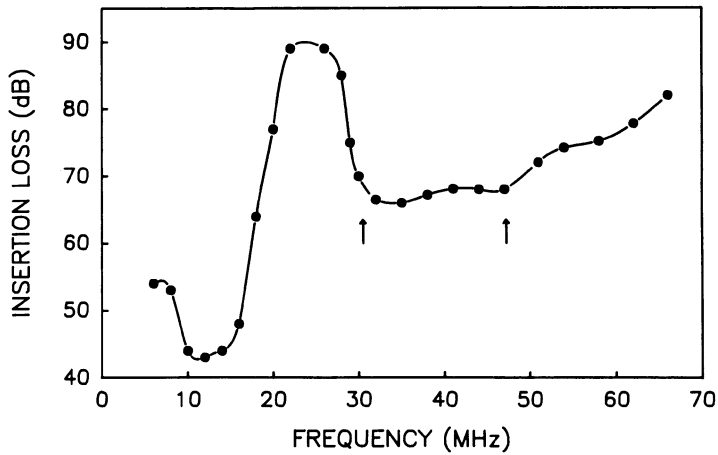


Fig. 1. Insertion loss as a function of frequency for a lithium niobate wedge transducer with fundamental 10-17 MHz, epoxy bonded on to an aluminium block with cylindrical lens.

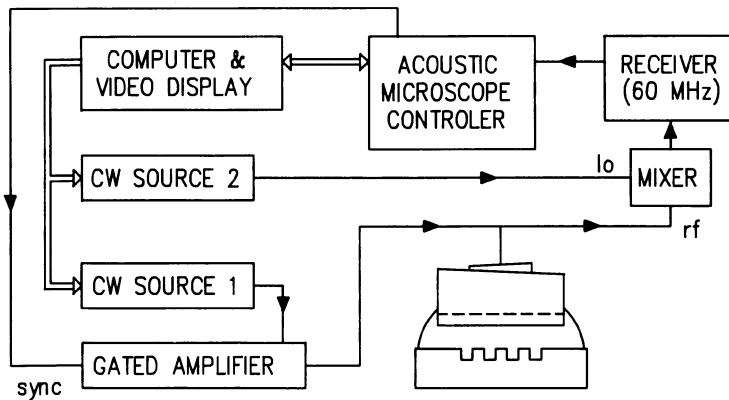


Fig. 2. Electronic system used for frequency scanning.

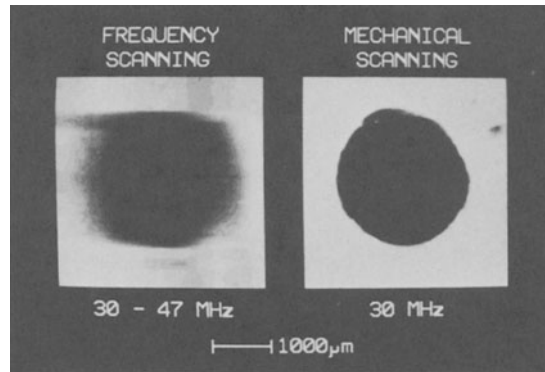


Fig. 3. Images comparison for mechanical and mechanical-frequency scanning of a 2 mm diameter hole drilled in plexiglass.

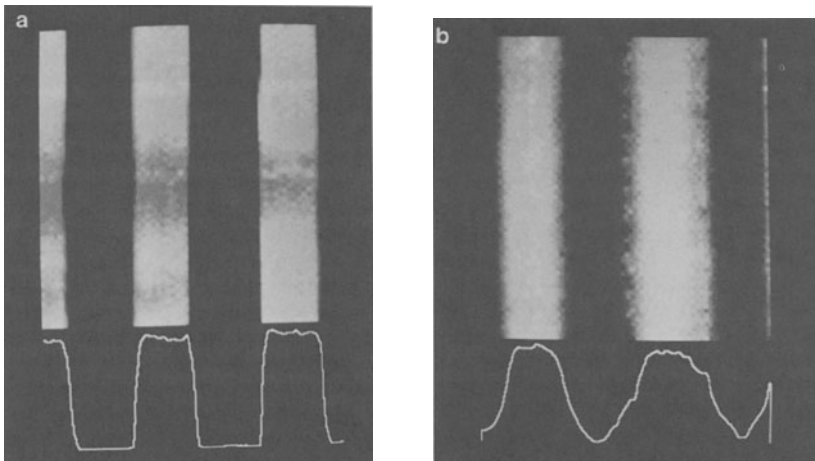


Fig. 4. Acoustic images of a periodic structure machined in an aluminium block obtained by mechanical-frequency scanning: (a) mechanical scanning perpendicular to the structure, (b) frequency scanning perpendicular to the structure. Field of view: 3mm x 3mm.

corresponds to the more or less direct reflection from the approximately flat central part of the hole. The surrounding dark area is due to scattering of acoustic energy out of the lens by the curved surface near the circumference of the hole.

Figure 6 shows an acoustic image with the frequency scanning system. A number of interesting features come out in this image. There is considerably more fringing observed than for the single frequency image of Figure 5; the fringing is due to interference between the directly reflected beam from the surface and that reflected by the hole, where the phase difference depends on the radial distance. For a given frequency (position along the horizontal axis) some correspondence can be found between the images of Figures 5 and 6. Finally the image in Figure 6 is clearly elongated. This is because in this preliminary work for imaging purposes we used a rough approximation that the position is linearly proportional to the frequency. This is in fact a poor approximation as an inverse relation would be more realistic. This is shown directly in the results of Figure 7 which were obtained by measuring the resonant frequency as a function of position. It is seen that the variation of frequency with position is by no means linear. This effect will be corrected automatically in a new version of the data acquisition system. For present purposes the aim was to demonstrate that acoustic imaging was indeed possible with the wedge transducer acoustic microscope for both surface and subsurface features.



Fig. 5. Conventional acoustic image of the blind hole in a plexiglass plate.

## CONCLUSION

This technique is well adapted to the study of materials and non-destructive evaluation. The principal advantages are that it is potentially very fast and also simple conceptually and technologically as regards the acoustics and electronics. It could form the basis of a cheap and performing system for assembly line inspection where the mechanical movement in the transverse direction is provided by the production facility. There is also an interesting possibility of extending the technique to higher frequencies.

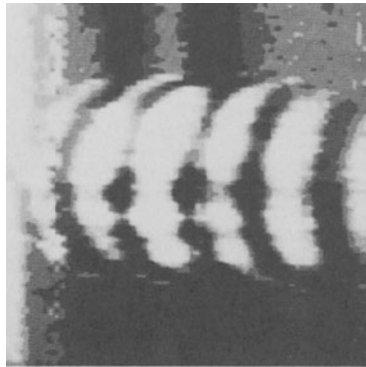


Fig. 6. Image of the hole in Figure 5 with frequency scanning in the horizontal direction.

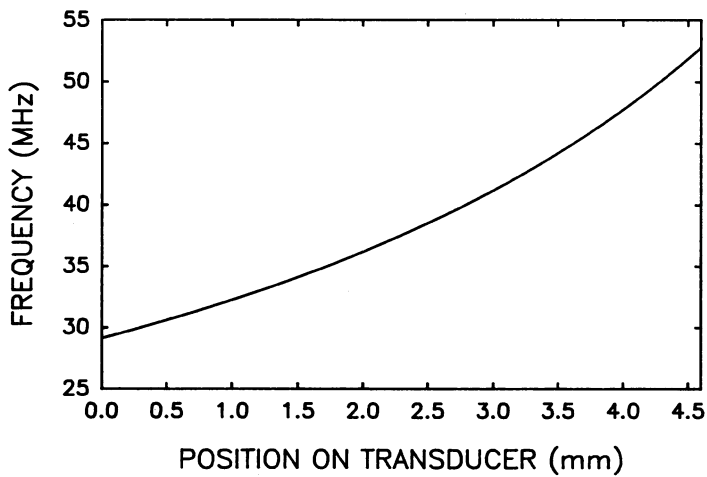


Fig. 7. Calibration of local resonant frequency as a function of distance along the wedge transducer.

The main disadvantage at present is the resolution degradation, which is the price that must be paid for the convenience of electronic scanning. However the system is by no means optimised, and further work is planned in the directions of device simulation, Schlieren imaging of the acoustic sound field and a theoretical analysis of diffraction effects in order to find the best configuration. Finally the present study was done with available electronics which were not suited to fast scanning and efforts will be made to increase the electronic scanning rate considerably.

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